Skill, Thrill, and Will: The Role of Metacognition, Interest, and Self-Control in Predicting Student Engagement Over Time

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Abstract

Maintaining learning engagement throughout adolescence is critical for long-term academic success. This research sought to understand the role of metacognition and motivation in predicting engagement over time. In two longitudinal studies with 2,325 and 207 adolescents (ages 11-15), metacognitive skills, interest, and self-control each uniquely predicted math engagement. Additionally, metacognitive skills worked with interest and self-control interactively to shape engagement. In Study 1, metacognitive skills and interest were found to compensate for one another. This compensatory pattern further interacted with time in Study 2, indicating that the decline in engagement was forestalled among adolescents who had either high metacognitive skills or high interest. Both studies also uncovered an interaction between metacognitive skills and self-control, though with slightly different interaction patterns.

Keywords: Student engagement, metacognition, interest, self-control, adolescence

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Uninterested, Eric yawned in response to his algebra teacher's lecture. He was certain at this point that Mr. Moretz underwent special forces training in enacting student boredom. It was no surprise that yet again, he found his thoughts drifting away from the algebra problems at hand. Somewhere along his way, Eric had become disengaged with math. When he got problems wrong, he lacked the skills to reflect upon and adjust his mental strategies, and he had lost his interest in learning math, making the whole subject seem futile. These factors made math extremely frustrating for Eric, and eventually, he lost his will to stay engaged in the material. A lack of skill, thrill, and will led him to disengage from mathematics learning.

Disengaged youth like Eric exist today in mathematics classrooms across the world, leading both educators and researchers alike to wrestle with big questions about both overall learning engagement and math-specific engagement: What factors predict engagement? Why do some students find math tasks engaging while others find them boring? Is there a certain combination of personal characteristics common to engaged math learners? Self-regulated learning theories suggest that a complex combination of metacognitive and motivational factors shape student engagement (Eccles, 2009; Zimmerman & Moylan, 2009).

Cognitively, mathematics learning is an incremental process through which math-related expertise develops when new knowledge is integrated with previously learned skills and knowledge. Self-regulated learning researchers have demonstrated the profound role of metacognitive skills for learning in general and math in particular (Hacker, Dunlosky, & Graesser, 2009; Schneider & Artelt, 2010). To acquire and accumulate knowledge, students must learn how to monitor, evaluate, and adjust their own learning progress, strategies, and outcomes (Schoenfeld, 1992).

However, metacognitive skills are just one piece of the puzzle: Self-regulated learning theories also illuminate the critical role of motivation in supporting engagement. As most math-related tasks involve intricate operations and abstract concepts that tend to increase in complexity over time, setbacks and struggles are common in mathematics classrooms. For these reasons, both interest and self-control are critical for maintaining engagement. That is, not only do students need sufficient metacognitive skills to accomplish the mathematics task at hand, but they also need to find it interesting while having the self-control necessary to maintain their focus and attention (Fredricks, Blumenfeld, & Paris, 2004; Reschly & Christenson, 2012).

In this research, we echo self-regulated learning theories in proposing that metacognitive skills, interest, and self-control form a socio-cognitive foundation for effective math learning. Notably, these three constructs are not independent of one another and may work together in ways that synergize or compensate for one another. For example, it could be that students with low metacognitive skills may nevertheless maintain engagement if interest or self-control is high, or students with low interest may stay engaged even if their metacognitive or self-control skills are strong. Despite the theoretical support for interaction effects among metacognitive skills, interest, and self-control on engagement, no longitudinal studies have yet examined whether they uniquely and interactively predict engagement in math learning over time.

In response, we leverage two longitudinal datasets with adolescent samples to examine whether metacognitive skill, interest, and self-control each uniquely contributes to engagement and how these constructs may work in concert to shape math engagement over time. Integrating these conceptually diverse but practically informative constructs will lead to a better understanding of how best to engage students in mathematics learning.

Student Engagement

Researchers have broadly conceptualized engagement as the quality of students' interactions or involvement with learning activities and contexts (Wang, Degol, & Henry, 2019). Although there are different definitions of engagement, scholars have established that it is a multidimensional construct consisting of at least three components: behavioral, cognitive, and emotional engagement. Behavioral engagement encompasses participation, persistence, and effort; cognitive engagement refers to attention and willingness to put forth mental investment in learning; and emotional engagement reflects affective reactions to learning activities (e.g., enjoyment, enthusiasm). In this study, we focus on behavioral and cognitive engagement because they are highly correlated and considered critical for math learning (Taningco, Mathew, & Pachon, 2019). In fact, studies have indicated that students must actively participate in and concentrate on the learning process as well as employ the necessary effort and strategies to excel in math (Boaler, 2013). However, fostering behavioral and cognitive engagement in math poses a challenge to educators because many adolescents view math learning as a difficult and boring process (Leslie et al., 2015). Unsurprisingly, students' behavioral and cognitive math engagement were found to decline significantly during secondary school (Wang et al., 2016).

Metacognitive Skills

Metacognition is a multifaceted phenomenon that involves the awareness and regulation of one's thoughts (Brown, 1987; Flavell, 1987). Metacognitive processes take the form of three skills: planning, monitoring, and evaluating. Planning refers to identifying how to reach a goal; monitoring entails assessing one's understanding and progress toward that goal; and evaluating refers to assessing the process of goal attainment. Metacognitive interventions have revealed positive effects on math performance, especially for low-achieving students (Dignath, Buettner, & Langfeldt, 2008). In addition, an observational study has shown that teachers who provided metacognitive supports in their instruction had students who demonstrated higher growth in conceptual math knowledge than those in classrooms with lesser or no metacognitive supports (Zepeda, Hlutkowsky, Partika, & Nokes-Malach, 2019). Still other experimental studies have illustrated that students with metacognitive skills experience a variety of positive math learning outcomes, including better problem-solving skills, concentration, and persistence when facing challenges (Cardelle-Elawar, 1995; Mevarech & Amrany, 2008). Over time, metacognitive skills are central for the integration and accumulation of knowledge while also serving as a critical predictor of engagement in learning.

Situational Interest

Another essential predictor of math engagement is situational interest. Situational interest has been identified as a catalyst for developing students' regulatory learning processes (Renninger & Hidi, 2015). Broadly defined, situational interest encapsulates a more momentary experience of interest within a specific concept (i.e., situational interest occurs at the intersection of an individual with their context; Hidi & Renninger, 2006). Because situational interest represents a momentary, latent disposition, it is essential that the accompanying context—in our case, mathematics—be deemed relevant, useful, and fun by a student, else their situational interest may remain untriggered. There is well-established evidence documenting the association between interest and math engagement and achievement. When students find math enjoyable and useful, they are more likely to participate in class activities and gain a deeper understanding of the content (Wang, 2012). These students also tend to be reasonably engaged in learning, as they are more attentive, more willing to expend effort, and more likely to go beyond what is required (Wang, Fredricks, Ye, Hofkens, & Linn, 2016). Furthermore, situational interest helps students persist in the face of challenges and protects them from experiencing the exhaustion associated with cognitively engaging in taxing mathematics endeavors (Reeve et al., 2015).

Self-Control

In addition to developing interest, adolescents may need self-control to remain engaged. Self-control is defined as the ability to resist a tempting or desirable option with an immediate or momentary benefit in favor of selecting a less desirable option that will generate a much larger benefit in the long-run (Duckworth, Taxer, Eskreis-Winkler, Galla, & Gross, 2019), and research has established that self-control plays a role in supporting academic achievement (Duckworth, Tsukayama, & Kirby, 2013; Mischel et al., 2014). As children enter adolescence, their growing capacities in behavioral regulation and coordination pave the way for better management of their learning processes and perseverance through academic tasks, thus contributing to academic engagement (Galla et al., 2019). For example, choosing to concentrate in class rather than talk or text with classmates requires that students resist temptation and regulate their attention to avoid distraction. Hence, self-control should increase learning-focused behaviors that support the accumulation of positive experiences within the classroom. Indeed, one study found that self-control mediated the association between attachment security and engagement in learning as observed in students' fifth-grade classroom setting (Drake, Belsky, & Fearon, 2014), while another investigation found positive associations between school engagement and academic self-control among adolescents (Stefansson, Gestsdottir, Birgisdottir, & Lerner, 2018).

