Cognitive Appraisals, Achievement Emotions, and Students' Math Achievement:

A Longitudinal Analysis

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Abstract

Based on control-value theory (CVT), we examined longitudinal relations between students' control and value appraisals, three activity-related achievement emotions (enjoyment, anger, and boredom), and math achievement ($N = 1,716$ fifth and seventh grade students). We assessed appraisals and emotions with self-report measures of perceived competence in math, perceived value of math, and math emotions, and achievement with school grades in math. All variables were measured in each of three consecutive annual assessments. Using structural equation modeling, we tested the CVT proposition that appraisals, emotions, and achievement show reciprocal relations over time. We hypothesized that (a) control-value appraisals influence the emotions, (b) the emotions influence achievement, and (c) achievement reciprocally influences appraisals and emotions. Supporting these hypotheses, the findings show that students' perceived competence and perceived value positively predicted their subsequent enjoyment and negatively predicted their anger and boredom, controlling for prior levels of these variables, gender, and prior achievement. Students' enjoyment positively predicted subsequent math achievement; anger and boredom negatively predicted achievement. Achievement showed reciprocal positive predictive effects on subsequent perceived competence, value, and enjoyment, and negative effects on subsequent anger and boredom; the effects on enjoyment and boredom were significant from Time 1 to 2 only. As posited in CVT, the effects of achievement on the emotions were mediated by perceived competence. In sum, the findings suggest that enjoyment, anger, and boredom influence students' achievement in mathematics, and that control-value appraisals and achievement are important antecedents of these emotions. Implications for future research and educational practice are discussed.

Keywords: Achievement emotion; math achievement; control-value theory; adolescence; longitudinal studies

Educational Impact and Implications Statement

This study highlights the importance of students' control and value beliefs for their emotions during math learning. These emotions, in turn, impacted students' math achievement. Our findings suggest that promoting positive perceptions of control and value can be a powerful approach for fostering learners' positive emotional experiences and academic achievement.

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During compulsory schooling, students spend on average 7,533 hours in the classroom (OECD, 2018). In this time frame, they are expected to equip themselves with knowledge and skills they will need to be successful in their adult lives. Due to its tremendous significance, the classroom is "infused with intense emotional experiences" (Pekrun et al., 2007, p. 13). Available evidence confirms that students experience a broad range of different emotions in the classroom (Pekrun, Muis, et al., 2017; Raccanello, Hall, et al., 2018). For at least three reasons, it is pivotal to investigate these emotions. First, emotions are important educational outcomes in their own right given that they are key components of psychological well-being and health (e.g., Frenzel et al., 2007a). Second, emotions affect students' motivation, interest, self-regulated learning, and academic achievement, over and above the effects of cognitive abilities, prior achievement, or demographic variables (e.g., Burić & Sorić, 2012; Pekrun et al., 2002; Pekrun, Lichtenfeld, et al., 2017; Pinxten et al., 2014). Third, emotions also influence students' career choices and their motivation to participate in lifelong learning (Harackiewicz et al., 2000; Wigfield et al., 2002).

However, research on education largely neglected students' emotional experiences throughout the 20th century, with research on test anxiety and attributional emotion studies being the sole exceptions. Students' test anxiety has been studied since the 1930s (Stengel, 1936) and is researched extensively since the beginning of the 1950s (e.g., Mandler & Sarason, 1952; see Pekrun et al., 2002, 2007). A few years later, attributional research began to examine the role of causal attributions for emotions following success and failure (Weiner, 1985, 2019). Over the past 20 years, there has been a considerable increase in research in this field. Emotions have become a focal construct in contemporary educational research.

One theoretical paradigm that has guided this research is Pekrun's (2006, 2018) control-value theory (CVT) of achievement emotions. Studies testing CVT's core tenets have demonstrated that students' emotions are related to their perceptions of personal control over, and value of, achievement-related tasks and outcomes, as well as their academic achievement. However, previous research has either examined linkages between perceived control or value and emotions (e.g., Putwain, Pekrun, et al., 2018), or between emotions and achievement (e.g., Putwain, Becker, et al., 2018), but failed to examine the interplay between all four constructs as proposed by CVT and detailed below.

To address this gap in the literature, the present research employed a longitudinal design to test relations between cognitive appraisals, emotions, and achievement over a three-year period. We examined reciprocal linkages between these constructs in the domain of mathematics. We focused on mathematics due to its significance as a core subject in school curricula, and because it has been identified as a strong predictor of students' future social and economic participation (OECD, 2014; Patton et al., 1997). As we were interested in students' emotional experiences during ongoing achievement-related activities in the classroom, we focused on emotion related to these activities (i.e., activity emotions; Pekrun, 2006). We tracked three major activity emotions: enjoyment, anger, and boredom. These three emotions occur most frequently in the classroom and are best documented in the literature on activity emotions (see Camacho-Morles et al., 2021). By focusing on these emotions, our study contributes to the evidence on core constructs in this nascent literature. In addition to analyzing reciprocal relations between appraisals, these three emotions, and math achievement, we probed mediation effects by testing both the indirect effects of cognitive appraisals on achievement via emotions, and the indirect effects of achievement on emotions via cognitive appraisals.

In the following sections, we outline core propositions of CVT as well as extant evidence, and delineate our hypotheses. Subsequently, we detail our methodological approach, and present and discuss our findings as well as their implications for future research and practice.

Control-Value Theory of Achievement Emotions

CVT (Pekrun, 2006, 2018) integrates propositions from different theoretical approaches that share common basic assumptions, including expectancy-value models of emotions (Lauermann et al., 2017; Pekrun, 1992; Turner & Schallert, 2001), attributional theories (Graham & Taylor, 2014), models of stress-related achievement emotions (e.g., Folkman & Lazarus, 1985), theories of test anxiety (Zeidner, 1998), theories of perceived control (Perry, 2003), and models targeting the effects of emotions on learning and performance (Pekrun, Lichtenfeld, et al., 2017). These different conceptual frameworks are complementary rather than mutually exclusive. While previous theories and research (e.g., attributional theories) have mainly considered emotions related to achievement outcomes (i.e., success and failure), CVT also explains emotions related to achievement activities themselves. As such, CVT expands previous theoretical approaches by addressing a broader range of achievement emotions.

Concept of Achievement Emotions

CVT defines achievement emotions as emotions directly linked to achievement activities or their outcomes. They can be organized in a three-dimensional taxonomy involving the following dimensions (Pekrun, 2006, 2018; Pekrun et al., 2007): (1) object focus (i.e., activity-versus outcome-related emotions); (2) valence (i.e., positive/pleasant versus negative/unpleasant emotion); and (3) the degree of activation (activating vs. deactivating). With regard to the first dimension, activity emotions relate to ongoing achievement-related activities (e.g., enjoyment arising from learning, boredom experienced during classroom instruction), whereas outcome

emotions pertain to the outcomes of these activities. Outcome emotions comprise prospective, anticipatory emotions (e.g., hope for success, anxiety of failure) and retrospective emotions (e.g., pride or shame experienced after feedback about achievement; Pekrun, 2006). The second and third dimensions—positive versus negative, and activating versus deactivating—can be used to differentiate between four broad groups of emotions: (1) positive activating (e.g., enjoyment, hope, pride); (2) positive deactivating (e.g., relaxation, relief); (3) negative activating (e.g., anger, anxiety, shame); and (4) negative deactivating (e.g., boredom, hopelessness).

Antecedents of Achievement Emotions

As implied by its name, CVT proposes that two types of cognitive evaluations function as core determinants of achievement emotions: control appraisals and value appraisals. Control appraisals refer to individuals' perceptions of their competence and control over achievement-related activities and outcomes, including perceived competence, causal expectations (self-efficacy expectations and outcome expectations), and causal attributions. Value appraisals relate to the perceived positive and negative values of these activities and outcomes. Positive values render activities and outcomes attractive and desirable, such as the interestingness and personal relevance of learning materials, or the usefulness of success for one's future career. Negative values render them undesirable, such as the aversive feelings that can accompany intense effort, or the costs incurred by failure. The theory also differentiates between intrinsic and extrinsic values. Intrinsic value refers to aspects of activities and outcomes that make them valuable in their own right, regardless of any outcomes of the activity, or further consequences of immediate outcomes. Extrinsic value relates to the instrumental utility of an activity to generate outcomes, and of outcomes to generate further outcomes (Pekrun, 2006; Putwain, Pekrun, et al., 2018).

According to CVT, different combinations of control and value appraisals evoke different

emotions (for an overview of basic assumptions about appraisals and emotions, see Pekrun, 2006, 2018; Pekrun & Perry, 2014; Pekrun et al., 2007). The theory posits that activity emotions are triggered by perceptions of competence to perform achievement activities and the value of these activities, prospective outcome emotions by causal expectations of future success and failure and the perceived value of these outcomes, and retrospective outcome emotions by causal attributions of success and failure that did already occur, combined with perceptions of the value of these outcomes.

Regarding activity emotions, CVT proposes that high levels of perceived control and positive value elicit enjoyment. For instance, the more students are interested in a math task and the more they feel capable of solving it, the more they will enjoy working on it. Negative value is expected to arouse anger. For instance, if students are working on a task involving unappealing content (i.e., negative value) and task demands seem unreasonable, they will experience anger. Anger may also arise when working on a difficult task that is perceived as taking too much effort, which is experienced as aversive. In contrast, although not directly addressed in CVT, it is plausible to assume that perceiving positive value in learning materials and achievement activities reduces students' anger in achievement settings. In addition, perceived control should play a role in the arousal of anger. In its original version (Pekrun, 2006), CVT proposed that high levels of control promote anger. In recent revisions (Pekrun, 2018; Pekrun & Perry, 2014), this proposition has been dropped. In fact, it seems reasonable to assume that high control makes it possible to change achievement activities and make them less aversive. As such, we posit that anger is promoted by low levels of perceived control.

Finally, low levels of any value are expected to generate boredom, as in monotonous, routine activities that lack sufficient challenge or target tedious content. Alternatively, if a task is

seen as too difficult, it may also be difficult for learners to detect its value. If value is lacking, boredom can emerge under both high and low control conditions (Pekrun, 2006; Pekrun et al., 2007; Putwain, Pekrun, et al., 2018; Westgate & Wilson, 2018).

Links between Emotions and Achievement

According to CVT, emotions influence students' cognitive resources, their motivation to learn, their use of learning strategies and, by implication, their performance. Positive activating emotions such as enjoyment are assumed to be positively associated with students' academic achievement: They preserve cognitive resources, help focus attention on the learning task, strengthen interest and intrinsic motivation, and facilitate deep learning (Artino et al., 2010; Pekrun, 2006, 2009; Pekrun et al., 2002, 2004, 2011). The opposite pattern of effects is expected for negative deactivating emotions such as boredom. Boredom may induce mind wandering and direct attention away from academic tasks, reduce both intrinsic and extrinsic motivation, and foster shallow information processing, implying negative effects on students' achievement (Daniels et al., 2009; Malkovsky et al., 2012; Pekrun et al., 2004, 2010, 2011). Achievement effects for negative activating emotions such as anger are considered to be more complex and variable. On the one hand, anger can prompt task-irrelevant thinking (e.g., ruminating about unfair treatment by a teacher), which leads to a reduction of cognitive resources available for learning. Furthermore, anger can undermine intrinsic motivation to learn. As such, anger can have negative effects on achievement. On the other hand, anger can promote extrinsic motivation to invest effort to overcome obstacles and avoid failure, which would entail positive effects on achievement (Lam et al., 2015; Pekrun et al., 2011).

