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CHILD DEVELOPMENT

EMPIRICAL ARTICLE

Developmental trajectories of achievement emotions in mathematics during adolescence

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Abstract

This study examined how adolescents' emotions in mathematics develop over time. Growth curve modeling was applied to longitudinal data collected annually from 2002 to 2006 (Grades 5–9; $N = 3425$ German adolescents; $M_{age} = 11.7$, 15.6 years at the first and last waves, respectively; 50.0% female). Results indicated that enjoyment and pride decreased over time (Glass's $\Delta s = -.86$, $-.71$). In contrast, negative emotions exhibited more complex patterns: Anger, boredom, and hopelessness increased ($\Delta s = .52$, .79, .26), shame decreased ($\Delta = -.12$), and anxiety remained stable ($\Delta = .00$). These change trajectories of emotions were associated with change trajectories of perceived control, intrinsic value, achievement value, and achievement in mathematics. Implications and future directions are discussed.

Achievement emotions—emotions induced by achievement activities and outcomes (Pekrun, 2006, 2021)—are key in explaining individual differences in children's learning and academic success (e.g., Pekrun et al., 2017). However, there is little understanding of how achievement emotions change during adolescence, and which factors influence their trajectories. Answers to these questions would provide insights to help adolescents maintain positive achievement emotions and benefit from them in the classroom and beyond. Therefore, the present study examines the change trajectories of seven key achievement emotions (enjoyment, pride, anxiety, anger, boredom, shame, and hopelessness) in mathematics in adolescents by analyzing large-scale longitudinal data. The study also investigates the roles of adolescents' perceived control in mathematics, the value of mathematics, and their individual characteristics (such as gender and family background) in the change trajectories of these emotions.

Abbreviations: AEQ–M, Achievement Emotions Questionnaire–Mathematics; CVT, control–value theory; LSAY, Longitudinal Study of American Youth; MAR, missing-at-random; PALMA, Project for the Analysis of Learning and Achievement in Mathematics; SEM, structural equation modeling; SES, socioeconomic status.

Achievement emotions and factors relevant to their developmental trajectories

Achievement emotions can be classified into two groups based on their object focus: (a) *activity emotions* (emotions induced by achievement activities) and (b) *outcome emotions* (emotions induced by success and failure outcomes). In addition, achievement emotions differ in valence (positive vs. negative) and arousal (activating vs. deactivating). Important activity emotions include activating positive emotions (e.g., enjoyment during favorite lectures), activating negative emotions (e.g., anger about task demands), and deactivating negative emotions (e.g., boredom during repetitive tasks). Important outcome emotions include activating positive emotions (e.g., pride about achieving good grades), activating negative emotions (e.g., anxiety before an examination and shame about receiving poor grades), and deactivating negative emotions (e.g., hopelessness when expecting failure in an exam). Achievement emotions have been conceptualized as momentary responses (e.g., feeling anxious before a particular examination) and habitual responses (e.g., experiencing anxiety before every examination).

Previous longitudinal studies often assessed habitual achievement emotions. The findings suggest that they are reciprocally related to academic achievement (e.g., Ahmed et al., 2013; Forsblom et al., 2021; Pekrun et al., 2017). Specifically, enjoyment and pride occur after academic success, whereas anger, anxiety, shame, boredom, and hopelessness arise after failure. These emotions are predictive of subsequent achievement, with positive emotions typically facilitating motivation and performance, and negative emotions undermining academic outcomes. Negative emotions can also lead to other maladaptive outcomes beyond academic performance, such as increased risk-taking behavior due to boredom, increased aggression due to shame, and an increased risk of depression due to hopelessness (Kılıç et al., 2020; Liu et al., 2021; Thomaes et al., 2008). Given these effects of emotions, it is important to understand the underlying factors shaping achievement emotions to provide insights into how children can maintain positive emotions and prevent negative emotions in achievement settings from childhood throughout adolescence.

Control–value theory (CVT; Pekrun, 2006, 2021; Pekrun et al., 2023), a prominent appraisal theory of achievement emotions, provides a theoretical framework to understand the factors influencing the development of these emotions. CVT is conceptually related to expectancy–value theories of achievement motivation. While appraisal theories propose that subjective beliefs and perceptions are critical for explaining emotions, expectancy–value theories focus on the relevance of beliefs and perceptions for motivation and decision-making (e.g., Eccles & Wigfield, 2020).