Interactive Relationships among Metacognitive Skill, Interest, and Self-Control

Self-regulated learning theories state that academic learning is a cyclical process in which learners are metacognitively, motivationally, and behaviorally in control of their learning as it unfolds and pertains to future learning experiences (Pintrich, 2000; Zimmerman, 2000). Students start by accessing their motivational beliefs and existing metacognitive skills to process the learning task. They then engage with learning materials while monitoring and adjusting their motivations, metacognitive strategies, and behaviors accordingly to stay focused on learning. We propose that metacognitive skills, interest, and self-control each uniquely contributes to explaining academic engagement over time and within this self-regulated learning process; however, these three components may also impact and interact with each other (Miele & Molden, 2010; Nelson, Kruglanski, & Jost, 1998).

Metacognitive skills and interest. Although there is a paucity of literature addressing the interaction between metacognitive skills and interest on math engagement, limited evidence does indicate these constructs might be related. For example, students with high interest in learning tend to use more metacognitive strategies than students with low interest (McWhaw & Abrami, 2001), and students' metacognitive strategy use has been positively associated with their interest, task value, and engagement in learning (Sungur, 2007). These studies suggest that metacognitive skills and interest may synergize to promote heightened engagement. Other evidence suggests these constructs may compensate for one another (Tzohar-Rozen & Kramarski, 2014). For example, prior work has shown that increasing the metacognitive or motivational aspect of self-regulated learning results in better math learning outcomes (Dignath et al., 2008; Tzohar-Rozen & Kramarski, 2014). That is, high situational interest may help students maintain engagement even in the absence of students' metacognitive awareness of learning progress. Likewise, having strong metacognitive skills can give students the experience of progress and learning and may maintain engagement even among those with low interest.

Metacognitive skills and self-control. Despite little research on the connection between metacognitive skills and self-control, there are studies examining metacognitive skills and conscientiousness (a construct highly similar to and correlated with self-control). Students' conscientiousness has been positively associated with metacognition (Kelly & Donaldson, 2016), and as argued by self-regulated learning theories, metacognitive skills may enhance the effectiveness or importance of self-control in maintaining engagement (Zimmerman, 2000). For example, having a high level of self-control should provide more opportunities for students to engage their metacognitive skills. Absent the self-control to avoid distraction and maintain focus, metacognitive skills may have fewer opportunities to come online. On the other hand, these two constructs may compensate for one another. For example, having the ability to resist distractions and concentrate on the task at hand may allow students to stay engaged even when they have low ability to track their learning progress.

Interest and self-control. Limited extant literature has provided some insight into how interest and self-control might work together to shape engagement. For example, research has revealed that individuals high in conscientiousness are more likely to persist through boring tasks (Sansone et al., 2010), and situational interest and conscientiousness have predicted academic effort, with conscientiousness moderating the relation between interest and academic effort (Trautwein et al., 2015). In the case of Trautwein's work (2015), conscientiousness was less related to academic effort when students' situational interest was high, whereas students' situational interest was less related to academic effort when they had high conscientiousness (i.e., a compensatory relationship).

Current Study

Research has shown that students' math engagement follows a declining trajectory starting in fifth or sixth grade (Li & Lerner, 2011; Wang & Eccles, 2012a, 2012b). This conundrum is compounded by the significant academic and social challenges associated with the transition to secondary schools (Eccles et al., 1993; Wang, Degol, Amemiya, Parr, Guo, 2020). With the increasing curriculum complexity and academic demands in math learning, secondary school students need adequate skills, a willful interest, and self-control to feel motivated to process math learning tasks. Given students' declining engagement patterns (e.g., Gottfried, Marcoulides, Gottfried, & Oliver, 2009), we examined engagement not as a single cross-sectional snapshot, but as a dynamic construct that changes over the course of a school year. In addition to examining how each of these three psychological constructs affects student engagement, we further consider whether these interactions might work to forestall declines in engagement.

We sought to test our research questions by conducting two longitudinal studies with different temporal lenses. Rather than focusing on students' reactions to hypothetical scenarios in laboratory settings, we tracked self-reports of motivational and metacognitive processes. Because student engagement may evolve over different time scales (e.g., over weeks or years; Wang et al., 2019), we assessed how metacognitive skills, interest, and self-control predicted long-term engagement across multiple years (Study 1) and how they predicted day-to-day engagement over three weeks (Study 2). The measurement approach linking these two study designs was a focus on the degree to which students could regulate metacognition, motivation, and behavior to remain engaged in learning.

In Study 1, 2,325 fifth-, seventh-, and ninth-grade students completed assessments measuring metacognitive skill, interest, self-control, and math engagement once per year for four years. In Study 2, 207 eighth-grade students completed measures assessing the same constructs at the end of each day's math class for three weeks. Across these two studies, we hypothesized that metacognitive skill, interest, and self-control would positively and uniquely predict math engagement, as assessed at the yearly and daily level. We also expected metacognitive skill to interact with interest or self-control to predict engagement, though it remains an open question as to whether these interactions will be compensatory or synergistic. In other words, our tests of main and interaction effects were theory-driven and confirmatory; our deeper investigation into direction and pattern of interaction effect was exploratory. Once a significant interaction pattern was identified in Study 1, we confirmed said patterns in Study 2. Hence, our analyses represent a hybrid of exploratory and confirmatory approaches.

Study 1

Study 1 served as an initial test of metacognition, interest, and self-control as predictors of math engagement with a four-year longitudinal data analysis on a large sample of secondary school students.

Method

Participants and Procedure

The sample consisted of 2,325 fifth- (31.7%), seventh- (35.9%), and ninth-grade (32.5%) students from 20 public schools in the Mid-Atlantic region of the United States (M_{age} = 13.94 at wave 1; 50.6% male; 55.3% White, 44.7% racial minority; 65.3% free or reduced-price lunch). In the 2014-2015 academic year, all fifth-, seventh-, and ninth-grade students in the 20 schools were invited to participate in a longitudinal study on student engagement in school. The first four waves of data were analyzed in this study, with Wave 1 commencing in the spring of 2015 and Wave 4 being completed in the spring of 2018.

With assistance from the students' teachers, the research team distributed letters about the study and consent/assent forms for students and their parents. Students who agreed to participate in the study (more than 98% at Wave 1) completed a web-based survey in a classroom with technology during school time. Research staff members were available during survey administration to answer any questions that students had about the survey's purpose or content. To ensure that students with varying literacy skills could effectively complete the survey, all survey questions were audio-recorded, and students were provided with headphones to listen to the questions.

Measures

Math engagement. Math engagement was assessed at each wave using the *Math Engagement Scale*, a well-validated engagement scale with strong reliability and construct and predictive validity (Fredricks et al., 2016; Wang et al., 2016). The seven-item scale assessed behavioral and cognitive engagement, including students' attention, effort, and task persistence in math class (e.g., "I stay focused in math"; "I put effort into learning math"; "I keep trying even if something is hard in math."). Item responses fell along a five-point scale ranging from 1 (*not at all like me*) to 5 (*very much like me*). Cronbach's *α*s ranged from .81 to .89.

Math metacognitive skill. Using six items adapted from the Metacognitive Self-Regulation Scale of the *Motivated Strategies for Learning Questionnaire* (Pintrich, Smith, Garcia, & McKeachie, 1991), students reported on their ability to plan, monitor, and evaluate their math learning at each wave (e.g., "I ask myself questions to make sure I understand the material I have been studying in math class"; "I used what I learned today to make sense of our earlier math classes"; "I tried to understand my mistakes when I got something wrong in math").

Students responded on a 5-point Likert scale ranging from 1 (*not at all like me*) to 5 (*very much like me*). Crohnbach's αs ranged from .75 to .78.