Reciprocal Links Between Appraisals, Emotions and Achievement

CVT hypothesizes that cognitive appraisals elicit emotions which, in turn, influence

learning and achievement. Additionally, it acknowledges that emotions, control appraisals, and performance outcomes are linked by reciprocal causation; that is, performance outcomes are thought to shape subsequent perceptions of control over performance, which are considered to influence subsequent emotions. Success during learning is posited to strengthen students' perceived control and to thereby promote the experience of positive emotions, whereas failure is expected to undermine perceptions of control and to thereby elicit negative emotions (Pekrun, 2006; Pekrun, Lichtenfeld, et al., 2017).

CVT does not specify the possible mediational role of value in effects of achievement on emotion. However, predictions regarding effects of achievement on value can be derived from the achievement motivation literature. In classic achievement motivation theory, it was assumed that the value of achievement is a negative function of expectancy. As pointed out by Atkinson (1957, p. 362), "one cannot anticipate the thrill of a great accomplishment if, as a matter of fact, one faces what seems a very easy task." Success is known to have positive effects on expectancy of further success. Given positive effects of successful achievement on expectancy and negative effects of expectancy on value, it would follow that achievement negatively impacts value. Alternatively, success in a given task domain could exert a positive influence on valuing the domain due to the selective advantage of engaging in domains that bring success and resulting positive outcomes, relative to domains in which one is less successful and, therefore, obtains less positive outcomes. As such, although the intrinsic value of success in the domain may be reduced, its overall value may be increased due to positive outcomes resulting from success (see also Wigfield et al., 2020).

Given these opposing effects, the net impact of achievement on value may be difficult to predict. In line with the difficulties in deriving clear predictions, the few longitudinal studies that

examined this link did not yield consistent evidence, with some studies showing positive effects (e.g., Wang, 2012; Weidinger et al., 2020) and others null effects (e.g., Dettmers et al., 2010; Nuutila et al., 2018; Robinson et al., 2019).

Prior Research on CVT

Appraisal Antecedents

Corroborating core assumptions of CVT, cross-sectional evidence shows that high levels of perceived control and positive value are positively related with students` enjoyment. Evidence comes from studies with primary school students (Goetz et al., 2008; Putwain, Becker, et al., 2018), secondary school students (Camacho-Morles et al., 2019; Goetz et al., 2008; Hagenauer & Hascher, 2014; Mercan, 2020; Van der Beek et al., 2017), and university students (Pekrun et al., 2011) that investigated students' emotions in math, science, and language classes, computer-based collaborative problem-solving, and university courses. Longitudinal research examining relations between appraisals and enjoyment is rare, but initial evidence suggests that prior control and positive value appraisals positively predict later enjoyment in primary school (Putwain, Pekrun, et al., 2018), secondary school (Goetz, Frenzel, et al., 2010; Mercan, 2020; Pekrun et al., 2019) and university students (Garn et al., 2017) during math and language classes as well as university courses.

Research investigating the control–value origins of anger is scarce (see Pekrun & Perry, 2014; Camacho-Morles et al., 2019). Cross-sectional studies have shown that control and positive value appraisals are negatively related to secondary school students' anger during math, physics, and language classes (Goetz, Cronjaeger, et al., 2010; Peixoto, Sanches, et al., 2017) and computer-based collaborative problem solving (Camacho-Morles et al., 2019). In longitudinal studies, prior control negatively predicted students' subsequent anger during math

classes in secondary school (Pekrun et al., 2019) and during university courses (Garn et al., 2017).

As for boredom, CVT proposes that this emotion can arise under both high and low control conditions (i.e., under- and overchallenging tasks) if perceived value is low. However, cross-sectional evidence suggests that both control and value appraisals are negatively related to students' boredom, including secondary school students' boredom during math, science and language classes (Goetz, et al., 2008; Peixoto, Sanches, et al., 2017) and computer-based collaborative problem solving (Camacho-Morles et al., 2019), as well as university students' boredom during courses at university (Pekrun et al., 2011). Using a longitudinal design, Putwain, Pekrun et al. (2018) showed that primary school students' perceived control in math negatively predicted their boredom during math classes.

Emotions and Academic Achievement

Consistent with CVT, cross-sectional research shows that positive activating emotions (enjoyment, hope, and pride) are positively related with math and language performance in primary (Raccanello, Brondino, et al., 2018) and secondary school students (Ahmed et al., 2013) as well as course performance in university students (Artino et al., 2010; Daniels et al., 2009; Malkovsky et at., 2012; Pekrun et al., 2002, 2004, 2011). Relations between negative deactivating emotions (boredom and hopelessness) and achievement were negative in these studies. Extant longitudinal studies with primary school students (Pinxten et al., 2014; Putwain, Becker, et al., 2018) and secondary school students (Pekrun, Lichtenfeld, et al., 2017; Pinxten et al., 2014) point to reciprocal effects between students' emotions and achievement in math. Similarly, university students' emotions and course performance have been shown to be linked by reciprocal effects (Gibbons et al., 2018; Pekrun, Hall, et al., 2014). In these studies, positive

emotions such as enjoyment positively predicted subsequent achievement, and higher levels of achievement positively predicted the subsequent experience of positive emotions. In contrast, negative emotions such as anger and boredom negatively predicted subsequent achievement, and lower levels of achievement were related to higher levels of subsequent negative emotions.

Longitudinal Relations between Appraisals, Emotions, and Achievement

As outlined above, CVT suggests that students' appraisals, emotions, and achievement influence each other over time. However, as yet, studies have focused on bivariate relations between appraisals and emotions (e.g., Putwain, Pekrun, et al., 2018) or between emotions and achievement (e.g., Putwain, Becker, et al., 2018). Studies analyzing the full sequence from appraisals to emotions and emotions to achievement are lacking, with the following exceptions.

Van der Beek et al. (2017) explored the links between Grade 9 students' enjoyment, anxiety, self-concept, and achievement in mathematics. Enjoyment, self-concept, and achievement were positively correlated, whereas anxiety related negatively to both self-concept and achievement. Peixoto, Sanches, et al. (2017) investigated Grade 6 and 8 students' control-value appraisals, emotions, and achievement in mathematics. Control and value appraisals were negatively related to anger and boredom. Anger, in turn, was negatively related to math achievement. Boredom was not significantly related to achievement. However, both studies used cross-sectional designs that preclude any inferences about the temporal ordering of variables. Furthermore, the study of Van der Beek et al. (2017) included only one type of appraisal.

Longitudinal evidence comes from a study by Hagenauer and Hascher (2014), who examined cross-lagged relationships between control and value appraisals, enjoyment, and achievement in mathematics over two measurement points within a one-year period from Grade 6 to Grade 7. The authors tested all possible associations among the variables under study.

Several of the expected cross-lagged effects were observed. As expected, students' prior enjoyment was positively related to their achievement in the following school year. However, the authors also observed a negative effect of students' prior control appraisals on their enjoyment in the following school year (ß = -.19), which was an unexpected finding that was not consistent with the bivariate correlation between the two variables (r = .33). In interpreting the findings of this study, we note two issues. First, there were substantial correlations between perceived control and enjoyment (rs = .51 and .55) as well as perceived value and enjoyment (rs = .59 and.55), which may have made it difficult to disentangle relations of appraisals and enjoyment with achievement. Second, in addition to longitudinal effects, the authors included synchronous (cross-sectional) effects of achievement on appraisals, and appraisals on enjoyment, in their modeling procedure, which may have undermined the power of the analysis to detect longitudinal effects.

Finally, Pinxten and colleagues (2014) investigated cross-lagged effects between perceived control (competence beliefs), enjoyment, and achievement in math using a five-wave design where measures were repeatedly collected from the third until the seventh grade. The authors reported unexpected findings with regard to reciprocal linkages between students' math enjoyment and achievement. Specifically, there were positive links between prior math achievement and subsequent enjoyment, whereas the links in the opposite direction, that is, between prior enjoyment and subsequent math achievement, were negative. Moreover, the study found positive effects of prior enjoyment on subsequent perceived control. However, the opposite direction of this link was not significant for any of the time intervals. The authors concluded that the unexpected and nonsignificant results were caused by high correlations (rs = .60 - .70; i.e., multicollinearity) between perceived control and enjoyment.

Another possible explanation for the nonsignificant results in the study of Pinxten et al. (2014) could be the strong autoregressive effects of some of the examined constructs over time (ß range = .41 - .71), which implies a reduction in the power of predictors to explain variance in the outcome variable (Adachi & Willoughby, 2015; Pekrun, Lichtenfeld, et al., 2017). High stability of the examined constructs over time could be a plausible explanation for the findings of Hagenauer and Hascher (2014) as well, considering the strong autoregressive effects for some of the constructs included (ß range = .36 - .84).

Taken together, evidence for the hypothesized relations between students' control-value appraisals, emotions, and achievement is still inconclusive. The two available longitudinal studies had limitations in terms of including only one type of appraisal (Pinxten et al., 2014) or only two waves of data collection (Hagenauer & Hascher, 2014). Furthermore, both studies were limited to one select emotion (i.e., enjoyment) and did not include negative emotions.

Aims and Hypotheses of the Present Research

The present study used CVT (Pekrun, 2006, 2018; Pekrun & Perry, 2014) as a conceptual framework for analyzing relations between pre- and early adolescent (fifth and seventh grade) students' control appraisals, value appraisals, activity emotions, and math achievement. Expanding on previous research that considered only select constructs, or relied on cross-sectional data as outlined earlier, our goal was to investigate reciprocal relations between all four constructs over time. Our design also allowed for examining the possible mediational role of activity emotions in linking students' control-value appraisals and subsequent math achievement, and to analyze the mediational role of appraisals in the relation between achievement and subsequent emotions. Going beyond the few prior studies employing longitudinal designs, we included both control and value appraisals, examined both positive and negative emotions

frequently experienced by students, and used a three-wave design including annual assessments over the time span of three years. Autoregressive effects, synchronous relations between the constructs, measurement error, and the influence of background variables were controlled in the analysis, thus enabling robust estimation of the relations between appraisals, emotions, and achievement.

By analyzing reciprocal relations between perceived control, perceived value, emotions, and achievement over three waves, the study represents a major advance over previous longitudinal research that did not include all four constructs, did not examine reciprocal effects, or included only two waves To our knowledge, the present investigation is the first to include all four core constructs of CVT in multiple assessments over more than two waves while using latent analysis to control for measurement error. Our study thus provides a more comprehensive test of the theory than available to date.

Research has shown that achievement emotions, control- and value-related constructs such as self-concepts of ability, achievement expectancies, and interests, are organized in domain-specific ways (Goetz et al., 2007, 2008; Pekrun, 2006). Taking domain specificity into account, the present study focused on students' experiences in math. Mathematics is one of the most important school subjects. Math constitutes a core subject in the curriculum, and math skills are needed in a broad range of professions as well as activities in daily life (Dündar et al., 2014; OECD, 2014; Patton et al., 1997). Proficiency in mathematics is vital for students' future social and economic participation. As such, math classes are likely to generate strong emotions.

Prior research captured control appraisals either with measures assessing students' perceptions of being able to influence their academic performance (e.g., Camacho-Morles et al., 2019; Garn et al., 2017; Pekrun et al., 2011) or with measures of academic competence beliefs

and self-concepts (Hagenauer & Hascher, 2014; Goetz et al., 2008; Goetz, Cronjaeger, et al., 2010; Mercan, 2020; Peixoto, Sanches, et al., 2017; Pinxten et al., 2014; Putwain, Pekrun, et al., 2018). In the present study, we followed the CVT proposition that activity emotions depend on perceptions of competence. We employed a domain-specific measure of competence beliefs, namely perceived competence in math, to assess students' perceived competence. According to CVT, domain-specific competence appraisals are foundational for activity emotions in a given domain (Pekrun & Perry, 2014; Putwain, Pekrun, et al., 2018). Value appraisals were assessed using a measure for perceived positive value of math.