CVT considers perceived control and value as key appraisals driving achievement emotions. Perceived control concerns competence perceptions, self-efficacy expectations, expectations of success and failure, and causal attributions of success and failure. Perceived value refers to the subjective values of achievement activities and their outcomes. While there are many facets of values, CVT particularly focuses on the following two types to explain achievement emotions: (a) intrinsic value (the inherent value of an achievement activity itself, regardless of its outcomes) and (b) achievement value (the importance of attaining success and avoiding failure). According to CVT, learners' focus is on their actions rather than on achievement (i.e., success or failure) when they experience activity emotions, whereas learners are more focused on outcomes when they experience outcome emotions. Thus, the intrinsic value of achievement activities is considered to play a key role in activity emotions, while achievement value is considered to play a key role in outcome emotions (Frenzel et al., 2007; Pekrun, 2006, 2021; Pekrun et al., 2023).

According to CVT, appraisals of these aspects trigger different emotions. Specifically, positive activity emotions, such as enjoyment, are thought to arise when learners perceive high control and high intrinsic value. Positive outcome emotions, such as pride, occur when high control is combined with high achievement value. In contrast, negative activity emotions (e.g., anger and boredom) would arise when learners perceive low intrinsic value. CVT also posits that boredom arises when perceived control is very low or very high (i.e., when learners find achievement activities too difficult or too easy). Negative outcome emotions (e.g., anxiety, shame, and hopelessness) are hypothesized to be triggered by the combination of perceived lack of control and high achievement value. It should be noted that learners' appraisals are not only determined by situational factors (e.g., task difficulty) but also by their stable control–value beliefs related to a certain situation or subject domain. These beliefs can lead to recurring appraisals, resulting in similar emotional responses across different occasions (habitual emotions).

Empirical studies generally support the role of perceived control and value in achievement emotions. Supporting CVT, learners with stronger beliefs about perceived control, intrinsic value, and achievement value are more likely to feel stronger enjoyment and pride (Forsblom et al., 2021; Putwain et al., 2018). In contrast, anxiety, shame, and hopelessness are experienced by learners who perceive a lack of control and high achievement value (Frenzel et al., 2007). Additionally, anger and boredom are associated with lower perceived intrinsic value (Forsblom et al., 2021; Pekrun et al., 2010; Putwain et al., 2018). While CVT predicts a curvilinear relation between boredom and perceived control, empirical research typically shows a negative association (Forsblom et al., 2021; Pekrun et al., 2010), presumably because

tasks at schools are normally created not to be extremely easy (i.e., students do not typically face situations where perceived control is too high). Anger has also been associated with lower levels of perceived control (Forsblom et al., 2021). Thus, it seems that lack of perceived control is predictive not only of negative outcome emotions but also of negative activity emotions. The literature also offers evidence for the interaction effects between control and value (e.g., Goetz et al., 2010; Shao et al., 2020), though studies do not always differentiate different facets of value (for exceptions see Pekrun et al., 2023; Putwain et al., 2018).

Importantly, perceived control, intrinsic value, and achievement value decline during adolescence due to several developmental and environmental factors (for reviews see Eccles & Roeser, 2011; Wigfield et al., 2015). First, as adolescents advance through grades, they perceive academic studies as increasingly difficult, but less meaningful. Such changes are associated with a decline in perceived control, intrinsic value, achievement value, and commitment to competence-related activities (Metsäpelto et al., 2017; Scherrer et al., 2020; Watt, 2004). Second, while younger children are typically optimistic about their competencies, they become more realistic in terms of perceived control as they grow into adolescents (e.g., Marsh, 1989). Such decline in perceived control is particularly salient when adolescents face social comparison (Crone & Fuligni, 2020). In fact, compared with younger children, adolescents' perceived control is more negatively affected by social comparison (Marsh et al., 2015). Over time, this increased sensitivity to social comparison can contribute to a reduction in perceived control. Third, as adolescents progress through secondary school, the school environment and teachers' behavior tend to become more controlling and less emotionally supportive (Eccles et al., 1993), and classroom practices become more focused on performance and competition (Anderman & Midgley, 1997). At the same time, with increasing age adolescents develop a greater need for autonomy. The mismatch between needs for autonomy and a restrictive school environment could reduce the intrinsic value of achievement activities (Eccles et al., 1991).