Math situational interest. Math interest was assessed at each wave using the *Math Interest Scale*, a four-item scale demonstrating good reliability and validity (Eccles et al., 2005; Wang, 2012; Wang et al., 2016). The interest scale measured the extent to which students enjoyed and took pleasure in learning math and taking part in math lessons (e.g., "I feel good when I am in math class"; "I enjoy learning new things about math"; "I look forward to math class"). Item responses ranged from 1 (*not at all like me*) to 5 (*very much like me*). Crohnbach's *αs* ranged from .90 to .92.

Math self-control. Using four items adapted from the *Becoming Effective Learners Survey Battery* (Farrington, Levenstein, & Nagaoka, 2013), students reported on their self-control dispositions in math class at each wave (e.g., "If there are distractions in math class, I make myself pay attention"; "If a topic in math class is boring, I make myself pay attention"; "Even when math coursework is not interesting, I manage to keep working until I finish"). Items were rated from 1 (*not at all like me*) to 5 (*very much like me*). Crohnbach's *αs* ranged from .79 to .84.

Covariates. We included three time-level covariates that were related to math engagement in the analyses: (a) adolescents' perceived relationship with the math teacher (three items; e.g., "My math teacher helps me when I need help"; "My math teacher understands how I feel about things in class"; *α's* range: .78 - .83); (b) math course grade; and (c) the year of the study. We also included several student-level covariates collected from the school record: (a) grade level; (b) gender; (c) race; and (d) free/reduced-price lunch status.

Missing Data

With a longitudinal design, 1,489 adolescents (64.0%) were recruited at Wave 1, 629 (27.1%) at Wave 2, 142 (6.1%) at Wave 3, and 65 (2.8%) at Wave 4. Since first participation, 1,140 (51.0%) adolescents had no waves of data missing; 491 (23.1%) had one wave of data missing; 363 (15.6%) had two waves of data missing; and 331 (10.3%) had three waves of data missing. Participants with more waves of data were more likely to be girls (than boys; $r = .06$, $p < .05$), White youth (than racial minority youth; $r = .19$, $p < .001$), students who paid for lunch (than those in a free/reduced lunch program; $r = .18$, $p < .001$), and have higher math performance ($r = .24$, $p < .001$) than their peers with less waves of data. We handled missing data using full-information maximum likelihood estimation (FIML), which allowed us to include all available data and identify the parameter values with the highest probability of producing the sample data (Baraldi & Enders, 2010). As a sensitivity analysis, we used multiple imputation approach to handle missing data and achieved the same results.

Measurement equivalence was assessed to ensure that the content of each item in the measures of math engagement, metacognitive skills, interest, and self-control was interpreted in the same way across groups. We found empirical support for measurement equivalence of these underlying constructs across time and grade.

Analytic Plan

We first examined the degree of within-student variance in math engagement at baseline compared to between-student variance and between-school variance. The intraclass coefficients indicated that 75% of the engagement variance was at the within-student level, 14% of the variance was at the between-student level, and 11% of the variance was at the between-school level. We then used multilevel models to address the study questions by assigning Level 1 to time and Level 2 to students while accounting for school random effect. The outcome of interest was math engagement at Level 1. Level 1 key predictors included metacognitive skills, interest, self-control, and year of the study (i.e., time). At Level 2, we explored the variation in students' average level of math engagement across four years by including time-invariant covariates. In addition, we investigated the interactions among metacognitive skills, interest, and self-control as well as how such interactions varied over time. Interaction terms were estimated using group mean centered terms at the individual- and school-levels.

Results

Table S1 (supplemental document) presents the means, standard deviations, and correlations for each of the key predictor and outcome variables. The first set of analyses showed longitudinal associations between metacognitive skill, interest, self-control, and math engagement over time (model 2, Table 1). The second set of analyses examined whether metacognitive skill interacted with interest and self-control to predict math engagement and whether the interaction effect varied by time (models 3 and 4, Table 1).

Main Effects of Metacognitive Skill, Interest, and Self-Control

As shown in Table 1, there was a linear decline in math engagement across four years, but metacognitive skills, interest, and self-control were positively associated with changes in math engagement over time. Specifically, greater metacognitive skills, interest, and self-control protected against the normative rate of decline in math engagement.

Interaction Effects of Metacognitive Skills, Interest, Self-Control, and Time

We found two interaction effects (model 3, Table 1) that show a compensatory relation between metacognitive skills and self-control (B = -.03, SE = .01, $p < .05$, ES = .03) and between metacognitive skills and interest (B = -.07, SE = .01, $p < .001$, ES = .09). The interaction between interest and self-control was not significant. We also examined the three-way interaction among metacognition, interest, and self-control and it was non-significant. In Figures 1a and 1b, we plotted the interaction at high (Mean + 1 SD) and low (Mean - 1 SD) levels of each variable (Also see supplemental document for the interaction plots using LOOP command in Mplus). In Figure 1a, a simple slopes analysis of this interaction revealed that metacognitive skills were a stronger predictor of math engagement ($B = .46$, $t = .37$) for students with low self-control than for students with high self-control ($B = .41$, $t = .35$). This suggests that for students with low self-control, the effect of metacognitive skills was more important for math engagement. Moreover, a simple slopes analysis of the interaction in Figure 1b revealed that among students with low metacognitive skills, interest was a strong predictor of math engagement ($B = .51$, $t = .40$). By contrast, among students with high metacognitive skill, the effect of interest was weaker ($B = .36$, $t = .34$). This finding suggests that for students with low metacognitive skills, interest was particularly important for math engagement. We also tested the interaction of metacognition and interest with time as well as the interaction of metacognition and self-control with time but did not find them significant, suggesting that these interactions remained stable over time.

Sensitivity analysis. We examined whether different mechanisms may be involved in students' math performance (versus math engagement) by testing math course grade as an additional outcome (see supplemental material). Most of the main results held, except the interaction effect between metacognitive skill and self-control became marginal. This result is consistent with the literature stating that students' self-control tends to be more predictive of achievement-related classroom behavior (e.g., engagement) than academic performance because of its indirect effect on actual achievement (Rotgans & Schmidt, 2011; Wang, Degol, & Henry, 2019).

Summary

Study 1 was based on large-scale longitudinal data over four years. As such, it included an overarching view on the link between metacognition, interest, and self-control over time. The results revealed that math interest and metacognition compensated for each other, such that while engagement declined over time for the sample as a whole, engagement was higher if levels of metacognition or interest were high. We also found the same compensation effect for metacognitive skills and self-control. Given the large sample size, this study allowed us to test for relationships with a high level of statistical power.

STUDY 2

In Study 2, we aimed to replicate Study 1's results while examining longitudinal links among metacognitive skills, interest, self-control, and math engagement using a daily-diary method over a three-week period, resulting in 16 measurement occasions. This time length has been recommended as an ideal observation window to capture meaningful within-person variability and reduce participant burden for daily diary research (Bolger et al., 2013).

Method

Participants and Procedures

Participants were a cohort of 207 eighth-grade students (M_{age} = 13.87; 55.1% male; 32.4% White, 67.4% racial minority; 66.2% qualified for free or reduced-price lunch status) attending a public school in the Northeastern region of the United States. In the 2015-2016 academic year, we invited all fifth- and eighth-grade math teachers in the school to participate in a daily diary study. Due to the intensive nature of the study, only eighth-grade math teachers agreed to participate. Consequently, all eighth-grade students in the current school were invited to participate in a year-long study on classroom engagement. More than 99% of the eighth-grade cohort agreed to partake in the study. All study procedures occurred in students' math classrooms on computerized tablets. The current study collected two types of data across the 2017-2018 school year: a pre-daily diary survey (Fall, 2017) and a 16 days of daily diary responses (Spring, 2018; data were collected during the final five minutes of each day's math class for 16 days). To address potential literacy difficulties, students were provided with headphones to listen to the audio-recorded questions.

Measures

Math engagement. Students' engagement in their math class was assessed at the pre-daily diary survey and 16-day daily diaries using the *Math Engagement Scale* (Fredricks et al., 2016; Wang et al., 2016). In the pre-daily diary survey, students were asked seven questions about their behavioral and cognitive engagement, including attention, effort, and task persistence in math class (e.g., "I stay focused in math"; "I put effort into learning math"; "I keep trying even if something is hard in math"). These seven items were averaged together to create composite engagement scores in which higher scores indicated greater math engagement. Students' pre-daily diary survey score on the math engagement ($\alpha = .81$, $M = 3.70$, $SD = 0.73$) was used as a student-level covariate.