Regarding students' emotions, we were interested in understanding the development of their emotions in the classroom setting, given that students spend many hours in the classroom as noted earlier (OECD, 2018). As such, we chose to examine students' class-related emotions rather than their emotions experienced during test situations. Students experience class-related emotions on a daily basis, whereas test taking occurs only a few times during a school year in Portuguese schools. Given this context, class-related emotions are especially intriguing for investigating the effects of emotions on students' learning and achievement (see also Putwain, Becker, et al., 2018).

To capture students' emotional experiences during ongoing activities in classroom instruction, we decided to measure class-related activity emotions. We sought to measure activity emotions that are frequently experienced by learners (Pekrun et al., 2002) as well as conceptually distinct in terms of the above-mentioned dimensions of activation and valence, including enjoyment (positive and activating), anger (negative and activating), and boredom (negative and deactivating). By considering class-related activity emotions, our study expands upon traditional perspectives, such as test anxiety research and attributional studies, which focused on test- and

outcome-related emotions.

The first goal of the study was to examine relations between appraisals and these achievement emotions. We aimed to examine the generalizability of previous findings using student samples from another country and cultural context, different measurement instruments than previous studies, and a three-wave longitudinal approach. However, we also sought to extend previous evidence by examining reciprocal relations between perceived control as well as perceived value, on the one hand, and emotions, on the other, across the three waves. By including three waves, we were able to test for cross-lagged effects across two time intervals, in contrast to the few existing longitudinal studies cited earlier. On the basis of CVT and the extant evidence, we hypothesized that control and positive value appraisals would be positively related to subsequent enjoyment and negatively related to subsequent anger and boredom.

The second goal was to analyze the relations between each of the three emotions and math achievement. In analyzing these relations, we sought to investigate the generalizability of the existing findings summarized earlier. As such, and in accordance with the propositions of CVT, we hypothesized positive relations between enjoyment and math achievement, and negative relations between boredom and math achievement. Regarding anger, theoretical propositions imply that anger can have both positive and negative effects on achievement (Lam et al., 2015; Pekrun, 2006; Pekrun et al., 2011). However, as research has consistently shown negative relationships between anger and achievement (Lam et al., 2015; Peixoto, Sanches, et al., 2017; Pekrun et al., 2019), we expected negative relations between anger and math achievement. In line with CVT and initial longitudinal evidence (Pekrun, Lichtenfeld, et al., 2017; Pinxten et al., 2014; Putwain, Becker, et al., 2018), we hypothesized substantial cross-lagged relations between emotions and math achievement.

The third goal was to expand existing research by testing for mediational effects in the links between appraisals, emotions, and achievement. Specifically, based on CVT (see Pekrun, Lichtenfeld, et al., 2017), we hypothesized indirect effects of cognitive appraisals on math achievement mediated by emotions, as well as reverse indirect effects of math achievement on emotions mediated by control appraisals. These mediational effects have not been examined in prior research. We left as an exploratory question whether effects of achievement and emotions would also be mediated by value appraisals, since CVT makes no assumption regarding mediation by value appraisals. As argued earlier, different predictions regarding effects of achievement on value can be derived from the literature, and empirical evidence on effects of achievement on value is scarce and not consistent.

To deal with multicollinearity between variables, we conducted two complementary sets of cross-lagged analyses, with one set focusing on bivariate relations of perceived control and emotion, perceived value and emotion, or emotion and achievement, and the other set simultaneously including all four constructs. Following the procedure recommended by Pinxten et al. (2014), we chose this combination of analyses to provide a comprehensive and detailed account of the relations linking the CVT constructs.

To consider potentially confounding variables, we controlled for both students' gender and previous math achievement. Research on gender differences in math achievement is inconsistent. While meta-analyses (e.g., Else-Quest et al., 2010; Lindberg et al., 2010; Voyer & Voyer, 2014) document similar math performance in female and male students, data from the OECD Programme for International Student Assessment (PISA) indicate that boys performed better than girls across the OECD countries (OECD, 2015). Evidence for gender differences in competence-related beliefs and achievement emotions in math is more consistent. Across studies

and different cultural contexts, girls tend to report lower competence beliefs (Else-Quest et al.,

2010; Goetz et al., 2013; Kyttälä & Björn, 2010), less enjoyment and pride, and more anxiety,

shame, and hopelessness in math as compared with boys (Frenzel et al., 2007a, 2007b), even

when there are no differences in achievement.

In sum, the present research probed the empirical validity of the following set of

hypotheses:

Hypothesis 1: Prior perceived control and perceived positive value positively predict

subsequent enjoyment and achievement, and negatively predict subsequent anger and boredom.

Hypothesis 2: Prior enjoyment positively predicts subsequent math achievement, and

prior math achievement positively predicts subsequent enjoyment. Prior boredom and anger

negatively predict subsequent math achievement, and prior math achievement negatively predicts

subsequent boredom and anger.

Hypothesis 3: Enjoyment, anger, and boredom are mediators in the effects of cognitive

appraisals on math achievement.

Hypothesis 4: Perceived control is a mediator in the effects of math achievement on

enjoyment, anger, and boredom.

Method

Study Design and Participants

The study comprised three annual assessments. Data was collected from 1,716 students

from 135 classrooms in 12 public schools located in an urban area of Portugal. At the first

assessment (Time 1), these students were 10–15 years old ($M = 11.57$ years; $SD = 1.38$; 50.2%

female) and either in fifth grade or seventh grade (see Table 1 for details). At Time 2, the sample

consisted of 1,531 students who were 11–16 years old ($M = 12.49$ years; $SD = 1.34$; 50.8%

female) and either in sixth grade or eighth grade. At Time 3, the sample consisted of 1,330

students who were 12–17 years old (50.5% female; $M = 13.52$ years; $SD = 1.33$) and either in

seventh grade or ninth grade.

We chose to focus on the age group of 10-17 year old students because adolescence is a

critically important period in students' academic development, both due to developmental

demands on adolescent identity formation and the impact of major school transitions, including

the transition from elementary to secondary school (Eccles & Wigfield, 2020; Pekrun,

Lichtenfeld, et al., 2017). These transitions can trigger changes in self-perceptions that impact

students' emotion and motivation. Empirical findings confirm that students' academic emotions

can change substantially during this period, with positive emotions such as enjoyment typically

showing a decrease and negative emotions an increase across school years (Hagenauer &

Hascher, 2014; Vierhaus et al., 2016).

The sample was representative for the Portuguese student population with regard to

students' gender, academic achievement, and socio-economic background (Authors, 2016,

2017). Regarding socio-economic status, students' parents had the following educational

background, which is representative for educational attainment in the broader Portuguese

population (OECD, 2014): Twenty-five percent of students' mothers and 21% of their fathers

had a university degree; 33% of mothers and 31% of fathers had completed upper secondary

education; and 41% of mother and 48% of fathers left school before completing Grade 12.

In Portugal, students' in Grades 5 to 9 usually have five sessions of math class per week.

The math instruction students receive is primarily teacher-centered and expository, with teachers

explaining the content and demonstrating how to solve math problems. However, individual

exercises, collaborative problem solving, and group discussion are used as well. Contents taught

range from numerical operations, algebra, and geometry, to measurement and basics of data

processing and statistics across the target grade levels.

Procedure

The study used data from a broader project on student motivation ("Title"; see Authors,

2016, 2017). The project received ethical approval from the Institutional Review Board of the

Portuguese Ministry of Education (MIME-0342500001). Participating schools were contacted

through their school boards. School boards and the corresponding schools were selected to

represent a wide range of students from different socio-cultural backgrounds. Written parental

consent was obtained for participating students. Participation was voluntary, and participants

were assured of the confidentiality of their answers. Students who participated were

compensated at the end of each school year with a small gift (a pencil or pen).

In the annual assessments, students answered the same questionnaire to report on their

control appraisals, value appraisals, and achievement emotions. Questionnaires were filled out

during regular class time. A research assistant and a trained undergraduate student administered

the instruments. In addition, data about students' math achievement was recorded from their

official report cards. Data was collected in the second trimester of each school year (i.e., between

March and April).

Measures

Perceived Control

The Competence in Mathematics subscale of the Self-concept and Self-esteem Scale for

Pre-Adolescents (Peixoto, Mata, et al., 2017; Peixoto & Almeida, 2010, 2011) was used to

measure students' competence beliefs in math as an indicator for their domain-specific control

appraisals (five items; "Some young people have difficulties solving math exercises"; "Some

young people manage to solve math problems very quickly"; "Some young people think that

they are good math students"; "Some young people have difficulties solving math problems";

"Some young people think that they do not have good grades in math"). Participants responded

to items on a four-point Likert scale (1 = *completely different from me* to 4 = *exactly like me*).

Cronbach's alpha was .90, .89, and .90 for Times 1–3, respectively.

Perceived Value

Perceived positive value was measured with the value subscale of the Portuguese version

of the Intrinsic Motivation Inventory (IMI; McAuley et al., 1989; Monteiro et al., 2015).[1] Four

items were used to tap students' perceived positive value of math ("Math assignments have value

to me"; "Math activities are valuable to me"; "Doing math assignments can be positive for me";

"I think that math activities are important"). Participants responded to items on a six-point Likert

scale (1 = *never* to 6 = *always*). Cronbach's alpha was .88, .89, and .90 for Times 1–3,

respectively.

Achievement Emotions

Students' achievement emotions in math were measured with the class-related enjoyment,

anger, and boredom scales of the Achievement Emotions Questionnaire for Preadolescent

Students (AEQ-PA; Peixoto et al., 2015). Each of the scales included four items (enjoyment: "I

enjoy being in my math class"; "I am motivated to go to math class because it's exciting"; "I feel

good when I am in math class listening to the teacher"; "I'm glad it paid off to go to math class";

anger: "I feel anger welling up in me during math class"; "Because I'm angry, I get restless in

math class"; "Thinking about all the useless things I have to learn in math makes me irritated";

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[1] The value scale of the Intrinsic Motivation Inventory represents a global measure of positive value rather than intrinsic value.

"After math class, I am angry"; boredom: "I get bored during math class"; "I feel like leaving the classroom during math class because it is so boring"; "Math class bores me"; "I find math class fairly dull").

The instructions asked participants to indicate how the typically feel in relation to math classes. Items were answered on a five-point Likert scale (1 = *completely disagree* to 5 = *completely agree*). Cronbach's alphas were .88, .89, and .87 for enjoyment; .80, .79, and .83 for anger; and .92, .93, and .93 for boredom at Times 1–3, respectively.

Achievement

Math achievement was assessed via school grades obtained at the end of the third term of each academic year. These grades are summative scores based on multiple exams and correspond to students' final grade of the school year. Teachers are advised to construct their exams and grade students' performance relative to the national curriculum for the school year. As such, these grades best represent students' achievement relative to the curriculum in mathematics. Math grades of the third term were highly correlated with the grades of the first term (Time 1: r = .84; Time 2: r = .82; Time 3: r = .84) and of the second term (Time 1: r = .89; Time 2: r = .90; Time 3: r = .89; all p < .001), thus documenting reliability.

Covariates

Students' gender (coded 1 for male and 2 for female) and their prior math achievement assessed in Grade 4 and 6, respectively, served as control variables and were included as covariates in the analyses.