Given these changes in perceived control and value, adolescents are expected to experience changes in their habitual achievement emotions. Specifically, the decline in control and value should result in lower levels of positive achievement emotions, including enjoyment and pride, but increased negative activity emotions, such as anger and boredom. Negative outcome emotions, such as anxiety, hopelessness, and shame, should result from lack of perceived control combined with high achievement value; thus, their developmental changes are more difficult to predict (i.e., reduced control with age should exacerbate these emotions, but reduced achievement value should decrease them). However, shame is often considered a self-conscious emotion (i.e., an emotion based on attention to the self). Self-conscious emotions are typically heightened during adolescence because of increased social comparison (Somerville et al., 2013). Thus, adolescents may experience more shame as they grow older. In summary, CVT and previous relevant research suggest that different emotions with the same valence may show unique developmental trajectories during adolescence: Positive emotions are expected to decrease, negative activity achievement emotions are expected to increase, and negative outcome emotions may not show a clear increase.

Empirical findings on developmental changes in achievement emotions

Despite these theoretical predictions, the literature on how achievement emotions change over time is limited. Moreover, existing studies do not provide a clear picture of the developmental changes in achievement emotions during adolescence. Within the limited literature, achievement anxiety in mathematics has been examined the most frequently. However, longitudinal studies of developmental changes in math anxiety report inconsistent results. For example, average levels of math anxiety sometimes increase (Meyer & Schlesier, 2021), but sometimes remain stable (Ahmed et al., 2013; Sainio et al., 2021). In contrast to anxiety, boredom typically shows a steady increase in mathematics and other subjects (Ahmed et al., 2013; Grazia et al., 2021; Meyer & Schlesier, 2021; Vierhaus et al., 2016). Mirroring the results for boredom, previous research also observed a decrease in the average levels of enjoyment in mathematics and other subjects (Hagenauer & Hascher, 2010; Meyer & Schlesier, 2021; Pinxten et al., 2014; Vierhaus et al., 2016). However, findings for pride, a closely related positive emotion, are inconsistent; some studies found that students' pride in their mathematics competence decreased during adolescence (Ahmed et al., 2013; Meyer & Schlesier, 2021), whereas others reported no change (Sainio et al., 2021).

These inconsistent patterns may be due to sampling characteristics (e.g., differences in gender-based distribution) or the relatively small number of waves in some studies ($k=3$), which is not ideal for describing within-person changes in achievement emotions (Diallo et al., 2014). To overcome these problems, recent research has analyzed large-scale multi-wave longitudinal data on math anxiety based on a nationally representative sample from the USA (Longitudinal Study of American Youth [LSAY]; Wang et al., 2020). The results revealed that the average levels of math anxiety remained stable during adolescence, from Grades 7 to 12. A subsequent study further showed that change trajectories of math anxiety are associated with those of math utility value and math self-concept (Wang et al., 2021). Assuming that self-concept reflects perceived control

(see Marsh et al., 2019, for details), these results align with CVT's proposition that developmental changes in achievement anxiety are closely associated with those in perceived control and perceived values (see also Ahmed et al., 2012). However, developmental changes in emotions other than anxiety, such as shame or hopelessness, have received little attention in the literature. Thus, there is a need to more comprehensively examine developmental changes in achievement emotions in a large sample with sufficient data points per person.

Another important question concerns individual differences in change trajectories of achievement emotions. Perceived control and value beliefs develop differently across children and adolescents (Wigfield et al., 2015). For example, children with greater mathematics achievement may experience less decline in the intrinsic value of mathematics (Gottfried et al., 2007), and a higher socioeconomic status (SES) is associated with a smaller decline in perceived control in literacy (Archambault et al., 2010). If achievement emotions are affected by perceived control and value beliefs, as suggested by CVT, they should develop differently across adolescents. Supporting this idea, lower SES and lower initial math grades were associated with stronger anxiety in the LSAY dataset (Ahmed, 2018; Wang et al., 2020). However, knowledge about the roles of SES and initial achievement in the development of other achievement emotions is sparse.

Previous research has also shown gender differences in emotions in mathematics. Typically, girls report lower levels of positive achievement emotions and perceived control in this domain (Else-Quest et al., 2010; Goetz et al., 2013). Such gender differences may amplify over time. In fact, based on the LSAY dataset, Wang et al. (2021) revealed that relative to boys, girls were more likely to show a steady increase in math anxiety during adolescence. However, research on control–value beliefs presents a picture that is less clear: Gender differences in perceived control or value for mathematics became smaller in some studies (e.g., Jacobs et al., 2002) but remained similar in other studies (e.g., Watt, 2004). Thus, it remains unclear how gender affects change trajectories of achievement emotions.