During each day of the daily diary, students responded to three math engagement items that were adapted from the *Math Engagement Scale*: "I stayed focused in math class today"; "I put effort into learning in math class today"; and "I paid attention in math class today." For these items, adolescents responded on a 5-point Likert scale from 1 = *not at all* to 5 = *very much*. The three items were averaged to create daily composite scores of students' math engagement ($\alpha_{\text{Total}} = .91$, $M_{\text{Total}} = 3.11$, $SD_{\text{Total}} = 0.69$).

To test the validity of the daily diary self-report measure, we examined the correlation between students' average daily reports of engagement and their scores in the teacher gradebook (which included classwork, homework, and tests/quizzes) during the daily diary period. If students' self-reports of engagement were valid, we expected them to be moderately correlated, given that they assess engagement-related information (e.g., classwork and homework completion) and mathematical skill (e.g., test performance). We found that students' daily self-report of math engagement was moderately correlated with gradebook performance, $r = .47$, $p < .001$, thus supporting the validity of the daily diary measure.

Math metacognitive skill. To assess daily math metacognitive skill, students were asked three items from the Metacognitive Self-Regulation Scale of the *Motivated Strategies for Learning Questionnaire* (Pintrich et al., 1991) each day at the end of math class: "I ask myself questions to make sure I understand the material I have been studying in today's math class."; "I used what I learned today to make sense of earlier math classes"; "I tried to understand my mistakes when I got something wrong in math class today." Students responded on a 5-point Likert scale ranging from 1 = *not at all* to 5 = *very much*. The three items were averaged together to create daily composite scores of students' math metacognitive skill ($\alpha_{\text{Total}} = .83$, $M_{\text{Total}} = 2.79$, $SD_{\text{Total}} = 0.75$).

Math situational interest. To assess daily interest in math class, students were asked each day at the end of math class with three items from the *Math Interest Scale* (Eccles et al., 2005; Wang et al., 2016): "I enjoyed math class today; "I felt good in math class today"; "I had fun in math class today." Students responded on a 5-point Likert scale ranging from 1 = *not at all* to 5 = *very much*. The three items were averaged together to compute daily composite scores of students' situational interest in math class ($\alpha_{\text{Total}} = .87$, $M_{\text{Total}} = 2.79$, $SD_{\text{Total}} = 0.75$).

Math self-control. Students responded to two items that were adapted from the *Becoming Effective Learners Survey Battery* (Farrington et al., 2013; Galla et al., 2018) to assess daily experiences of self-control in math class: “When there were distractions in math class, I made myself pay attention”; “When the math lesson was boring, I kept working until I finished.” These items used a 5-point Likert scale from 1 = *not at all* to 5 = *very much*. The two items were averaged together to form daily composite scores of students’ self-control in math class (α_{Total} = .81, M_{Total} = 3.70, SD_{Total} = 0.81).

Day-level covariates. We included a list of day-level covariates that may have contributed to student engagement in the analyses: (a) the *level of distraction* (i.e., “There were distractions in math class today; for example, other students talking during the lesson”); (b) the *level of boredom* (i.e., “The math lesson was boring today”); and (c) the *day of the study* to account for potential time and fatigue effects of study participation.

Student-level covariates. At the student level, we included the following covariates collected from the pre-daily diary survey or school record: (a) students’ math engagement (see engagement description above); (b) students’ relationship with their math teacher (eight items; e.g., “My math teacher is patient and understanding”; “I like my math teacher”; α = .89); (c) prior year’s standardized mathematics performance; (d) gender; (e) race; and (f) free/reduced-price lunch status.

Analytic Plan

This study investigated how students’ metacognitive skills, interest, and self-control in mathematics related to their daily math engagement. Our data had a nested structure in which 16 daily diary assessments were nested within 207 students, and these students were nested within nine classrooms. The intraclass correlation (days within person) indicated that 42% of the engagement variance was at the person level and 53% of the variance was at the daily level. At the classroom level (students within classroom), the intraclass correlation indicated that only 5%

of the variance in engagement was at the classroom level. We then used multilevel models to address the study questions by assigning time to Level 1 and students to Level 2 while accounting for classroom random effect.

The outcome of interest was daily math engagement at Level 1. Level 1 key predictors included metacognitive skills, interest, self-control, and day of the study (i.e., time). At Level 2, we explained the variation in students' average level of math engagement across the daily diary period by including student-level covariates. We also investigated the interactions among metacognitive skills, interest, and self-control as well as how such interactions varied over time.

Missing data. The amount of missing data varied at both the daily and student levels. Of the possible 3,312 daily diary assessments (16 days, 207 students), there was 30.3% missing data at the daily level (N = 1,119 missing daily assessments), which was either due to students not finishing the daily dairy (N = 927) or being absent that day (N = 192). There were also varying levels of missing data at the student level. Given the school-based nature of the study, participation rates were generally high: 100% completion rate for pre-daily diary survey; 94% of students completed at least one day of their daily diary; and there was an average of 11.25 diary entries out of 16 total possible entries.

We next examined if student factors were associated with the number of responses provided in the study across the pre-daily diary survey and daily diary assessments. Students with more available data reported higher self-control (r = .10, p = .002) and pre-daily diary math engagement (r = .05, p = .04), received higher prior year math standardized test scores (r = .06, p = .01), and were more likely to be racial minorities (r = -.05, p = .01). To retain all 207 students in analyses, we accounted for missing data through full-information maximum likelihood estimation (FIML). As a sensitivity analysis, we used multiple imputation approach to handle missing data and achieved the same results.

Results

Main Effects of Metacognitive Skills, Interest, and Self-Control

Table S2 (supplemental document) presents the zero-order correlations among daily-level and student-level variables. The results of the final multilevel model predicting daily math engagement are shown in Table 2. A significant main effect of time revealed that students' math engagement deteriorated over time. As expected, students with greater metacognitive skills, interest, and self-control in math reported higher daily math engagement on average.

Interaction Effects of Metacognitive Skill, Interest, Self-Control, and Time

Regarding the interaction effects among the key predictors (Model 3, Table 2), results revealed that the association between students' metacognitive skills and math engagement varied based on interest (B = -.04, SE = .01, p < .05, ES = .06) and self-control (B = .04, SE = .02, p < .05, ES = .04). The interaction between interest and self-control was not significant. We also examined the three-way interaction among metacognition, interest, and self-control and it was non-significant. In Figures 2a and 2b, we plotted these interactions at high (Mean + 1 SD) and low (Mean - 1 SD) levels of each variable (See supplemental document for the interaction plots using LOOP command in Mplus). Both plots revealed that metacognitive skills moderated the main effects of self-control and interest on math engagement. In Figure 2a, the metacognitive skill and self-control interaction revealed that among students with low metacognitive skills, the effect of self-control was negligible (B = .04, t =1.33). But among students with high metacognitive skills, the effect of self-control was significant (B = .11, t = 3.68). One way to interpret this pattern is that metacognitive skills may have "activated" the effect of self-control on engagement.

As shown in Figure 2b, the metacognitive skill and interest interaction revealed that among students with low metacognitive skills, interest was a strong predictor of math engagement (B = .25, t = 12.95). By contrast, among students with high metacognitive skills, the effect of interest was weaker but still significant (B = .18, t = 6.52). This finding suggests that for students with low metacognitive skills, math interest was particularly important for math engagement. Together, these results paint different pictures of students with high versus low metacognitive skills. Among students with high metacognitive skills, both self-control and interest were predictive of engagement; but, for students with low metacognitive skills, self-control was not significant, while interest was particularly important for supporting engagement.

Further analyses revealed that the metacognitive skill and interest interaction also varied over time (Model 4, Table 2; Figure 3), indicating that being high on *either* metacognitive skill *or* interest helped forestall the decline in math engagement over time. Specifically, the decline in engagement was particularly steep when both metacognitive skills and interest were low. By contrast, math engagement remained relatively stable over time when either metacognitive skills, interest, or both dimensions were high.