Data Analysis

Structural Equation Modeling

Descriptive analyses and analyses of manifest correlations were conducted using SPSS version 25 (IBM, 2015). Following established recommendations, latent relations between control appraisals, value appraisals, achievement emotions, and math achievement were analyzed using structural equation modeling (SEM) with Mplus 8 (Muthén & Muthén, 1998–2017). Although none of the variables showed substantial deviation from normal distributions (for all variables, skewness < 2 and kurtosis < 7; see West et al., 1995), we used MLR estimation (maximum likelihood estimation with robust standard errors) to account for any existing amount of non-normality. MLR estimation is robust to the non-normality of observed variables. To account for the nested structure of the data, we used the type = complex option implemented in Mplus (Muthén & Muthén, 1998–2017), which corrects standard errors for nestedness while preserving the use of the covariance matrix from the full sample to calculate parameters. We modeled student data as nested within schools rather than classrooms as we did not recruit intact classes but samples of students from a defined number of schools, similar to other national and international student assessments (e.g., the OECD Programme for International Student Assessment, PISA). Students attended 135 classrooms at Time 1; due to changes in class composition, they were distributed across 216 classrooms at Time 3. As such, schools were defined as clusters, similar to other studies using school-based sampling (as well as studies using class-based sampling when class composition changed over time; see, e.g., Marsh et al., 2018; Nagengast & Marsh, 2011; OECD, 2009).

Preliminary analyses indicated substantial multicollinearity among the three emotions considered (see Table 3 for bivariate correlations). This issue has been encountered in previous studies that have analyzed effects of multiple emotions simultaneously (e.g., Peixoto, Sanches, et al., 2017; Pekrun, Lichtenfeld, et al., 2017). Therefore, we conducted separate analyses for each

emotion. Furthermore, as outlined earlier, previous research testing relations between appraisals, emotion, and achievement has produced unexpected or nonsignificant results due to multicollinearity between appraisals and the other variables (see Hagenauer & Hascher, 2014, Marsh et al., 2005, Pinxten et al., 2014). Consequently, we tested two different sets of models. In the first set, we tested relations between the variables in bivariate models of reciprocal effects. We estimated these effects for a) perceived control and emotion, b) perceived value and emotion, and c) emotion and math achievement, separately for each of the three emotions. In the second set, we tested four-variate models of reciprocal effects between all four variables (i.e., control, value, emotion, and achievement) separately for each emotion (see Figure 4). In these models, we also tested for indirect effects. Gender and prior math achievement were included as covariates in all models.

Emotions and appraisals were modeled as latent constructs. Math achievement and gender were examined as manifest variables. A correlated uniqueness approach was adopted to control for systematic measurement error. Through this approach, correlations between residuals for identical appraisal and emotion items across measurement points were included.

To assess goodness of model fit, several indexes were used. Since chi-square values are highly sensitive to sample size (Marsh et al., 1988), we considered the comparative fit index (CFI), Tucker-Lewis index (TLI), root mean square error of approximation (RMSEA), and standardized root mean squared residual (SRMR). Values greater than .90 for CFI and TLI and less than .08 for RMSEA and SRMR are generally considered indicative of good fit (Kline, 2011). The more conservative guidelines of Hu and Bentler (1999) set a threshold of .95 for CFI and TLI, and less than .05 for RMSEA.

Measurement Invariance

A crucial precondition for testing longitudinal SEMs is longitudinal measurement invariance. It must be ensured that repeatedly measured variables represent the same construct in the same metric over time (Liu et al., 2016). Thus, we sequentially evaluated models of configural, metric, and scalar invariance (Meredith, 1993) for perceived control, perceived value, and each emotion. For analyzing correlations and path coefficients, metric invariance is the minimum requirement (Chen, 2007). Metric invariance demands equal patterns of factor loadings and equal factor loadings over time. For stepwise comparisons of models with different restrictions on invariance, we followed recommendations by Chen (2007) specifying that changes of $\geq$ -.010 for CFI, $\geq$ .015 for RMSEA, and $\geq$ .030 for SRMR indicate non-invariance.

Missing Data

As is typical for longitudinal studies, there was some amount of missing data, primarily due to some participants having changed school after the first assessment or being absent at the time of data collection. There were 6.0%, 12.7%, and 23.6% of missing data at T1, T2, and T3, respectively. As such, compared with other longitudinal studies, attrition was relatively low. To evaluate potential bias in missing data, we conducted Little's test for data missing completely at random (MCAR; Little, 1988) and a series of t-tests comparing mean values on the study variables for participants with complete versus incomplete data. Little's test was statistically significant ($p < .001$), suggesting that the data were not MCAR. Results from t-tests pointed to a few significant differences between students with complete versus incomplete data: Older students, students with lower math grades in the year before data collection, and students with lower math grades, lower perceived control, higher anger, or higher boredom at Time 1 were less likely to participate at all three waves. No other difference was statistically significant (ps $>.05$).

For large samples even small differences can be statistically significant. Therefore, we calculated effect sizes (Cohen's d) to evaluate the relevance of the differences. Most effects sizes were small by conventional standards (ds = 0.15–0.19), implying that the differences can be considered as trivial despite significance (Cohen, 1988). Effect sizes for the differences in math achievement in the year before data collection and at Time 1 were moderate (ds = 0.28 and 0.50, respectively). As such, we included these two variables in our analytic models to correct for disproportional attrition (see Collins et al., 2001; Nicholson et al., 2017). We treated the data as missing at random (MAR) and handled missing data using full-information-maximum-likelihood (FIML) estimation. FIML provides an adequate approach to deal with missing data in longitudinal studies (Jeličič et al., 2009). Moreover, it produces trustworthy, unbiased parameter estimates even with large numbers of missing values when the variable causing missingness is included in the model (Enders, 2010; Nicholson et al., 2017).

Results

Preliminary Analyses

Table 3 provides manifest and latent correlations among appraisals, emotions, and math achievement. The manifest correlations indicate that students' perceived control and perceived value were positively related to their enjoyment and negatively related to their anger and boredom. The correlations were moderate to large (Cohen, 1998). Students' enjoyment correlated positively with their math achievement, anger and boredom correlated negatively with their math achievement. These correlations were small to moderate and of similar size for all three emotions.

The latent correlations were derived from a CFA model including all appraisal, emotion, and achievement variables. The model showed a good fit to the data, $\chi^2(1{,}963) = 3{,}475.287$, p

<.001; CFI = .975; RMSEA = .021; and SRMR = .026. Latent correlations showed the same

pattern as their corresponding manifest correlations. These observed relationships were also

consistent with previous research on appraisals, emotions, and math achievement (e.g., Peixoto,

Sanches, et al., 2017; Pekrun et al., 2011; Pekrun, Lichtenfeld, et al., 2017).

The results for the tests of measurement equivalence over time are shown in Table 2. The

goodness of fit indices for the baseline models for the perceived control, perceived value, and

emotions showed a good fit for all constructs, $\chi^2(87) = 383.57$, $p < .001$ for perceived control,

$\chi^2(51) = 291.84$, $p < .001$ for perceived value, $\chi^2(51) = 154.51$, $p < .001$ for enjoyment, $\chi^2(51) =$

128.71, $p < .001$ for anger, and $\chi^2(51) = 183.73$, $p < .001$ for boredom. We tested measurement

invariance across waves separately for perceived control, perceived value, and each of the three

emotions. The configural invariance models indicated a good fit to the data, with CFI > .969,

RMSEA < .053, and SRMR < .024 for all five constructs (see Table 2). The loss of fit for the

metric invariance models was ΔCFI ≤ .002, ΔRMSEA ≤ .005, and ΔSRMR ≤ .004 for all

constructs, showing clear support for metric invariance. The loss of fit for the scalar invariance

models was ΔCFI ≤ .007, ΔRMSEA ≤ .003, and ΔSRMR ≤ .004 for all constructs, indicating

clear support for scalar invariance as well. In sum, the findings demonstrated strong

measurement equivalence of the latent appraisal and emotion variables over time, indicating that

the variables met the recommended equivalence thresholds to be included in longitudinal

analysis.

Bivariate Reciprocal Models for Links of Emotions with Appraisals and Achievement

The bivariate models tested reciprocal relations between perceived control and emotions,

perceived value and emotions, and emotions and achievement. All models also included

correlations between variables at Time 1, and between their residuals at Times 2 and 3. Model fit is shown in Table 4. The results indicate that all models fit the data well.

Supporting Hypothesis 1, prior perceived control positively predicted subsequent enjoyment, and negatively predicted subsequent anger and boredom in the reciprocal effects models for perceived control and emotion (Figure 1). The reverse effects were not significant. In the models for perceived positive value and emotion (Figure 2), prior value positively predicted subsequent enjoyment, and negatively predicted subsequent anger and boredom. However, the effect of value on subsequent enjoyment and boredom was only significant between the first and second measurement points. The effects of prior emotion on subsequent value were also significant: Prior enjoyment positively predicted subsequent positive value, and prior anger and boredom negatively predicted value.

In line with Hypothesis 2, the proposed reciprocal relations between emotions and math achievement were fully confirmed for all three emotions (Figure 3). Prior enjoyment positively predicted subsequent math achievement, and prior math achievement positively predicted subsequent enjoyment. Prior anger and boredom negatively predicted subsequent math achievement, and prior math achievement negatively predicted subsequent anger and boredom.

Four-Variate Reciprocal Models

The three four-variate models accounted for all possible relations between students' appraisals, emotions, and math achievement (Figure 4). They also included correlations between all variables at Time 1, and correlations between residuals at Times 2 and 3. In addition, we evaluated both the indirect effects of appraisals measured at Time 1 on math achievement at Time 3 mediated by emotions at Time 2, and the indirect effects of math achievement at Time 1

on emotions at Time 3 mediated by cognitive appraisals at Time 2. All models fit the data well (Table 5).

Autoregressive effects and cross-lagged paths are shown in Table 6. The horizontal effects demonstrate substantial stability in math achievement (ß range = .55–.67) and perceived control (.65–.67) over time. This indicates that prior math achievement predicted subsequent math achievement, and prior perceived control predicted subsequent perceived control, thus leaving little room for the influence of other variables. Perceived value (.35–.50) and emotions (.38–.62) also showed considerable stability.

Testing the relations between appraisals, emotion, and math achievement simultaneously in the same model resulted in loss of significance for some of the bivariate reciprocal effects described above. This is in line with previous studies in which including appraisals, emotions, and math achievement in one model led to reduced effect sizes and loss of significance (Marsh et al., 2005; Pinxten et al., 2014). Nevertheless, many effects remained significant in the four-variate models, and followed the hypothesized patterns. Specifically, students' prior perceived control significantly predicted their subsequent emotions, except for the nonsignificant effect of perceived control at Time 1 on boredom at Time 2. Similarly, perceived value at Time 1 significantly predicted emotions at Time 2. Furthermore, math achievement at Time 1 predicted emotions at Time 2.

In the four-variate models, we also estimated reciprocal relations between appraisals and math achievement. In accordance with previous studies (e.g., Marsh et al., 2018; Pinxten et al., 2010), our analyses revealed reciprocal effects between perceived control and math achievement: Prior perceived control positively predicted subsequent achievement, and prior achievement

positively predicted subsequent perceived control. In contrast, perceived control and perceived positive value were not reciprocally related.

Results of our mediation analyses are displayed in Table 7. The indirect effects of appraisals on math achievement mediated by emotions were weak and not significant, thus not supporting Hypothesis 3. In contrast, and in line with Hypothesis 4, indirect effects in the reverse causal direction, that is, the effects of achievement on emotions mediated by appraisals, were significant for perceived control as a mediator in all three emotion models (enjoyment model: ß = .035, *p* < .001, 95% CI [.018, .053]; anger model: ß = .018, *p* < .05, 95% CI [-.034, -.004]; boredom model: ß = .023, *p* < .01, 95% CI [-.037, -.008]. Effects of math achievement on emotions mediated by value appraisals were not significant for any of the three emotions. These findings on the indirect effects of math achievement on emotions are in accordance with CVT, which postulates an influence of performance outcomes on subsequent perceptions of control that, in turn, affect subsequent emotions (Pekrun 2006, 2018; Pekrun, Lichtenfeld, et al., 2017).