The present study

This study aims to advance the understanding of developmental changes in achievement emotions during adolescence. We focus on investigating seven achievement emotions (enjoyment, pride, anger, boredom, anxiety, shame, and hopelessness) in mathematics, an achievement domain that is crucial for students' educational and subsequent occupational success and has been examined most often in research on students' emotions. Previous research has also observed large declines in control and value beliefs during adolescence, particularly for mathematics (Jacobs et al., 2002), which makes it an ideal domain for examining change trajectories of adolescents' achievement emotions.

We used a large-scale German longitudinal dataset on students' development in mathematics (Project for the Analysis of Learning and Achievement in Mathematics [PALMA]; Pekrun et al., 2007). The PALMA longitudinal study included five waves of data on all seven key achievement emotions, perceived control, value beliefs, school grades in math, and achievement in a standardized mathematics test. Most adolescents who took part in PALMA did not have a school transition during the time of the study, which allowed us to examine changes in achievement emotions not influenced by school transitions. Previous publications have reported findings based on the PALMA longitudinal dataset (see Table S1). For example, Pekrun et al. (2017) analyzed the dataset and revealed reciprocal relations between school grades and achievement emotions. However, none of these studies addressed the growth trajectories of achievement emotions, which is the focus of the current study.

The first objective of this study is to comprehensively examine how the seven achievement emotions develop during adolescence in the domain of mathematics. As described earlier, we expected a decrease in enjoyment and pride but an increase in anger and boredom. For anxiety, shame, and hopelessness, we left as an exploratory question as to whether they increased, decreased, or stayed at the same level.

The second objective is to examine the effects of adolescents' background characteristics, including gender, family SES, school track, and initial school grades in mathematics, on the change trajectories of achievement emotions. Given that school grades are typically correlated with intelligence, we added intelligence as a covariate to control its effects. We expected that higher SES and higher initial grades are associated with stronger positive emotions and weaker negative emotions in the first wave as well as smaller declines in positive emotions and smaller increases in negative emotions over time. Given the mixed findings in the literature described above, we left the effects of gender as an exploratory question.

Third, we sought to address the role of control–value beliefs in the development of these emotions. According to CVT, changes in achievement emotions are driven by changes in control–value beliefs. As such, change trajectories in achievement emotions should be associated with change trajectories in control–value beliefs. We also explored how changes in achievement emotions are associated with the interaction between changes in perceived control and those in value. Interactions proposed by CVT would entail particularly strong increases in negative outcome emotions when perceived control declines and achievement values increase over time. Positive outcome emotions should decrease less when both control and achievement values are maintained. In

addition, those who lose intrinsic value over time would demonstrate a larger decrease in enjoyment and a larger increase in anger especially when they lose perceived control (see also Forsblom et al., 2021).

The fourth objective is to understand the role of academic achievement in change trajectories of achievement emotions. Building on past findings on the reciprocal relation between achievement emotions and academic performance, we expect that a larger growth in academic achievement is associated with a larger increase (or a smaller decrease) in positive emotions and a larger decrease (or a smaller increase) in negative emotions over time. In other words, if adolescents begin to experience more anger and boredom and less enjoyment and pride as they advance through grades, these changes are likely accompanied by smaller increases in academic achievement.

METHOD

Participants and design

Data analyzed in this project are from the longitudinal PALMA study (Pekrun et al., 2007), which included annual assessments of students in German secondary schools from Grades 5 to 10 between 2002 and 2007. Samples were representative of the student population in the state of Bavaria (see Table 1) and included students from all three school types within the German public school system: lower-track schools (*Hauptschule*), intermediate-track schools (*Realschule*), and higher-track schools (*Gymnasium*). In Bavaria, students typically enter these schools in Grade 5 (i.e., the start of the PALMA study). Students in higher and intermediate-track schools stayed at least until Grade 10, whereas most students in lower-track schools left school after Grade 9. Thus, we made an a priori decision to focus on data from Grades 5 to 9. Every year, students' achievement emotions, control–value beliefs, and mathematics achievement were assessed toward the end of the school year. The Data Processing and Research Center (DPC) of the International Association for the Evaluation of Educational Achievement conducted sampling and the assessments. Trained external test administrators administered all assessments in the classrooms of the students. Active parental consent was obtained for participating in the study. Participants were not provided any incentives.