Discussion

Main Effects of Metacognitive Skills, Interest, and Self-Control

This study used self-regulated learning frameworks to examine the role of metacognition, interest, and self-control in predicting math engagement over time. Results from two demographically diverse adolescent samples revealed that students' metacognitive skills, interest, and self-control positively predicted overall math engagement, suggesting that math engagement is independently shaped by multiple theoretically significant constructs. Whereas prior research has identified all three of these constructs as important for shaping engagement

(Eccles, 2009; Zimmerman & Moylan, 2009), research has not previously considered whether and how they impact engagement simultaneously and longitudinally. Our results are a reminder of the multiplicity of factors that feed into student engagement: While several distinct factors were correlated with one another (e.g., interest, metacognitive skills, and self-control were all positively correlated with one another), they each made a unique contribution to understanding math engagement among adolescents. Thus, fostering interest, teaching metacognitive skills, and exhibiting high self-control each served to bolster math engagement during a developmental period when overall student engagement in learning tends to decline.

Interaction Effects of Metacognitive Skill, Interest, Self-Control, and Time

Our findings further revealed that metacognitive skills consistently worked with interest and self-control together, interactively, to shape adolescents' math engagement. The most robust and consistent finding of the present research is that metacognitive skills and interest interacted with one another to maintain high math engagement (Studies 1 and 2) and predicted declines in math engagement over time (Study 2). More specifically, metacognitive skills and interest were found to compensate for one another in Study 1, such that students who had low metacognitive skills maintained higher engagement if they had high interest, and students with low interest maintained higher engagement if they had high metacognitive skill. In Study 2, this compensatory pattern of metacognitive skills and interest further interacted with time, indicating that the decline in engagement over three weeks was forestalled among students who had either high metacognitive skills or high interest.

These results depict a clear distinction between students who scored low on both metacognitive skills and interest versus students who scored high on both constructs. Students who were low on both constructs showed the lowest engagement, and their engagement deteriorated over time in Study 2. Such students were lacking both interest and metacognitive skill, as they were neither interested in math nor where they able to evaluate their learning progress. By contrast, engagement was high and stable among students who were high on both interest and metacognitive dimensions or, just as importantly, high on just one of the two dimensions. When students did not simply enjoy math but also possessed the metacognitive skills to effectively evaluate their learning progress, they had high, sustained engagement. Moreover, the two dimensions appeared to compensate for one another: If students were high on either metacognitive skills or interest, their engagement remained stable despite being low on the other construct. Future studies that examine the constraints and thresholds of how much metacognitive skill is enough to boost interest (and vice versa) and the parameters of these factors will advance the self-regulated learning theory.

In addition, Studies 1 and 2 uncovered a significant interaction between metacognitive skills and self-control. In Study 1, metacognitive skills and self-control were found to compensate for one another, such that students who had low metacognitive skills maintained higher engagement if they had high self-control, and students with low self-control maintained higher engagement if they had high metacognitive skill. Study 2 showed that while self-control was associated with engagement, this relation was only true among students with high metacognitive skills. In other words, among students with a poor ability to plan, reflect upon, and evaluate their learning, higher self-control had little effect on their engagement; however, among students who had strong metacognitive skills, self-control appeared to help them use those skills effectively. In this way, our results indicate that metacognitive skills may bolster the benefits of having high self-control. These results also suggest that if students cannot control their behavior to stay focused on learning, they may not metacognitively monitor their learning process.

Although correlational, results are consistent with self-regulated learning theory's assertions that students who have both the metacognitive skills to evaluate their learning progress and the self-control to persevere through boredom and adversity may hold a potent combination of "skill and will" that fosters engagement.

While the interaction between metacognition and self-control was found in both studies, the pattern of interactions was notably different. Self-control was beneficial among students with low metacognitive skills in Study 1 (i.e., a compensatory effect), but it was beneficial among students with high metacognitive skills in Study 2 (i.e., a synergistic effect). One possible explanation for these differences related to study procedures and administration periods, with Study 1 occurring over a much longer period than Study 2 (i.e., four years versus three weeks). It appears that self-control may work in a compensatory fashion with metacognition over the long term, while self-control and metacognition may reinforce or complement each other to promote engagement on a daily basis. Given the cumulative and incremental nature of academic learning, studies have singled out aspects of self-control as being essential for long-term educational outcomes, such as academic attainment and college enrollment and completion (Blair & Raver 2015; Duckworth & Carlson 2013). On the other hand, recent studies have also indicated that students need to exercise both learning strategies and self-control to momentarily stay engaged in academic contexts, especially when learning a difficult or less interesting concept (Wang et al., 2019). As academic engagement consists of a multitude of processes that operates across varying time scales, the role of self-control and metacognitive skills in student engagement should be flagged for additional research.

Theoretical Implications

The interaction effects between metacognitive skill, interest, and self-control provide novel insight into the antecedents of engagement during the self-regulated learning process. The pattern of findings reveals that math engagement can be strengthened by distinct, compensatory constructs. Metacognition may be analogous to an internal “progress bar,” such as those commonly used in gamified learning strategies and online tasks to inform users of progress toward a goal (e.g., progress through an online learning module). The presence of such progress bars has been shown to independently increase engagement, particularly when progress is made at the beginning of the task (Villar, Callegaro, & Yang, 2013). Similarly, the “progress principle” holds that engagement is bolstered when people experience small gains and perceive progress toward their goals (Amabile & Kramer, 2011). Our results suggest that metacognitive skills that allow students to evaluate and apprehend their learning progress may help them stay engaged, even in a domain of low interest.

Similarly, interest also seemed to compensate for a lack of metacognitive skill. While a number of motivational theories of learning hold that engagement is bolstered by interest and value of the domain in question (Eccles, 2009; Renninger & Hidi, 2015), our work interjects the caveat that such interest may also predict declines in engagement even in the absence of metacognitive skills. As shown in study 2, interest alone carried engagement forward through time, even among students who did not have the skillset to evaluate progress or the experience of success in learning math tasks during the measurement period. As such, students with high interest may simply not require metacognitive realization that they are making progress to stay engaged.

One question these findings raise, however, is whether maintaining engagement with only one of the two constructs is advisable or if it is simply better than the alternative of being low on both. Notably, Study 1 did not find an interaction pattern with time over the four-year time window. It was only in Study 2, which studied a much shorter and intensive period (i.e., 16 days versus four years), that interest and metacognitive skills shared an interaction with time. It could be, for example, that while high metacognitive skills may help even uninterested students remain engaged in the short term, such disinterested engagement may be difficult to maintain over longer periods of time. Similarly, students who maintain an interest in math despite lacking metacognitive skills to effectively evaluate one's math knowledge may describe a potentially inefficient means to pursue deeper understanding of math knowledge in the long term. Nevertheless, the present research does offer empirical evidence that there are multiple paths to fostering learning engagement and that such efforts may contribute independently and interactively to student engagement over time.

Practical Implications

Our results suggest that educators have multiple routes for supporting adolescent students' math engagement. For example, educators may attempt to promote interest in their academic domain through novel instructional approaches (e.g., math-focused video games; Vendlinksi, Chung, Binning, & Buschang, 2011), boost metacognitive skills through engaging in direct instruction (Zepeda, Richey, Ronevich, & Nokes-Malach, 2015), and enhance self-control with goal setting and implementation intentions (Gollwitzer, 1999). If successful, each of these strategies may bolster engagement effectively.

The present findings also generated a hopeful message for practice: Math engagement can be maintained by boosting either metacognition *or* motivation. In other words, it is helpful but not necessary for students to be high in both dimensions to prevent declines in engagement over time. Granted, students had the highest engagement overall when both dimensions were high, but the real problem for maintaining engagement occurred among students who were low on both dimensions—that is, among students who were neither interested in math nor able to gauge and evaluate their progress in learning math. For these students, it is likely that math is prohibitively frustrating, with this frustration emanating from the fact that these students do not care about and have little metacognitive ability to evaluate and monitor their learning. Having interest can maintain engagement even when progress is opaque, while making progress metacognitively can maintain engagement even when interest is low.