Discussion

The aim of this study was to analyze relations between students' cognitive appraisals, emotions, and achievement. In an effort to overcome major limitations of previous research testing CVT propositions but focusing on select constructs only (e.g., Pekrun, Lichtenfeld, et al., 2017; Putwain, Pekrun, et al., 2018; Raccanello, Brondino, et al., 2018), our goal was to examine relations between all four key constructs addressed in this prominent theoretical framework. We tested relations between control appraisals, value appraisals, emotions, and math achievement across annual assessments spanning three school years using cross-lagged analyses. Probing longitudinal relations between the constructs also allowed us to address major design limitations of previous research which predominantly relied on cross-sectional designs unable to shed light

on temporal ordering of constructs, or used two waves of assessments only. In what follows, we summarize and discuss our findings, and deduce implications for future research as well as educational practice.

Relations between Appraisals and Emotions

Our first hypothesis focused on relations between appraisals and achievement emotions. In accordance with theoretical assumptions and prior empirical evidence (e.g., Hagenauer & Hascher, 2014; Peixoto, Sanches, et al., 2017; Pekrun et al., 2011), our cross-sectional analyses revealed positive relations between appraisals (i.e., perceived control and perceived positive value) and enjoyment. Conversely, and also in line with previous research (e.g., Bailey et al., 2014; Peixoto, Sanches, et al., 2017; Pekrun et al., 2011), perceived control and perceived positive value were negatively related to anger and boredom. For anger, these results suggest that CVT could be amended by considering the relevance of lack of control for students' anger experiences in the classroom, and by addressing the mitigating impact of positive value. Overall the results emphasize the importance of students' control appraisals and value for their emotional experiences in math learning. The more students feel competent and in control of their learning, and the more they value learning about math, the more they experience enjoyment. The findings are in accordance with Putwain, Pekrun, and colleagues' (2018) assumptions that students with high control beliefs view learning as an opportunity to develop their competence and mastery, and therefore experience it as enjoyable. It can be further assumed that under such circumstances, students also experience less boredom and anger.

Support for lagged relations between students` appraisals and subsequent emotions was found in the longitudinal models. In the bivariate models, longitudinal relations between students' perceived competence and emotions were fully confirmed: Prior perceived competence

positively predicted subsequent enjoyment, and negatively predicted subsequent anger and

boredom, controlling for prior emotion. Longitudinal effects of perceived positive value on

emotions were fully confirmed for anger and, for the first two measurement points, for

enjoyment and boredom. In the four-variate models including appraisals, emotions, and

achievement, the same effects emerged, speaking to the robustness of these findings. Students'

prior perceived competence predicted their subsequent emotions, except for the nonsignificant

relationship between perceived competence at Time 1 and boredom at Time 2. Students' positive

value beliefs at Time 1 significantly predicted their emotions at Time 2. Overall, the findings

largely support our assumptions and confirm Hypothesis 1. Specifically, the findings corroborate

the proposition of CVT that prior control and value appraisals influence subsequent emotions.

As such, the results are also in line with assumptions that can be derived from general

appraisal theories of emotions (see, e.g., Scherer et al., 2001; Scherer & Moors, 2019) and

theories of academic self-concept (e.g., Marsh et al., 2018). These theories imply that

perceptions of control, competence, personal agency, and coping potential generally facilitate the

experience of positive emotions such as joy. In contrast, perceptions of incompetence, lack of

control, lack of agency, and lack of coping potential are generally thought to exacerbate negative

emotions such as anger, anxiety, and hopelessness (see also Goetz, Cronjaeger, et al., 2010).

Relations between Emotions and Math Achievement

Our second hypothesis referred to the relation between emotions and math achievement.

In accordance with theory and empirical evidence (e.g., Dettmers et al., 2011; Pekrun,

Lichtenfeld, et al., 2017; Raccanello, Brondino, et al., 2018), correlational analyses revealed

positive relations between enjoyment and math achievement, and negative relations between

anger as well as boredom and achievement. Furthermore, the proposed reciprocal relationships

between emotions and achievement were fully confirmed in the bivariate models. Prior

enjoyment positively predicted subsequent achievement, and prior achievement positively

predicted subsequent enjoyment. Prior anger and boredom negatively predicted subsequent

achievement, and prior achievement negatively predicted later anger and boredom. These

findings are in line with those of previous studies (e.g., Pekrun, Lichtenfeld, et al., 2017)

showing that performing well at school can foster students` positive emotions and reduce their

negative emotions over time, while performing poorly can decrease positive emotions and

strengthen negative emotions in the long term. These emotions, in turn, impact future academic

success, corroborating the view that they constitute critical determinants of students' educational

trajectories. Taken together, our analyses of bivariate reciprocal effects provided strong support

for Hypothesis 2.

In the four-variate models, however, several of the relations between emotions and math

achievement were no longer significant. Similar issues pertaining to loss of significance of

previously significant constituent effects combined into more complex models have been

encountered in prior research. As noted earlier, Pinxten et al. (2014) and Marsh et al. (2005),

who examined relations between enjoyment (Pinxten et al.) or interest (Marsh et al.), competence

beliefs, and math achievement, showed that the detection of significant relations between

enjoyment or interest and math achievement was compromised when including perceived

competence in the model. The authors attributed this finding to the high correlations between

competence beliefs, on the one hand, and enjoyment or interest, on the other. This explanation is

plausible for our findings as well, as perceived control and perceived value were highly

correlated with enjoyment, anger, and boredom. Additionally, perceived control was strongly

correlated with math achievement. Another possible reason for the loss of previously significant

effects in the four-variate models pertains to the autoregressive stability of the study variables. Strong autoregressive effects (see Table 6) could have led to a reduction of the power of predictors to explain variance in the outcome variables (Adachi & Willoughby, 2015; Pekrun, Lichtenfeld, et al., 2017).

From an analytical point of view, discarding variables to reduce model complexity and increase power is a recommended strategy for dealing with high intercorrelations (i.e., multicollinearity) of variables (e.g., Dormann et al., 2013), which justifies our strategy of successively testing reciprocal relationships between cognitive appraisals, emotions, and math achievement using bivariate models. However, from a theory perspective, it makes sense to include all constructs in one model as CVT assumes that perceived control and perceived value jointly influence emotions, and that cognitive appraisals, emotions, and achievement are linked over time (Pekrun, 2006, 2018; Pekrun et al., 2007). Considering both theory and the analytical issues related to multicollinearity, conducting different analyses (bivariate models and four-variate models) may provide the most comprehensive picture possible.

Relations between Appraisals and Math Achievement

In the four-variate models, we also examined reciprocal relations between appraisals and math achievement. Results showed reciprocal effects between perceived control and math achievement: Prior perceived control positively predicted subsequent achievement, and prior achievement positively predicted subsequent perceived control. Given that control was operationalized in terms of perceived competence, these results support Marsh's Reciprocal Effects Model (REM) of academic self-concept and replicate previous findings confirming propositions of the REM (see, e.g., Marsh et al., 2018; Möller et al., 2011). On average, effects of perceived competence on achievement and reverse effects of achievement on perceived

competence were equally strong, thus lending support both to the self-enhancement model (self-concept promotes competence acquisition) and the skill development model (competence promotes self-concept) that were integrated in the REM. Given the broad empirical support for reciprocal links between students' perceived competence and achievement (Valentine et al., 2004), the findings also support the validity of the approach used to investigate competence-related perceptions in the present study.

Similarly, our findings for perceived control are in line with the proposition from Eccles's expectancy-value theory (EVT) that expectancy of success promotes achievement, and with related evidence from EVT studies (see Eccles, 2005; Eccles & Wigfield, 2020; Wigfield & Eccles, 2000). Similar to the present study which used perceived competence as a measure of control, EVT studies typically used measures of perceived competence to operationalize expectancy (see Marsh et al., 2019, for a conceptual discussion). However, in contrast to original EVT assumptions, perceived value was not a significant predictor of achievement in the present study. Overall, this pattern of findings is in line with theory and evidence that competence perceptions are stronger predictor of achievement, whereas value perceptions guide students' choices between tasks and career goals (Eccles & Wigfield, 2020).

Indirect Effects of Appraisals on Math Achievement

In the final step, we investigated mediation effects for each emotion in the four-variate models. The indirect effect of Time 1 appraisals on Time 3 math achievement mediated by Time 2 emotions was weak in magnitude and not significant (Hypothesis 3). In contrast, in our bivariate models, both the effects of prior perceived control on subsequent emotions, and of prior emotions on subsequent math achievement were significant and of substantial magnitude across both time intervals (i.e., T1-T2, and T2-T3). Furthermore, effects of prior positive value

appraisals on subsequent emotions were significant and substantial in the first interval (T1-T2).

Since significant effects of the predictor on the mediator and the mediator on the outcome are

two essential conditions to support mediation (MacKinnon et al., 2007), these findings are in line

with our hypothesis that emotions function as mediators in the link between appraisals and math

achievement.

Despite the promising findings of the bivariate models, it remains open to question why

Hypothesis 3 could not be confirmed in the four-variate models. One possible explanation

pertains to the long time interval of two years between the measurement points for the predictor

and outcome variables, leaving plenty of room for intervening processes that may overcast

effects. However, the reverse indirect effects of achievement on emotions as mediated by control

were significant despite this time interval, suggesting that length of time can only be part of the

explanation. A more plausible explanation may relate to the strength of the relationship between

prior emotions and subsequent achievement. In the bivariate models, emotions had significant

effects on achievement. In contrast, in the four-variate models including perceived competence,

emotions no longer had any significant effects on achievement, thus rendering indirect effects of

appraisals on achievement mediated by emotion nonsignificant. This pattern of findings suggests

that the lack of indirect effects resulted from multicollinearity between emotion and perceived

competence, as in the study by Pinxten et al. (2014). More research is needed to test the CVT

proposition that cognitive appraisals influence achievement through emotions, such as

experimental studies of mediation as well as field studies using shorter time intervals to capture

mediational processes.

Indirect Effects of Math Achievement on Emotions

As for the reverse causal direction (Hypothesis 4), indirect effects of math achievement on emotions mediated by control appraisals were significant for all three emotions in the four-variate models. There were pronounced effects of achievement on students' subsequent control appraisals, and these appraisals, in turn, predicted their emotions. The indirect effects of math achievement on emotions mediated by value appraisals were not significant. There were positive effects of achievement on value, as well as effects of value on the emotions; however, these effects were not sufficiently strong to let the indirect effects become significant. Overall, these results are in line with the CVT framework, which predicts that achievement influences subsequent control appraisals which, in turn, affect subsequent emotions (Pekrun, 2006; Pekrun, Lichtenfeld, et al., 2017). The effects of students' achievement on their competence beliefs is also in line with the vast literature documenting positive relations between students' achievement and their academic self-concept (e.g., Marsh & O`Mara, 2008; Marsh et al., 2018). Hypothesis 4 was thus confirmed.

Limitations and Directions for Future Research

Overall, the present study provides convincing support for CVT. It is based on a strong multi-wave design and used a robust strategy of latent longitudinal analysis controlling for autoregressive effects, reciprocal effects, measurement error, and important background variables, thus lending credibility to the findings. Nevertheless, there are limitations that should be considered when interpreting the results and deriving directions for future research. First, field studies like the present investigation have clear advantages in terms of ecological validity, but are limited in their ability to facilitate causal conclusions (however, see Grosz et al., 2020, for arguments supporting the derivation of causal conclusions from nonexperimental research). As such, the approach used herein should be complemented by experimental studies.