At Grade 5, there were 2070 students from 42 schools (49.6% female, M_{age} = 11.7 years). Proportions of students in lower-, intermediate-, and higher-track schools were 37.2%, 27.1%, and 35.7%, respectively. In each subsequent year, the study tracked those who had participated in the previous assessment(s) and incorporated those who had not yet participated in the study but had become members of PALMA classrooms at the time of the assessment. As a result, the sample sizes from Grades 6 to 9 changed in the following manner (Pekrun et al., 2017): 2059 (50.0% female, M_{age} = 12.7 years), 2397 (50.1% female, M_{age} = 13.7 years), 2410 (50.5% female, M_{age} = 14.8 years), and 2528 students (51.1% female, M_{age} = 15.6 years). Across all five assessments, a total of 3425 students (50.0% female) participated in the study. Proportions of those who participated in five, four, three, two, and one assessment(s) were 38.7%, 9.0%, 18.9%, 15.1%, and 18.3%, respectively. Because of the longitudinal design of the study, there are missing data (e.g., some students who took part in earlier PALMA data collections missed subsequent data collections due to absence on the day of the data collection or change of schools). Gender and family SES did not systematically alter the drop-out pattern; however, school track and intelligence were significantly associated with drop-out (see Supporting Information, Table S2). While these effects were overall small, we

TABLE 1 Proportion of immigration background for adolescents and their parents.

	Children (%)	Mother (%)	Father (%)
Wave 1			
Germany	93.1	85.6	85.1
Greece	0.1	0.1	0.2
Italy	0.05	0.6	0.6
Former Yugoslavia	0.3	0.7	0.6
Poland	0.1	1.3	0.9
Former Soviet Republics	3.4	3.9	3.7
Turkey	0.4	2.4	2.9
Other countries	2.5	5.3	5.9
Wave 3			
Germany	90.8	84.9	82.4
Greece	0.3	0.3	0.4
Italy	0.2	0.7	0.9
Former Yugoslavia	0.4	1	0.9
Poland	0.7	1.5	1.5
Former Soviet Republics	4.2	4.2	3.9
Turkey	0.7	2.3	2.5
Other countries	2.3	4.8	6.3
No responses	0.4	0.3	1.1
Wave 5			
Germany	91.9	85.2	83.5
Greece	0.4	0.3	0.4
Italy	0.4	0.5	1
Former Yugoslavia	0.6	1.1	1
Poland	0.5	1.3	1.3
Former Soviet Republics	3.5	4.2	3.6
Turkey	0.3	2.1	2.1
Other countries	2	5	6.2
No responses	0.5	0.4	0.9

Note: Immigration backgroud data were not obtained in the other waves.

included these background variables as auxiliary variables in our main analyses to address the systematic missingness associated with these variables (see below for details).

Measures

Achievement emotions

The Achievement Emotions Questionnaire–Mathematics (AEQ–M; Bieleke et al., 2021; Pekrun et al., 2011) was used to assess achievement emotions in mathematics. The AEQ–M assesses habitual emotions in mathematics by asking students to describe how they typically feel when attending class, doing homework, and taking tests and examinations in mathematics. It includes seven emotions in mathematics: enjoyment (9 items, e.g., "I enjoy my math class"; Cronbach's αs for each wave = .85–.89), pride (8 items; e.g., "After a math test, I am proud of myself"; αs = .87–.89), anger (8 items; e.g., "I am annoyed during my math class"; αs = .87–.88), anxiety (15 items; e.g., "I worry if the material is much too difficult for me"; αs = .90–.92), shame (8 items; e.g., "I am ashamed that I cannot answer my math teacher's questions well"; αs = .86–.89), boredom (6 items; e.g., "My math homework bores me to death"; αs = .86–.90), and hopelessness (6 items; e.g., "During the math test, I feel hopeless"; αs = .83–.88). Participants responded to items on a 1 (*strongly disagree*) to 5 (*strongly agree*) Likert scale. Following the model provided by previous studies (e.g., Pekrun et al., 2017, 2023), responses to different settings (i.e., class, homework, and examinations) were collapsed. This decision was supported by separate analyses, where the same achievement emotions across different settings were highly correlated (mostly >.70; see Table S3).

Control–value beliefs

We used the PALMA scale of perceived control (six items; e.g., "When I study hard at math, I succeed"; αs = .75–.84) to assess perceived control in mathematics. While the PALMA data include other measures related to perceived control (e.g., self-efficacy; Marsh et al., 2019; Pekrun et al., 2007), we made an a priori decision to focus on this scale to be consistent with a previous study (Murayama et al., 2013). We also used two additional scales (Frenzel et al., 2007) to assess intrinsic value of mathematics (three items; e.g., "No matter what grades I get, math is very important to me"; αs = .71–.74) and value of mathematics achievement (five items; e.g., "It is very important for me to get good grades in mathematics"; αs = .79–.83). Participants responded to items on a 5-point Likert scale from 1 (*strongly disagree*) to 5 (*strongly agree*).