Although a great deal of research has focused on ways to make mathematics more fun and interesting, teachers often believe that only high-achieving students benefit from being taught higher order cognitive processes, such as metacognition (Warburton & Torff, 2005; Zohar, Vaaknin, & Dagani, 2001). Yet, a growing body of research suggests that metacognitive skills can be effectively taught, and students who are taught these skills tend to benefit regardless of their prior skill levels (Schneider & Artelt, 2010). For example, researchers have developed metacognitive interventions tailored to math that teach students how to connect conceptual (e.g., difference between fractions) and procedural knowledge (e.g., how to find a common denominator) prior to solving a problem (see Schneider & Artelt, 2010 for an overview). These studies have shown that all students benefit from direct metacognitive skills instruction, including information on why, when, and how to use metacognitive strategies (Wang et al., 2020; Zepeda et al., 2015).

Limitations and Strengths

One of the potential limitations of the present work is that it relied on students' self-reports. This means that the present research operated from the assumption that students have introspective access to things like their metacognitive skills and self-control abilities. There is reason to question whether students do in fact have accurate access to these internal states and processes (Wilson, 2004), though studies have also shown that adolescents' subjective perceptions or experiences of their psychological characteristics, traits, and skillsets are strongly predictive of their academic and behavioral outcomes (Wang & Degol, 2014). For example, it is plausible that students who have better metacognitive skills are more accurate at assessing their motivational beliefs because these students are more attuned to their knowledge in general and have better memories of their experiences. Hence, it would be informative to measure the accuracy of students' reports about their metacognitive skills and motivational beliefs and examine how this accuracy may inflate or underestimate their effects on student engagement.

Furthermore, one necessary way to advance this scholarly work would be to gauge variables using behavioral (e.g., time spent on task) and observational (e.g., teachers and parents' reports of behavior) assessments to investigate whether different measurement methods similarly relate to different academic outcomes. For instance, the use of other methods such as a microgenetic approach within a specific learning task would reveal whether the specific self-regulated learning phases have a sequential or differential role in relation to students' engagement. These other methods would also determine whether the patterns found in this work are robust with different grain sizes of self-regulated learning processes.

Although students are reliable reporters of certain dimensions of engagement (e.g., cognitive engagement; Reschly & Christenson, 2012), it is imperative for future research to include other approaches to provide a more comprehensive picture of engagement over multiple assessments. For example, studies have suggested that teachers and school record data can provide useful and complimentary information on behavioral engagement (Wang et al., 2019). Given that studies indicate that self-report and retrospective scales for motivational beliefs (e.g., interest) are more predictive of classroom engagement than academic performance (Rotgans & Schmidt, 2011), future studies should also include additional outcomes (e.g., test scores) and investigate whether different mechanisms may be involved in the learning process (e.g., indirect effect of metacognition and motivation on academic performance through engagement).

Another limitation is that the study was correlational in nature. We attempted to address this limitation by using longitudinal study design with two different timeframes, which allowed us to examine how the links operated as the constructs had opportunities to evolve and change. However, it is likely that at least some of the observed relationships were reciprocal, for example, with higher math engagement causing as well as being caused by higher math interest. One remedy for this limitation would be to manipulate interest and metacognitive skills in a factorial design to observe whether each had both main and interactive effects on math engagement. Finally, although we were able to replicate the main results in both studies, in some cases the effect sizes and sample size were relatively small (e.g., the interaction effect of metacognitive skill and self-control, sample size in study 2). These findings should be replicated with different samples and graders to enhance the generalizability of the key findings.

Despite its limitations, this study had several strengths. One of the main strengths of the present approach is that it used two highly diverse samples and conceptually replicated the key interaction effects of metacognitive skills with interest and self-control on math engagement in both studies. Another notable strength of the present research is its use of longitudinal data, thus allowing the examination of time as a variable. Notably, we found that time interacted with interest and metacognitive skills during Study 2's daily measurements, but it did not interact with time in Study 1, where time was measured at the yearly level. This finding suggests that different psychosocial processes may unfold during shorter and intensive time scales, but the relationships may be relatively stable when viewed through a wider temporal lens. This study also provides promising evidence that there may be multiple pathways to promote and maintain students' math engagement over time. By fostering students' skill (i.e., metacognitive skills), will (i.e., self-control), or thrill (i.e., interest), researchers and practitioners alike may be able to keep students engaged through the adversities of mathematics learning and help them reach their full potential.

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Table 1

Multilevel Model Predicting Mathematics Engagement Over Four Years

Variables	**Model 1: Model with Covariates**	**Model 2: Main Effect**	**Model 3: Interaction Effect**	**Model 4: Interaction Effect Over Time**
Level 1 (Time)				
Time	-.09 (.02)***	-.01 (.01)	-.01 (.01)	-.01 (.01)
Math metacognitive skill		.46 (.02)***	.44 (.02)***	.44 (.02)***
Math interest		.20 (.02)***	.20 (.02)***	.19 (.02)***
Math self-control		.05 (.01)***	.05 (.01)***	.05 (.01)***
Teacher-student relationship		.05 (.01)***	.05 (.01)***	.05 (.01)***
Math achievement		.01 (.00)***	.01 (.00)**	.01 (.00)***
Metacognitive skill × Time			.02 (.02)	.02 (.02)
Interest × Time			.02 (.01)*	.02 (.01)*
Self-control × Time			.00 (.01)	.00 (.01)
Metacognitive skill × Self-control			-.02 (.01)*	-.03 (.01)*
Metacognitive skill × Interest			-.07 (.01)***	-.07 (.01)***
Interest × Self-control			.01 (.01)	.01 (.01)
Metacognitive skill × Interest × Time				-.00 (.01)
Metacognitive skill × Self-control × Time				.01 (.01)
Level 2 (Student)				
Grade Level	-.06 (.02)***	.01 (.01)	.01 (.01)	.00 (.01)
Male (vs. Female)	-.07 (.04)	-.03 (.02)*	-.04 (.02)*	-.04 (.02)*
White (vs. Minority)	.18 (.05)***	.12 (.02)***	.13 (.02)***	.13 (.02)***
Free/reduced-price lunch (vs. Paid)	-.28 (.03)***	-.07 (.01)***	-.07 (.02)***	-.07 (.02)***
Model fit indices	-9693.53	-5992.67	-3455.02	-3454.24

Note: The values in the parentheses indicate standard errors; the interactions were tested simultaneously; $^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$.

Table 2

Multilevel Model Predicting Daily Mathematics Engagement

Variables	**Model 1: Model with Covariates**	**Model 2: Main Effect**	**Model 3: Interaction Effect**	**Model 4: Interaction Effect Over Time**
Level 1 (Daily)				
Time	-.01 (.005) *	-.01 (.004) ***	-.01 (.004) **	-.01 (.004) *
Math metacognitive skill		.24 (.03) ***	.25 (.03) ***	.25 (.03) ***
Math interest		.23 (.02) ***	.21 (.02) ***	.21 (.02) ***
Math self-control		.07 (.03) *	.07 (.03) *	.07 (.03) *
Metacognitive skill × Time			.01 (.005) *	.01 (.005) *
Interest × Time			.01 (.003) ***	.01 (.004) **
Self-control × Time			-.00 (.005)	-.00 (.005)
Metacognitive skill × Self-control			.04 (.02) *	.04 (.02) *
Metacognitive skill × Interest			-.04 (.01) *	-.04 (.01) *
Interest × Self-control			.00 (.01)	.00 (.01)
Metacognitive skill × Interest × Time				-.01 (.003) ***
Metacognitive skill × Self-control × Time				.01 (.001)
Level 2 (Student)				
Math engagement (pre-daily diary survey)	.13 (.08)	.02 (.06)	.02 (.06)	.01 (.06)
Teacher-student relationship (pre-daily diary survey)	.09 (.08)	.005 (.06)	.01 (.06)	.01 (.06)
Math achievement (prior year)	-.00 (.005)	-.00 (.003)	-.00 (.003)	-.003 (.003)
Male (vs. Female)	.14 (.10)	.13 (.07)	.13 (.07)	.13 (.07)
White (vs. Minority)	.02 (.10)	.13 (.07)	.13 (.07)	.13 (.07)
Free/reduced-price lunch (vs. Paid)	-.09 (.10)	-.08 (.07)	-.07 (.07)	-.08 (.07)
Model fit indices	-2415.87	-2313.18	-2214.903	-2213.97