Second, the focal effects were relatively small in magnitude, as is typical for this type of longitudinal research (e.g., Marsh, et al., 2018; Pekrun, Lichtenfeld, et al., 2017. In interpreting effect size, it is important to consider that autoregressive effects, reciprocal effects, and effects of covariates were controlled in our models. As is typical in this type of research, there were substantial autoregressive effects (i.e., stability) in the study variables over time, leaving not much variance to be explained by other predictors. Given these controls, it is to be expected that effects derived from longitudinal models are smaller than the respective bivariate correlations. The longitudinal effects represent incremental effects of the predictors, over and above the influence of prior levels of the outcome variable and other predictors. Controlling for autoregressive stability also implies that the effects represent the influence of predictors on change in the outcome variables rather than their absolute levels. As such, the effects we found in the present study can be interpreted as meaningful and practically significant (see also Adachi & Willoughby, 2015; Pekrun, Lichtenfeld, et al., 2017).

A third point to consider is that math achievement was assessed using students' school grades rather than standardized test scores. There may be doubts about the psychometric quality of grades. However, grades constituted summative scores based on multiple exams in the present research, which may render them more reliable than grades for single exams. In fact, as noted earlier, grades showed substantial retest reliability in the present study. They were obtained from official records rather than students' reports, thus representing accurate data. In terms of validity, by focusing on grades we opted for an ecologically valid measure of students' achievement (for a similar strategy, see Pekrun, Lichtenfeld, et al., 2017). Harlen's (2004) review revealed high correlations of $r = .77–.92$ between teacher-assessed and externally benchmarked tests in mathematics, attesting to the validity of grades. Furthermore, for answering the present research

questions, a clear advantage of using school grades instead of scores from standardized

achievement tests is that grades act as sources of students' emotional development as they

provide feedback about their successes and failures (Pekrun, Lichtenfeld, et al., 2017).

Nevertheless, future research should complement the present findings with evidence on the links

between appraisals, emotions and scores from standardized achievement tests.

As for the relation between appraisals and emotion, it is important to note that all of these

constructs were assessed using self-report. As such, the relations between these constructs may

have been influenced by common method bias. For the relation between value and emotion, there

also is semantic overlap for two AEQ emotion items which not only target emotion but also

include value-related terms ("I'm glad it paid off to go class;" "Thinking about all the useless

things I have to learn in math makes me irritated"), which may contribute to common method

bias. The influence of such bias is minimized in the present longitudinal analysis due to

controlling correlations at baseline as well as autoregressive effects for both appraisals and

emotion. Nevertheless, it is an important avenue for future research to include alternative

measures of emotion such as facial expression analysis and physiological parameters.

Finally, the present study examined select appraisals and emotions, and it included

adolescent students from one country. Specifically, whereas we included perceived positive

value, we did not examine the role of negative value. Future studies should investigate negative

value given its proposed effects on the instigation of negative emotions such as anger (Pekrun,

2006). Similarly, the three emotions included in the study do not represent an exhaustive list of

the emotions experienced in math learning. It remains to be seen whether the observed interplay

between appraisals, emotions, and achievement also extends to other emotions, such as pride,

anxiety, or hopelessness. Regarding generalizability to other age groups, countries, and cultural

contexts, it is importance to note that the findings on correlational links between appraisals, emotions, and achievement are consistent with findings from other studies as discussed earlier, thus suggesting generalizability. Equivalence of functional relations between emotions, their origins, and their outcomes across contexts is a core tenet of control-value theory that is supported by cross-cultural evidence (Pekrun, 2018). Nevertheless, it is a task for future research to examine the generalizability of the findings on longitudinal effects and mediating mechanism resulting from the present study.

Implications for Educational Practice

Our study provides robust confirmatory evidence for CVT and broadens our understanding of students' enjoyment, anger, and boredom in math learning. It also yields insight into how relations between students' appraisals, emotions, and academic success unfold over time. On the one hand, the findings underpin the importance of students' control and value appraisals for their emotional experiences which, in turn, can affect their math achievement. On the other hand, the results highlight the significance of achievement outcomes for students` emotional experiences.

From a practical perspective, two important messages follow from these findings. First, the finding that perceived control and value are positively related to students' enjoyment and achievement, and negatively related to their anger and boredom, implies that teachers can foster students' positive emotional experiences and math achievement by encouraging them to adopt positive control and value appraisals. Second, the finding that students' math achievement predicts their emotions, with success promoting enjoyment and failure exacerbating anger and boredom, suggests that teachers can help students reduce negative and promote their positive

emotions and psychological wellbeing by creating learning environments that provide opportunities for experiencing success.

Prior research provides directions for how appraisal-oriented emotional support can be realized. Specifically, findings from motivational treatment interventions and research on emotion regulation suggest that teachers can positively influence students' control and value appraisals by changing their classroom practices in the following ways (Brisson et al., 2017; Gaspard et al., 2015; Harley et al., 2019; Hulleman et al., 2010; Kosovich et al., 2019; Linnenbrink-Garcia et al., 2016; Pekrun, Cusack, et al., 2014). Students' competence beliefs and perceived control can be supported by mastery-oriented instruction encouraging students to focus on strategies helping them to master a skill (Kitsantas et al., 2004). Implementing mastery goal structures in the classroom can help students to adopt mastery criteria for self-evaluation, which can positively influence their competence beliefs (Linnenbrink-Garcia et al., 2016; Kitsantas et al., 2004). In the same vein, a sense of mastery may be prompted by providing students with tasks that just slightly exceed their current level of competencies, implying that they are challenging but can be mastered with sufficient effort, and by motivating students to help each other to successfully complete challenging tasks. Moreover, teachers can provide students with feedback that is mastery-oriented and encouraging, which can be achieved by emphasizing the role of effort and providing students with actionable information about how they can further improve their learning (Linnenbrink-Garcia et al., 2016). A related way to increase students' sense of control is attributional retraining which guides students to attribute their failures to internal, unstable, and controllable causes (e.g., lack of effort, poor strategy use) rather than internal, stable, and uncontrollable causes (e.g., low ability; Linnenbrink-Garcia et al., 2016; Perry et al., 2014).

Recommendations on how to increase a sense of control can also be derived from the literature on emotion regulation. In this literature, the possible benefits of reappraisal strategies are highlighted (Gross, 2015; Jacobs & Gross, 2014). Accordingly, Harley et al. (2019) propose that teachers can help students to use reappraisal strategies to change their control appraisals. For example, teachers can strengthen students' sense of control by convincing them that they "can meaningfully contribute to the classroom discussion because of relevant personal experience or background" (Harley et al., 2019, p. 119). Another option for bolstering students' perceived control recommended by Harley et al. (2019) is to propose that students focus their attention on strengths rather than weaknesses, for example, by leveraging their respective strengths when carrying out difficult tasks during group work.

Likewise, students' value appraisals can be influenced by using strategies that promote reappraisal (Harley et al., 2019). One promising approach for helping students to perceive value and meaning in their schoolwork is to highlight relations of learning material to students' interests, hobbies, and everyday lives, as well as their importance for students' future careers of which students may previously have been unaware (Hulleman et al., 2010; Kosovich et al., 2019; Linnenbrink-Garcia et al., 2016). The goal is to provide students with more opportunities to create „meaningful connections to their own personal goals and aspirations" (Kosovich et al., 2019, p. 19). Although this remains speculative and requires empirical confirmation, the findings of the present study imply that changing control and value appraisals in such ways should also influence students' emotions.

Furthermore, as noted earlier, the findings suggest that positive emotions can be supported through providing students with opportunities for success or providing positive achievement feedback, and that negative emotions can be reduced by preventing students from

repeatedly experiencing failure. To this end, teachers could use task-oriented and intrapersonal standards to evaluate students' achievement rather than normative standards, accentuate mastery over competition goals (Pekrun, Cusack, et al., 2014; Pekrun et al., 2017), and create a culture of defining mistakes as opportunities to learn rather personal failure.

Conclusion

Expanding on prior research, the findings of this study support core theoretical propositions of CVT. The analyses confirmed that students' control-related beliefs and value appraisals shape their emotional experiences which, in turn, affect their achievement. Specifically, the results show that perceived competence and value predict students' enjoyment, anxiety, and boredom in mathematics, and that these emotions influence students' math achievement over time. In addition, the findings demonstrate that students' math achievement reciprocally influences their perceived competence and emotions, with competence perceptions mediating the effects of achievement on emotions. Taken together, the findings suggest that students' appraisals, emotions, and achievement are linked by reciprocal effects over time. These effects involve vicious cycles of maladaptive appraisals, negative emotions, and reduced performance, and virtuous cycles of adaptive appraisals, enjoyment, and successful performance. This knowledge can be used to guide future inquiry into intervention research targeting students' academic emotional lives.

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Table 1

Student Samples: Age and Gender

Time	Cohort 1				Cohort 2			
	n	M_{age}	SD_{age}	% female	n	M_{age}	SD_{age}	% female
1 (Grade 5 / 7)	950	10.58	.83	49.8	766	12.77	.90	50.5
2 (Grade 6 / 8)	845	11.52	.77	51.0	686	13.68	.83	50.4
3 (Grade 7 / 9)	711	12.51	.74	51.4	619	14.66	.83	49.5

Note. Cohort 1 started in grade 5; Cohort 2 started in grade 7.

Table 2

Measurement Equivalence of Appraisal and Emotion Constructs across Waves 1-3

Model	Configural Invariance				Metric Invariance				Scalar Invariance			
	CFI	TLI	RMSEA	SRMR	CFI	TLI	RMSEA	SRMR	CFI	TLI	RMSEA	SRMR
Perceived control	.971	.965	.045	.022	.971	.968	.044	.026	.969	.978	.043	.027
Perceived value	.969	.960	.053	.024	.968	.963	.051	.027	.966	.965	.050	.029
Enjoyment	.989	.986	.035	.018	.988	.986	.034	.022	.987	.986	.035	.026
Anger	.980	.975	.030	.024	.979	.976	.029	.027	.972	.971	.032	.030
Boredom	.988	.983	.043	.022	.986	.984	.038	.024	.985	.984	.039	.024

Table 3

Pearson Product-Moment Correlations for Appraisals, Emotions, and Math Achievement

		Perceived control			Perceived value			Enjoyment			Anger			Boredom			Math achievement		
		T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Perceived competence	T1		79	.68	.41	.36	.32	.52	.44	.40	-.43	-.41	-.36	-.46	-.38	-.33	.64	.58	.53
	T2	.72		.77	.35	.46	.39	.43	.57	.49	-.38	-.48	-.43	-.41	-.50	-.39	.63	.66	.59
	T3	.62	.69		.31	.38	.51	.39	.46	.67	-.33	-.40	-.56	-.35	-.43	-.57	.58	.61	.68
Perceived value	T1	.36	.31	.27		.63	.49	.81	.57	.40	-.58	-.43	-.32	-.69	-.51	-.32	.37	.34	.25
	T2	.32	.41	.33	.56		59	.56	.82	.50	-.46	-.58	-.43	-.52	-.71	-.45	.39	.42	.32
	T3	.28	.34	.46	.44	.54		.43	.58	.76	-.33	-.42	-.57	-.39	-.53	-.67	.36	.38	.41
Enjoyment	T1	.45	.38	.34	.71	.49	.39		.62	.49	-.66	-.46	-.36	-.87	-.58	-.39	.35	.34	.26
	T2	.38	.50	.40	.50	.73	.51	.55		.64	-.40	-.64	-.45	-.57	-.89	-.53	.36	.42	.35
	T3	.36	.43	.59	.35	.43	.68	.43	.58		-.31	-.43	-.64	-.42	-.59	-.84	.32	.36	.46
Anger	T1	-.36	-.33	-.28	-.48	-.39	-.28	-.66	-.39	-.31		.57	-43	.81	.45	.33	-.42	-.39	-.31
	T2	-.34	-.41	-.33	-.35	-.48	-.39	-.46	-.64	-.43	.47		.59	.51	.76	.49	-.38	-.45	-.37
	T3	-.31	-.35	-.49	-.27	-.37	-.50	-.36	-.45	-.63	.37	.50		.38	.50	.79	-.36	-.37	-.42
Boredom	T1	-.42	-.38	-.31	-.62	-.48	-.36	-.87	-.57	-.42	.69	.43	.34		.61	.40	-.36	-.35	-.28
	T2	-.34	-.46	-.38	-.46	-.65	-.48	-.58	-.89	-.59	.40	.65	.44	.57		.58	-.34	-.39	-.35
	T3	-.31	-.35	-.52	-.29	-.41	-.61	-.39	-.53	-.84	.29	.42	.71	.38	.54		-.29	-.32	-.40
Math achievement	T1	.60	.60	.56	.34	.36	.32	.34	.34	.29	-.38	-.34	-.32	-.35	-.33	-.28		.78	.69
	T2	.55	.63	.57	.31	.38	.35	.32	.39	.32	-.35	-.39	-.34	-.34	-.37	-.30	.77		.71
	T3	.50	.56	.64	.21	.29*	.38	.23	.31	.42	-.28	-.32	-.38	-.26	-.33	-.39	.69	.71	

Note. Coefficients below main diagonal are manifest correlations. All manifest correlations are significant at $p < 0.01$. Coefficients above main diagonal are latent correlations based on confirmatory factor analyses. All latent correlations are significant at $p < 0.001$. Coefficients are depicted for each wave (T1-T3).