Mathematics achievement

Mathematics achievement was measured by the PALMA Mathematical Achievement Test (Pekrun et al., 2007). The test, comprising multiple-choice and open-ended items, assesses students' modeling competencies and algorithmic competencies in arithmetics, algebra, and geometry. The scores were scaled using Rasch modeling which enabled the longitudinal analysis of change in achievement. To facilitate interpretation, we standardized the estimated achievement scores with mean = 100 and SD = 15 at Wave 1. Prior work has confirmed the unidimensionality and longitudinal invariance of the test scores (see Murayama et al., 2013).

Background variables

We included the following variables to examine their effects on trajectories of achievement emotions: gender (0 = female; 1 = male), non-verbal intelligence at Wave 1, mathematics grade at Wave 1 (i.e., end-of-the year school grade in mathematics), school type (track), and family SES. Intelligence was assessed based on the German adaptation of Thorndike's Cognitive Abilities Test (25 items; Heller & Perleth, 2000); we z-scored the scores across the whole Wave 1 sample prior to analyses. The mathematics grades reflect summative scores based on multiple examinations within the school year, representing students' achievement in the mathematics curriculum during the year (see Pekrun et al., 2017). They range from 1 (excellent) to 6 (poor). School type was coded using two orthogonal contrast variables as in Murayama et al. (2013): (a) a "Higher versus Others" contrast (higher-track = 2, intermediate-track = −1, lower-track = −1) and (b) an "Intermediate versus Lower" contrast (higher-track = 0, intermediate-track = 1, lower-track = −1). Family SES was measured using parent reports based on the EGP classification (Erikson et al., 1979). As done in prior studies (e.g., Pekrun et al., 2017), we included SES as a continuous variable (higher values represent higher family SES).

Strategy of data analysis

We applied structural equation modeling (SEM) to model the growth trajectories of achievement emotions as latent variables (latent growth curve modeling). SEMs were estimated using *Mplus* 8.5 (Muthén & Muthén, 1998–2017) applying maximum likelihood estimation. We adjusted the standard errors and chi-square statistics to correct for potential biases resulting from non-normality of the data using the MLR estimator. We addressed the nested structure of the data (i.e., students nested within schools; see Table 2 for the intraclass correlation coefficients) using cluster-robust

TABLE 2 Intraclass correlation coefficients of variables.

	Grade						Grade				
Variables	**5**	**6**	**7**	**8**	**9**	**Variables**	**5**	**6**	**7**	**8**	**9**
Enjoyment	.058	.070	.045	.040	.034	Hopelessness	.027	.035	.023	.025	.015
Pride	.028	.027	.018	.018	.026	Perceived control	.015	.033	.034	.020	.029
Anger	.038	.056	.031	.016	.030	Intrinsic value	.042	.044	.055	.041	.036
Anxiety	.029	.038	.025	.024	.025	Achievement value	.014	.028	.018	.022	.024
Shame	.044	.050	.034	.037	.046	Achievement scores	.388	.482	.517	.588	.528
Boredom	.035	.055	.051	.026	.036						

standard errors (with the <TYPE=COMPLEX> option). Missing data were handled by full-information maximum likelihood estimation which is based on the missing-at-random (MAR) assumption (Enders, 2010). MAR allows the missingness of a certain variable to be correlated with other variables in the model. The MAR assumption is likely to hold in longitudinal data, as scores for the same variable from other waves are included in the model (Marsh et al., 2019). Other analyses and visualizations were performed with R Statistical Software (R Core Team, 2021). The outputs of *Mplus* were read into R using the *MplusAutomation* package (Hallquist & Wiley, 2018). Tables and figures were produced using the *flextable* (Gohel, 2021) and *ggplot2* (Wickham et al., 2016) packages.

Our main analysis included the following three steps. The modeling decisions for the first two steps were made prior to data analysis.

Tests of measurement invariance

We first tested measurement invariance of achievement emotions and control–value belief scores to ensure that the latent factor means are comparable across waves, following the procedure used by Miyamoto et al. (2020). We tested four models: configural invariance, metric invariance, scalar invariance, and strict invariance (see Supporting Information for details). To investigate longitudinal changes of constructs over time, scalar or strict invariance model should be supported. The analyses were conducted separately for each emotion and each control–value belief.