Note: The values in the parentheses indicate standard errors; the interactions were tested simultaneously; * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

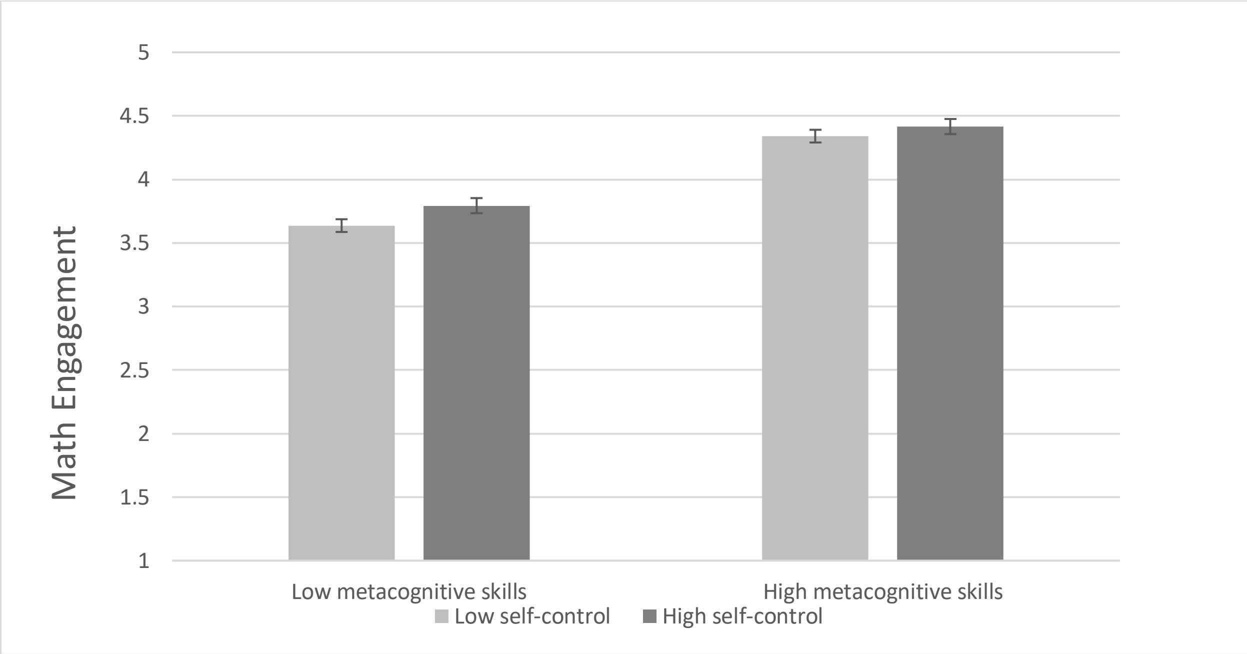

Figure 1a.
The interaction effect of metacognitive skill and self-control on math engagement over four years

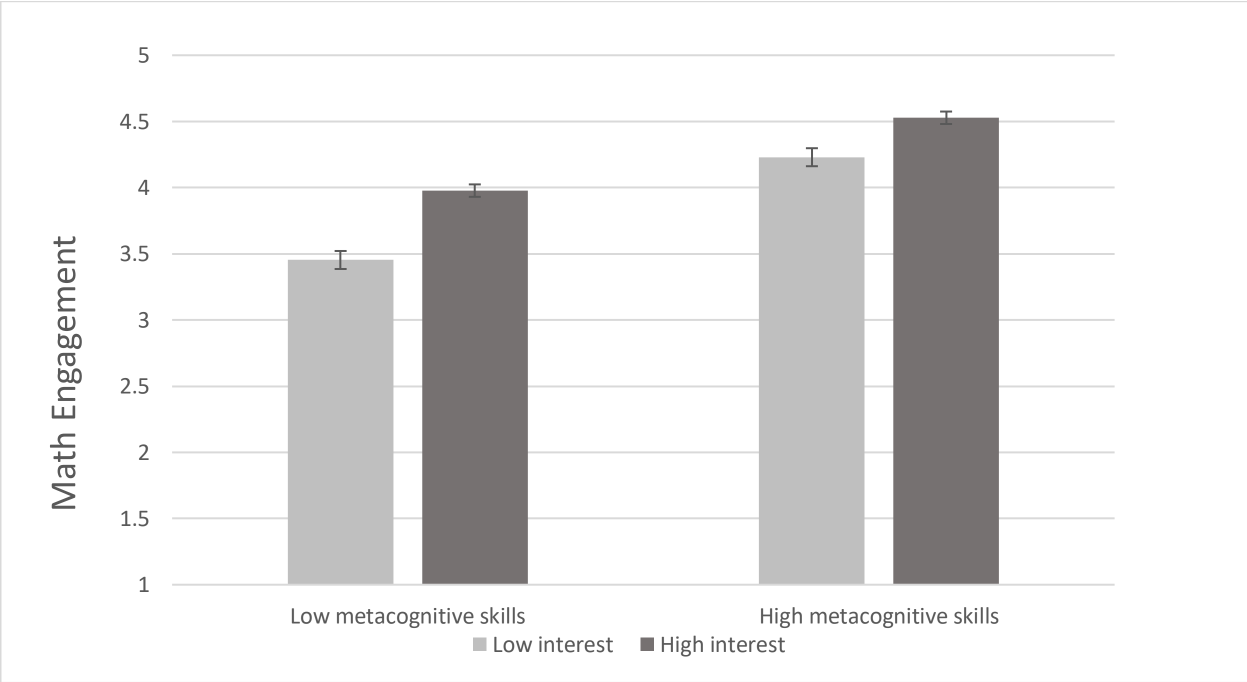

Figure 1b.
The interaction effect of metacognitive skill and interest on math engagement over four years

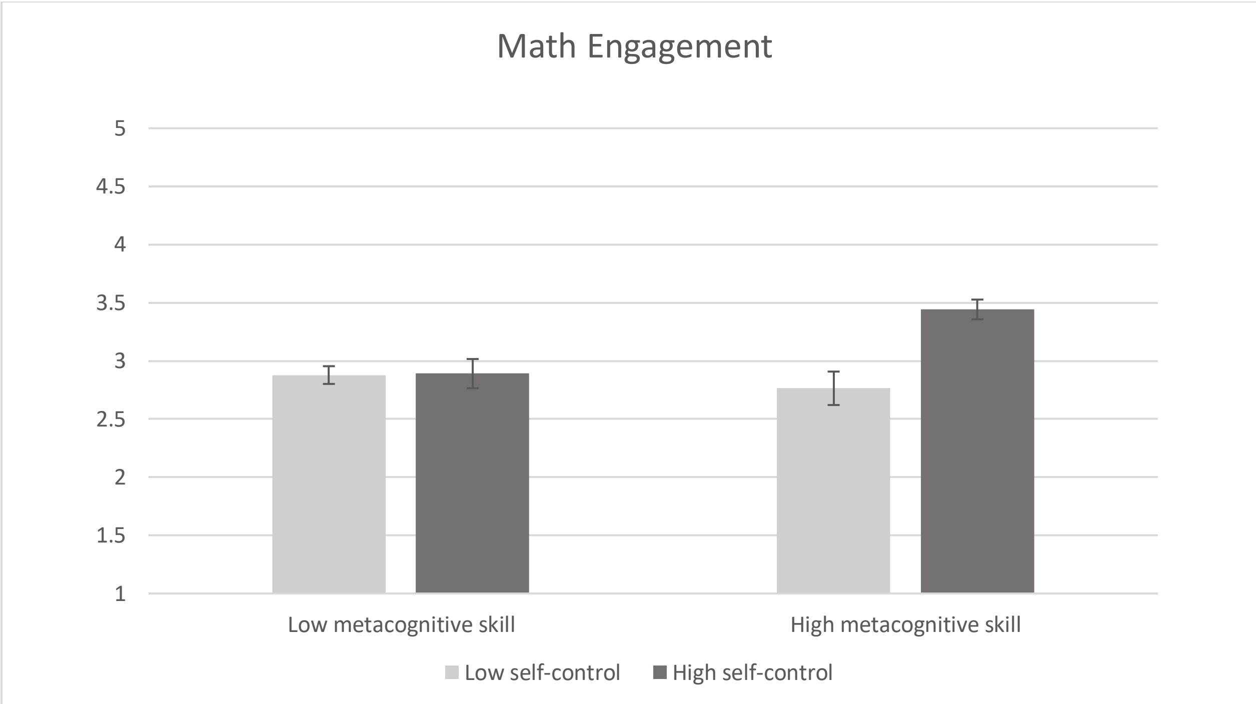

Figure 2a.
The interaction effect of metacognitive skill and self-control on daily math engagement