Table 4

Fit Indices of the Bivariate Reciprocal Effects Models

Models	χ^2	*df*	*p*	CFI	TLI	RMSEA	SRMR
Enjoyment - Control	864.42	336	.000	.977	.972	.031 [.028–.033]	.030
Enjoyment - Value	743.07	261	.000	.976	.971	.034 [.031–.036]	.037
Enjoyment – Ach.	352.39	96	.000	.983	.976	.400 [.036–.045]	.028
Anger – Control	806.91	336	.000	.974	.968	.029 [.027–.032]	.031
Anger – Value	656.37	261	.000	.971	.964	.030 [.027–.033]	.040
Anger – Ach.	233.70	96	.000	.984	.977	.029 [.025–.034]	.026
Boredom – Control	854.18	336	.000	.979	.975	.031 [.028–.033]	.028
Boredom – Value	729.51	261	.000	.973	.967	.033 [.030–.036]	.034
Boredom – Ach.	385.81	96	.000	.982	.975	.043 [.038–.047]	.025

Note. Control = Perceived control; Value = Perceived value; Ach. = Math achievement.

Table 5

Fit Indices of the Four-variate Models including Appraisals, Emotions, and Achievement

Model	χ^2	df	p	CFI	TLI	RMSEA	SRMR
Anger	12270.42	853	.000	.965	.959	.032 [.030–.033]	.032
Boredom	12196.92	809	.000	.972	.967	.032 [.031–.034]	.026
Enjoyment	12200.11	809	.000	.970	.965	.032 [.031–.034]	.028

Table 6

Longitudinal Relations between Appraisals, Emotions, and Math Achievement in the Four-Variate Models (Standardized Coefficients)

	Enjoyment Model		Anger Model		Boredom Model	
	T1 → T2 Path (SE)	T2 → T3 Path (SE)	T1 → T2 Path (SE)	T2 → T3 Path (SE)	T1 → T2 Path (SE)	T2 → T3 Path (SE)
Autoregressive effects						
Emotion	.380*** (.060)	.617*** (.069)	.421*** (.046)	.482*** (.045)	.449*** (.040)	.474*** (.046)
Control	.656*** (.027)	.653*** (.035)	.672*** (.026)	.665*** (.031)	.659*** (.025)	.656*** (.033)
Value	.495*** (.059)	.350*** (.065)	.524*** (.037)	.500*** (.038)	.492*** (.042)	.420*** (.046)
Achievement	.667*** (.020)	.549*** (.027)	.660*** (.021)	.556*** (.025)	.668*** (.020)	.557*** (.026)
Cross-lagged effects						
Control → emotion	.111** (.038)	.163*** (.043)	-.126** (.040)	-.088* (.042)	-.048 (.035)	-.109** (.038)
Emotion → control	.061 (.049)	.052 (.054)	-.005 (.030)	-.014 (.035)	-.063* (.031)	-.060 (.041)
Value → emotion	.192*** (.054)	-.094 (.065)	-.100* (.042)	-.071 (.042)	-.148*** (.039)	-.049 (.047)
Emotion → value	.093 (.063)	.240*** (.070)	-.092* (.042)	-.059 (.042)	-.122** (.041)	-172*** (.045)
Control → achievement	.148*** (.027)	.278*** (.033)	.138*** (.025)	.249*** (.029)	.133*** (.025)	.246*** (.030)
Achievement → control	.217*** (.025)	.172*** (.032)	.210*** (.027)	.166*** (.031)	.211*** (.025)	.166*** (.032)
Value → achievement	.047 (.042)	.030 (.048)	.011 (.022)	-.039 (.029)	.003 (.028)	-.054 (.034)
Achievement → value	.180*** (.029)	.141*** (.034)	.152*** (.030)	.117*** (.032)	.168*** (.029)	.124*** (.033)
Control → value	-.007 (.036)	-.001 (.041)	.006 (.033)	.051 (.040)	-.006 (.035)	.028 (.038)
Value → control	-.055 (.044)	-.033 (.048)	-.011 (.027)	-.003 (.031)	-.047 (.030)	-.032 (.038)
Emotion → achievement	-.017 (.043)	-.075 (.054)	-.048 (.026)	-.024 (.032	-.042 (.034)	-.052 (.028)
Achievement → emotion	.084** (.032)	.034 (.034)	-.090* (.035)	-.076* (.036)	-.096*** (.030)	-.043 (.034)

Table 6

Continued

Effects of covariates on T1 variables	Enjoyment Model		Anger Model		Boredom Model	
	Prior achiev.	Gender	Prior achiev.	Gender	Prior achiev.	Gender
T1 Control	.643*** (.016)	-.230*** (.019)	.643*** (.016)	-.230*** (.020)	.643*** (.016)	-.230*** (.019)
T1 Value	.356*** (.022)	.062* (.026)	.354*** (.023)	.061* (.025)	.354*** (.022)	.061* (.026)
T1 Emotion	.354*** (.024)	-.031 (.026)	-.401*** (.023)	-.055* (.027)	-.348*** (.023)	.021 (.024)
T1 Achievement	.818*** (.010)	.029* (.014)	.817*** (.010)	.029* (.014)	.817*** (.010)	.029* (.014)

Note. Value = Perceived value; Control = Perceived control; Achievement = Math achievement; Prior ach. = prior achievement. $^*p < 0.05$. $^{**}p < 0.01$. $^{***}p < 0.001$.

Table 7

Standardized Indirect Effects in the Four-variate Models Including Total Indirect and Specific Indirect Effects

|	Enjoyment model		Anger model		Boredom model	
	Path (SE)	95% CI [LL, UL]	Path (SE)	95% CI [LL, UL]	Path (SE)	95% CI [LL, UL]
Effects of Control 1 on Achievement 3	-.008 (.008)	[-.024, .001]	.003 (.004)	[-.005, .010]	.002 (.002)	[-.001, .007]
Effects of Value 1 on Achievement 3	-.015 (.012)	[-.038, .001]	.002 (.004)	[-.003, .008]	.006 (.006)	[-.002, .015]
Effects of Achievement 1 on Emotion 3						
Sum of indirect	.018 (.018)	[-.014, .046]	-.029* (.012)	[-.048, -.004]	-.031** (.012)	[-.051, -.012]
Specific indirect Control 2 as mediator	.035*** (.010)	[.018, .053]	-.018* (.009)	[-.034, -.004]	-.023** (.009)	[-.037, -.008]
Value 2 as mediator	-.017 (.013)	[-.040, .002]	-.011 (.007)	[-.022, .000]	-.008 (.008)	[-.022, .005]

Note. Control 1 = Perceived control at T1; Control 2 = Perceived control at T2; Value 1 = perceived value at T1; Value 2 = perceived value at T2;

Emotions 3 = emotion (enjoyment, anger, boredom) at T3; Achievement 1 = math achievement at T1; Achievement 3 = math achievement at T3.

LL and UL indicate the lower and upper limits of the 95% confidence intervals, respectively.