Growth curve modeling

Next, we estimated growth curve models with latent means to examine longitudinal change. Again, we analyzed each achievement emotion and belief separately. Among different ways of specifying growth curves, we made the a priori decision to use a latent basis model specification (see Supporting Information for details; Grimm et al., 2011). This specification adds two latent factors (i.e., intercept and slope; each with mean and variance estimates) to the strict invariance model estimated in the first step. The intercept factor represents individual differences in the latent scores at the first wave. The slope factor represents individual differences in the change from the initial to the final assessments. The model does not define the shape of the change trajectories a priori (e.g., linear and quadratic) other than the constraints that shapes are similar across individuals (the basic assumption of all growth curve models). Factor loadings of the slope factor define the shape of the change trajectory, and the slope factor itself quantifies the change score from Grade 5 to Grade 9. To identify the model, means of the latent factors were anchored to the first item in the scale (i.e., the item intercept of the first item was set to zero). We first estimated the mean intercept and mean slope factor scores across all participants; here, we included all the background variables (mentioned earlier) as auxiliary variables to avoid potentially biased estimates due to the systematic missingness associated with these variables. We then investigated the effects of these background variables on the intercept and slope factors of achievement emotions to examine their effects on change trajectories of achievement emotions.

We also computed standardized effect sizes to quantify the change of emotions from Grade 5 to Grade 9. This was done by dividing the slope factor mean (the change from Grade 5 to Grade 9) by the square root of the intercept variance (the *SD* of the mean at Grade 5). The measure is conceptually equivalent to Glass's Δ (a version of Cohen's *d*; Glass et al., 1981) based on the difference in the latent means at Grades 5 and 9 (positive value = increase).

Relations between different growth trajectories

Next, we examined whether intercepts and slopes for the achievement emotions were related to those of control–value beliefs. Theoretically, this can be achieved by applying a multivariate growth curve model in which growth trajectories of all emotions and control–value beliefs are estimated at once. Given the large number of

observed variables, however, this strategy was not computationally feasible. Therefore, for each growth curve model of a specific achievement emotion and belief, we estimated the factor scores of the intercept and slope factors using a regression method (Thurstone, 1935). We then computed partial correlations between intercept and slope factor scores of achievement emotions and those of the control–value beliefs while controlling for the background variables. As an exploratory analysis, we also addressed interactions between perceived value and perceived control. Specifically, we examined how the value–control interactions in the intercepts are associated with the intercept factor scores of achievement emotions, and how the value–control interactions in the slopes are associated with the slope factor scores of achievement emotions.

Finally, we examined whether intercepts and slopes of achievement emotions were related to those of the achievement scores. Specifically, we applied a latent basis model to achievement scores and estimated factor scores of the intercept and slope factors. We then computed partial correlations between the intercept and slope scores of achievement scores with those of achievement emotions while controlling for the background variables.

Note that all partial correlations were estimated by SEM to deal with missing data. Specifically, we computed the maximum likelihood estimates of the correlations between the residuals of the variables predicted by the background variables with linear regression models in SEM. The residual correlations are mathematically equivalent to partial correlations.

RESULTS

Prior to the main analyses, we aimed to establish measurement equivalence for emotions and control–value beliefs. As shown in Table S4, the most stringent strict measurement invariance was supported for all achievement emotions and control–value beliefs.

Growth curve modeling for achievement emotions

For each achievement emotion, we estimated a growth curve model. The fit of the growth curve models was very good overall (Table 3). As depicted in Table 3, the intercept and slope mean scores were negatively correlated for all emotions (i.e., reflecting regression to the mean). Figure 1a plots the latent means over time. Although the latent basis growth curve model does not specify a specific shape of change trajectories, we can still interpret the means for the slope factors as indicating overall change across persons: Positive scores indicate an average increase, whereas negative scores indicate an average decrease.

In line with our expectations, enjoyment and pride showed a decrease over time (latent slope means = −0.80, −0.55, $ps < .01$), whereas anger and boredom showed an increase (latent slope means = 0.36, 0.67, $ps < .01$). According to Cohen's (1988) criteria, the effect sizes of the changes were all large ($\Delta = -.86, -.71, .52, .79$). It is worth noting that most of these changes took place from Grade 5 to Grade 7 (Figure 1a). Like anger and boredom, hopelessness also showed a significant but smaller increase (latent slope mean = 0.18, $p < .01$, $\Delta = .26$). In contrast, shame showed a small but significant decrease (latent slope mean = −0.08, $p < .05$, $\Delta = -.12$), whereas anxiety did not significantly change over time (latent slope mean = 0.001, $p > .05$, $\Delta = .00$).