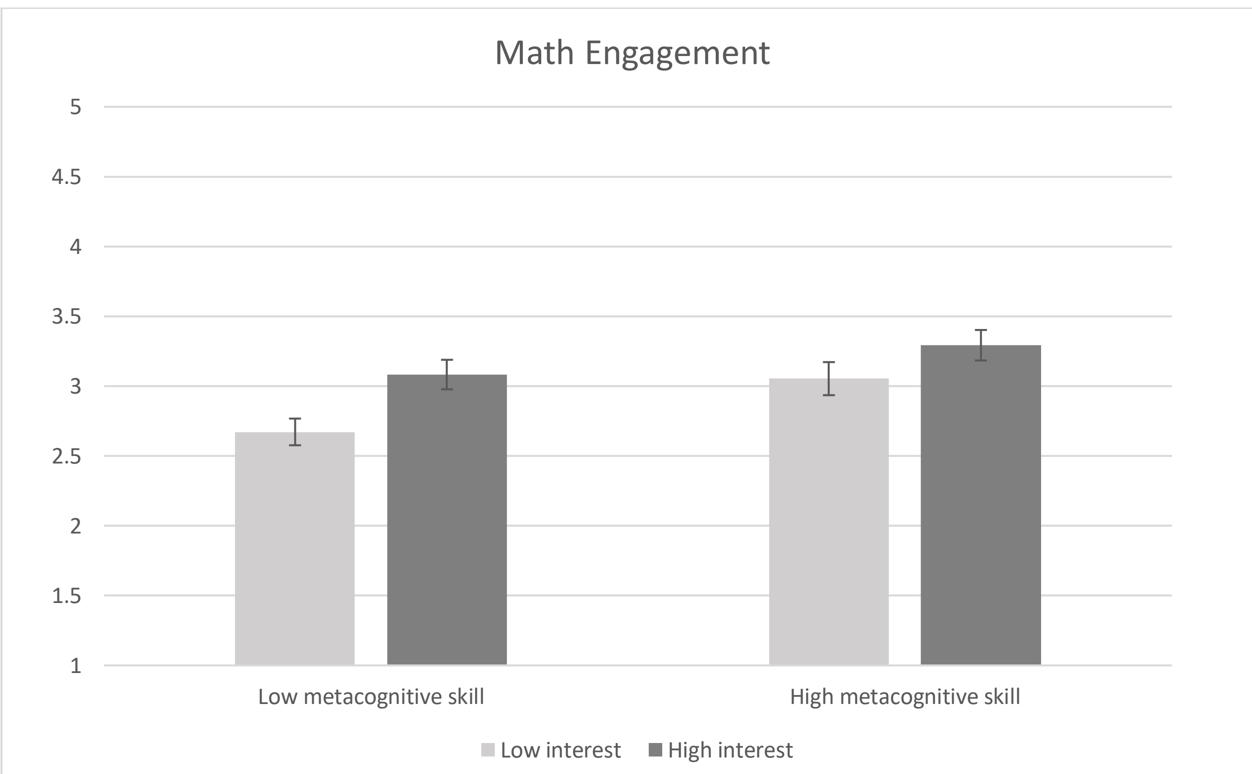

Figure 2b.
The interaction effect of metacognitive skill and interest on daily math engagement

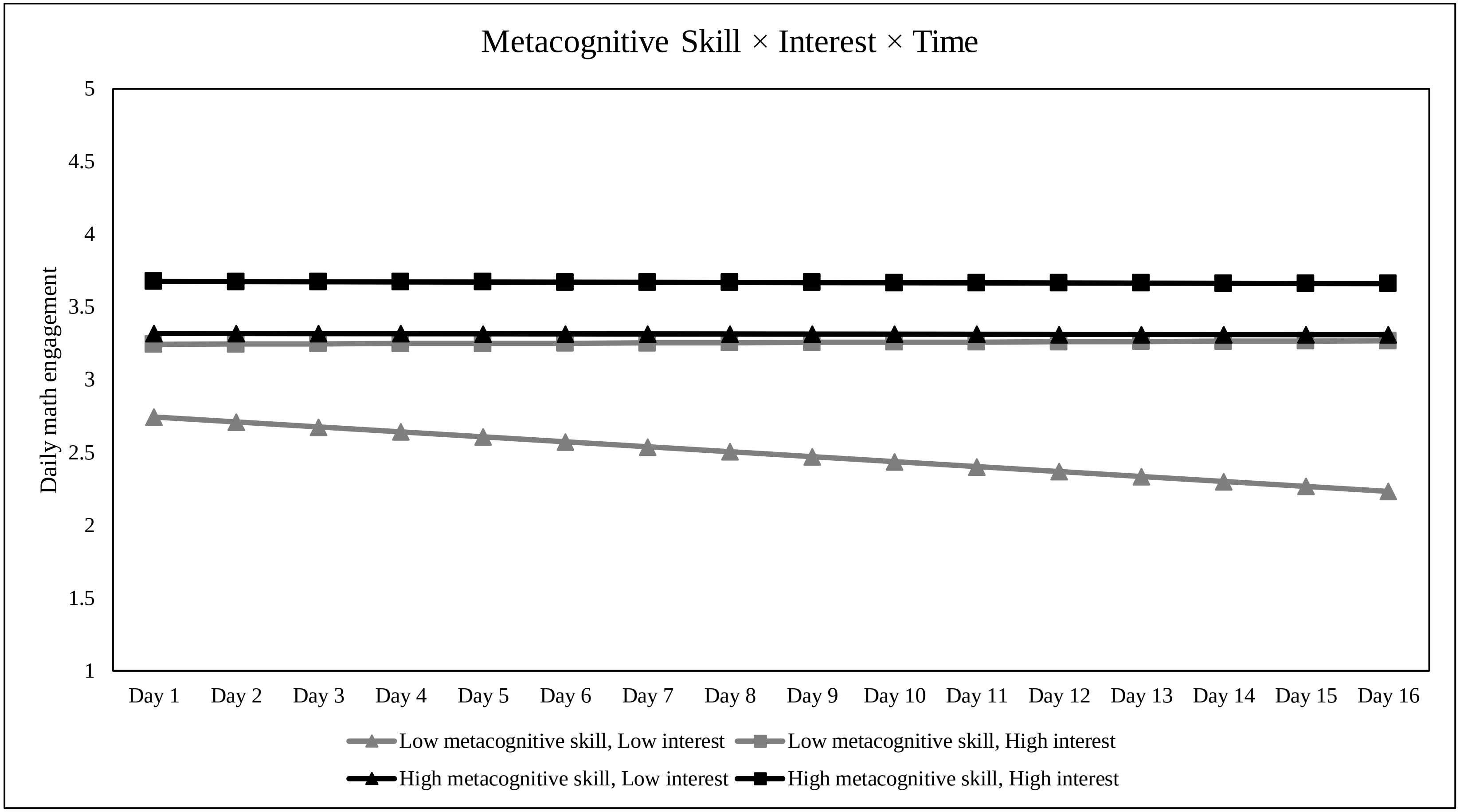

Figure 3
The interaction effect of metacognitive skill, interest, and time on daily math engagement