$^*p < 0.05.$ $^{**}p < 0.01.$ $^{***}p < 0.001.$

Figure 1

Reciprocal Effects Models for Perceived Control and Emotions
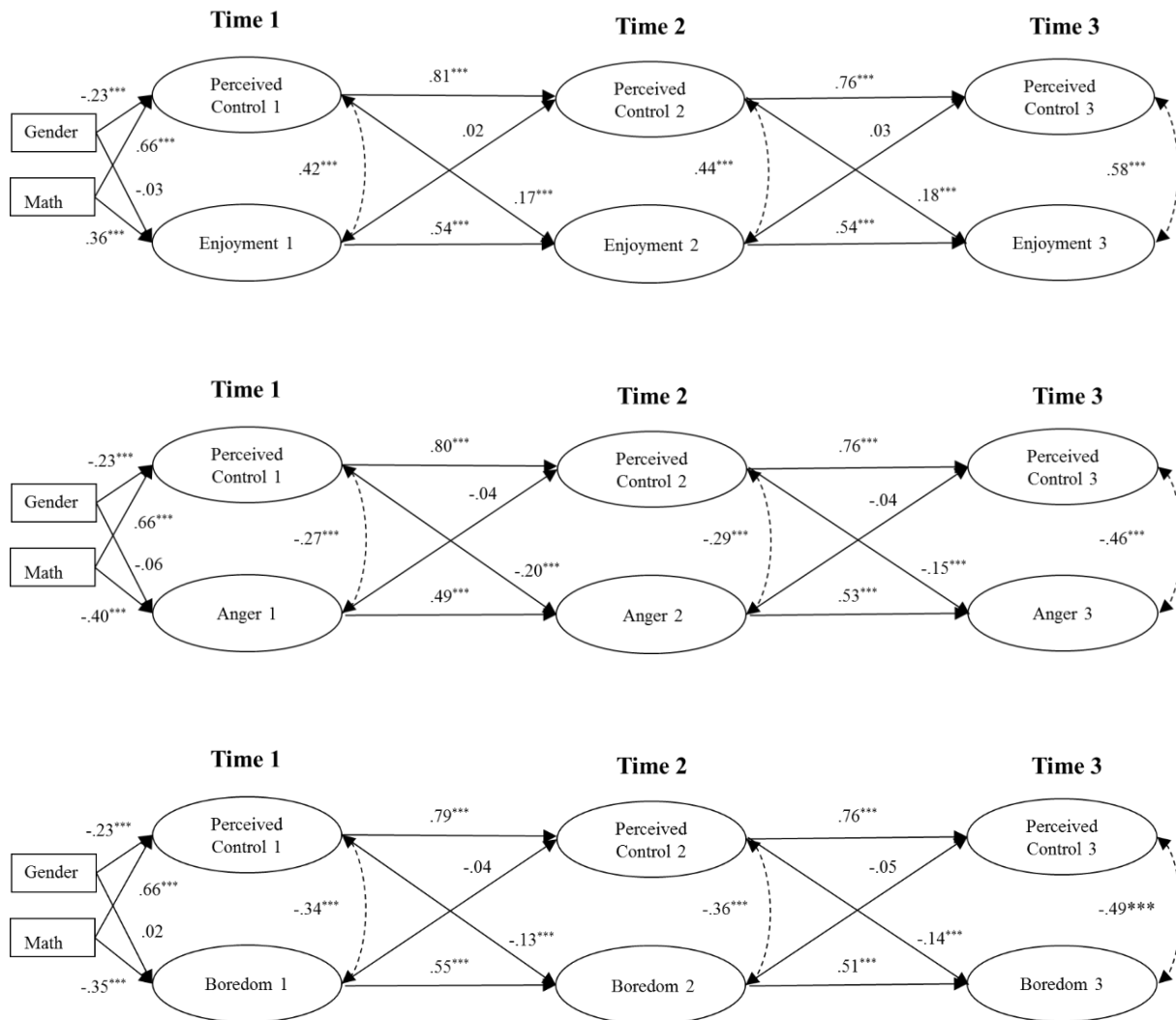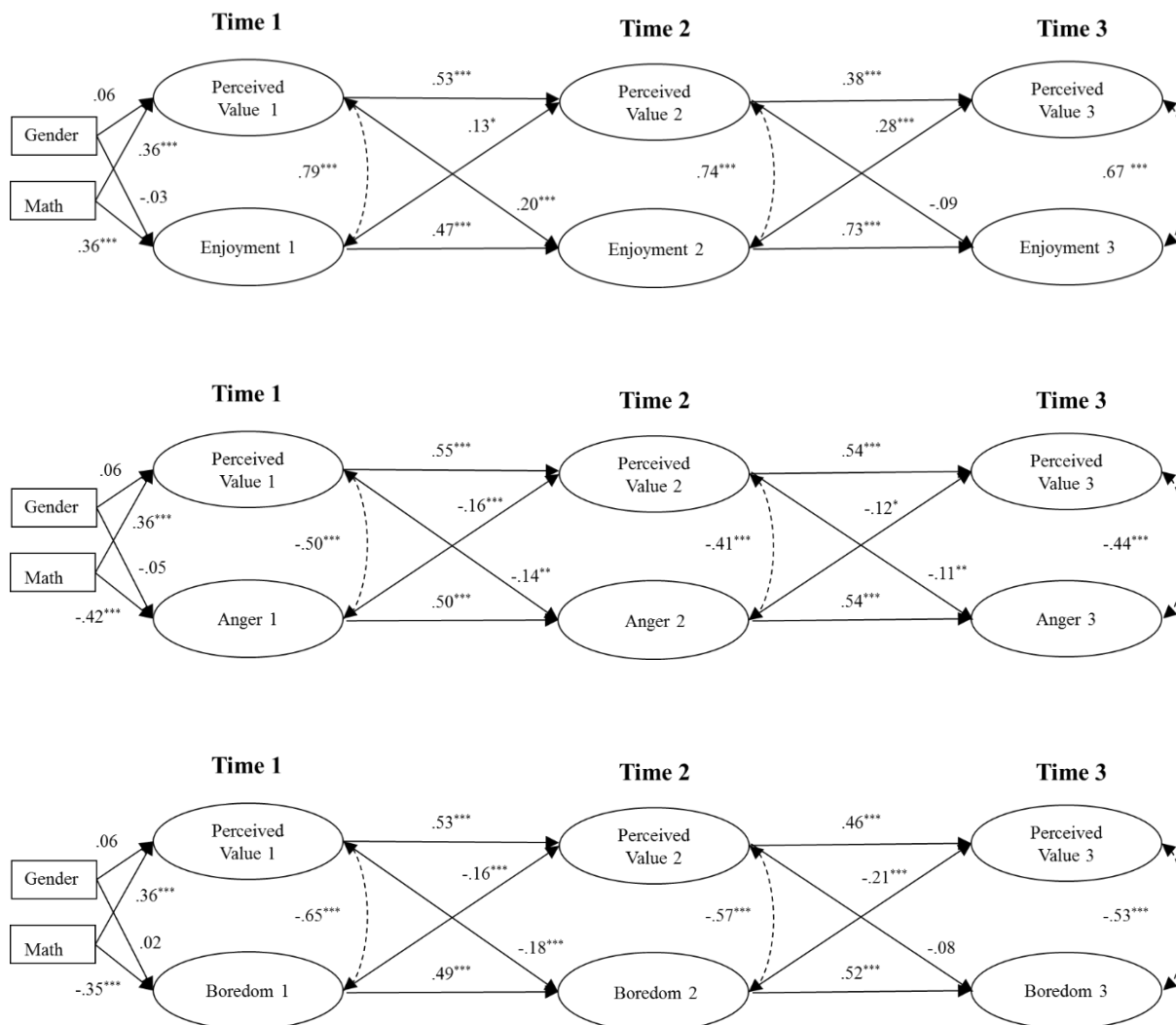

Note. Upper panel: reciprocal effects model for enjoyment and perceived control; middle panel: reciprocal effects model for anger and perceived control; lower panel: reciprocal effects model for boredom and perceived control. Math = prior math achievement.

*p < .05. **p < .01. ***p < .001.

Figure 2

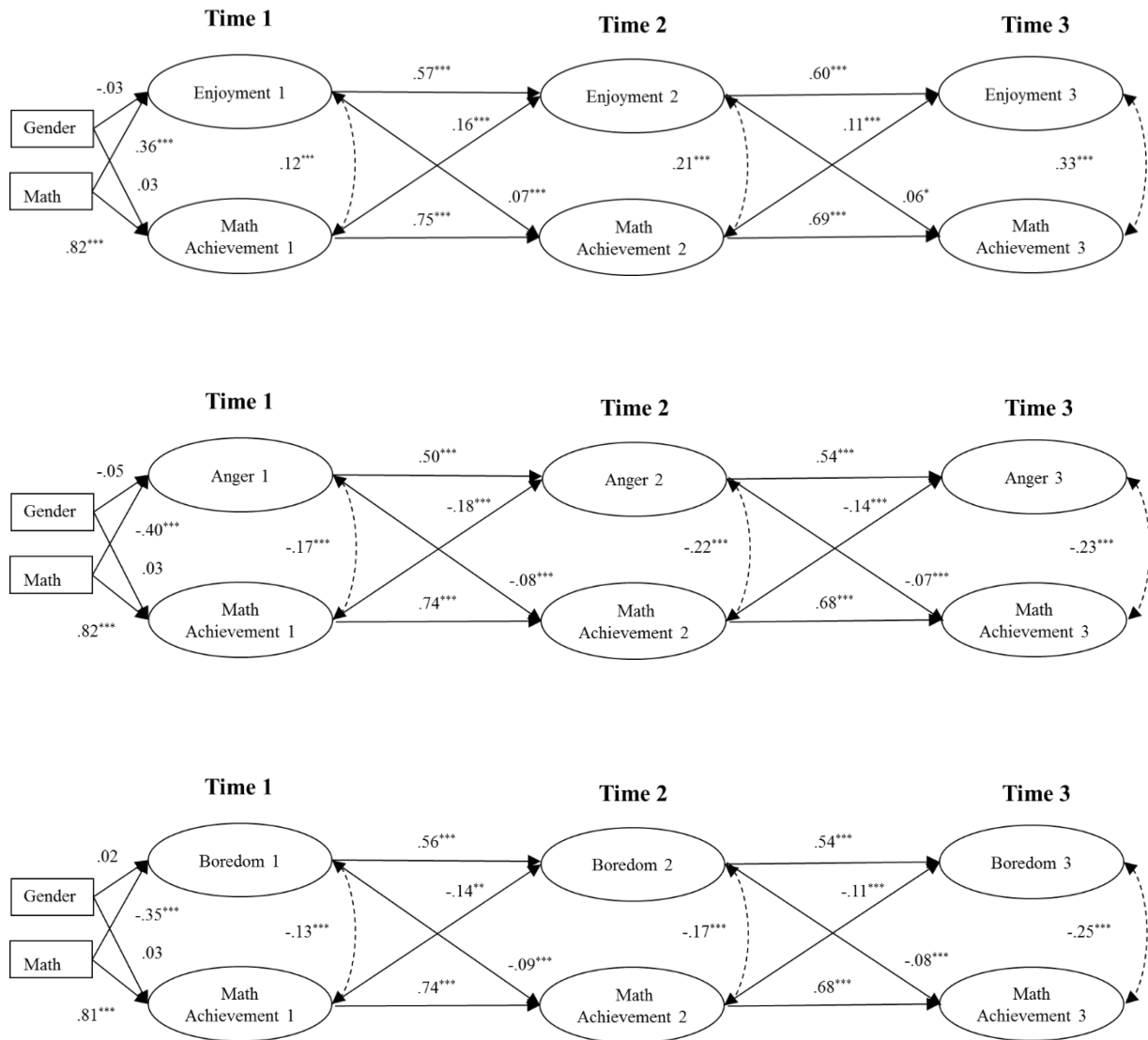*Reciprocal Effects Models for Perceived Value and Emotions*

Note. Upper panel: reciprocal effects model for enjoyment and perceived value; middle panel: reciprocal effects model for anger and perceived value; lower panel: reciprocal effects model for boredom and perceived value. Math = prior math achievement.

p < .05. **p* < .01. ***p* < .001.

Figure 3

*Reciprocal Effects Models for Emotions and Math Achievement*

Note. Upper panel: reciprocal effects model for enjoyment and math achievement; medium panel: reciprocal effects model for anger and math achievement; lower panel: reciprocal effects model for boredom and math achievement. Math = prior math achievement.

*p < .05. **p < .01. ***p < .001.

Figure 4

Basic Structure of the Four-Variable Models
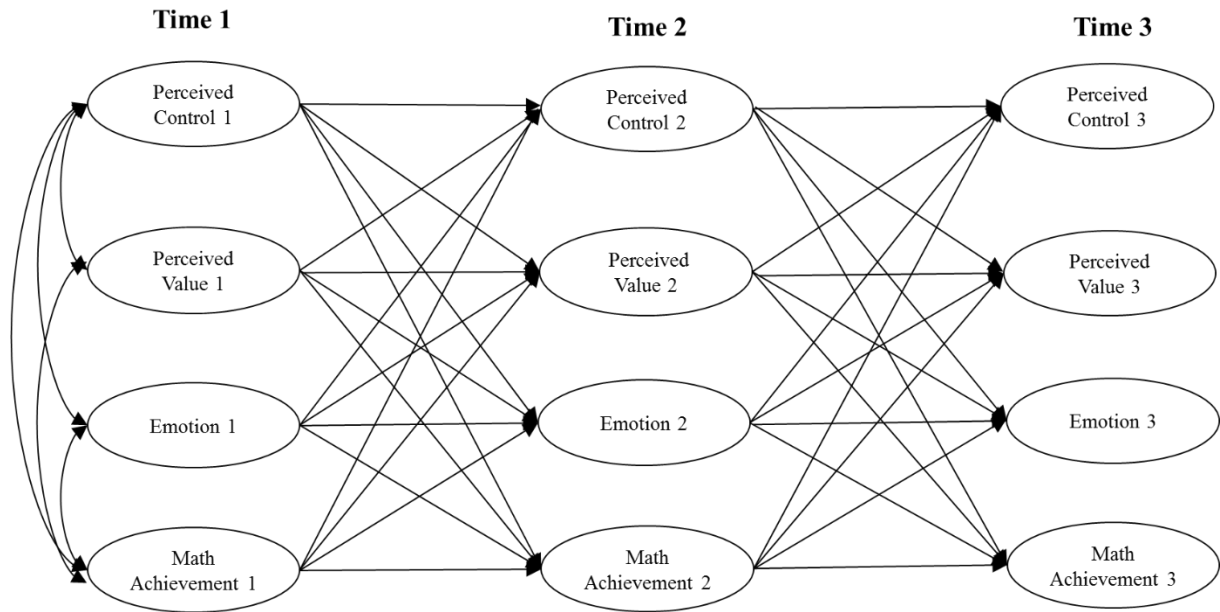
Note. Correlations of residuals and directional paths from the covariates to appraisals,

emotion, and achievement are not displayed.