Effects of background variables on intercepts and slopes of achievement emotions

We next investigated the effects of adolescents' backgrounds on the overall change trend of achievement emotions (Table 4). In general, school type did not have strong associations with either the intercept factor or the slope factor. We also found that those with higher family SES backgrounds showed stronger enjoyment and pride at the first wave; but family SES had little effects on the slope factors. Beyond family SES and school type, gender and initial mathematics grades were consistent predictors of the intercept factors (Figure 2). Specifically, boys, relative to girls, showed higher levels of enjoyment, pride, and boredom, and lower levels of anxiety and hopelessness in the first wave. In addition, higher initial grades were positively related to both of the positive emotions and negatively related to all five negative emotions in the first wave. Interestingly, boys showed a larger decrease in enjoyment and pride, and a larger increase in shame than girls. Likewise, students with high initial mathematics grades tended to show a larger decrease in enjoyment and pride, and a larger increase in anger, anxiety, shame, and hopelessness. In addition, higher levels of intelligence helped to maintain enjoyment and to prevent development of anger, anxiety, and hopelessness. As intelligence and initial math grades were correlated ($r = -.36$), we repeated the analysis without intelligence. The significant effects of initial math grade on enjoyment and pride were no longer significant, suggesting the potential presence of multicollinearity effects. However, the other originally significant effects on the slopes remained significant.

Relations between growth curves of achievement emotions and control–value beliefs

We next estimated a latent basis model for the control–value beliefs from Grade 5 to Grade 9. The models showed excellent fit (Table 3). In line with prior

TABLE 3 Latent basis curve models: intercepts, slopes, and model fit.

	Intercept factor		Slope factor		Factor loading					Intercept–slope correlation	ES (Grade 9–Grade 5)	Fit					
	M	Variance	*M*	Variance	Wave 1	Wave 2	Wave 3	Wave 4	Wave 5			χ^2	df	CFI	TLI	RMSEA	SRMR
Enjoyment	3.124**	0.861**	−0.797**	0.693**	0.00	0.517	0.875	0.961	1.00	−.62**	−0.86	3155.621	943	.948	.946	.026	.059
Pride	3.449**	0.595**	−0.549**	0.485**	0.00	0.434	0.803	0.953	1.00	−.49**	−0.71	1565.914	558	.965	.963	.023	.042
Anger	2.057**	0.465**	0.355**	0.375**	0.00	0.497	0.957	1.03	1.00	−.52**	0.52	2169.444	732	.956	.953	.024	.043
Anxiety	2.351**	0.300**	0.001	0.187**	0.00	0.183	0.740	1.21	1.00	−.36**	0.00	7449.017	2686	.931	.929	.022	.053
Shame	2.164**	0.474**	−0.081*	0.275**	0.00	0.504	0.939	1.04	1.00	−.34**	−0.12	1014.823	400	.977	.975	.021	.041
Boredom	2.036**	0.714**	0.665**	0.691**	0.00	−0.340	0.247	0.798	1.00	−.52**	0.79	1856.768	738	.962	.960	.021	.044
Hopelessness	2.040**	0.473**	0.177**	0.383**	0.00	0.262	0.807	1.12	1.00	−.32**	0.26	1051.696	406	.978	.976	.021	.035
Perceived control	4.056**	0.269**	−0.480**	0.316**	0.00	0.359	0.759	0.869	1.00	−.32**	−0.93	1169.271	406	.964	.961	.023	.044
Intrinsic value	3.480**	0.674**	−0.657**	0.690**	0.00	0.438	0.805	0.879	1.00	−.54**	−0.80	263.227	85	.981	.976	.024	.041
Achievement value	4.038**	0.334**	−0.481**	0.443**	0.00	0.511	0.894	1.01	1.00	−.48**	−0.83	1100.352	271	.949	.944	.029	.049
Achievement scores	100.260**	175.581**	28.856**	96.681**	0.00	0.388	0.516	0.858	1.00	.27**	2.18	9.857	7	1.00	1.00	.011	.017

Abbreviations: CFI, comparative fit index; ES, effect size; df, degrees of freedom; RMSEA, root mean square error of approximation; SRMR, standardized root mean square residual; TLI, Tucker–Lewis index.
*$p < .05$; **$p < .01$.

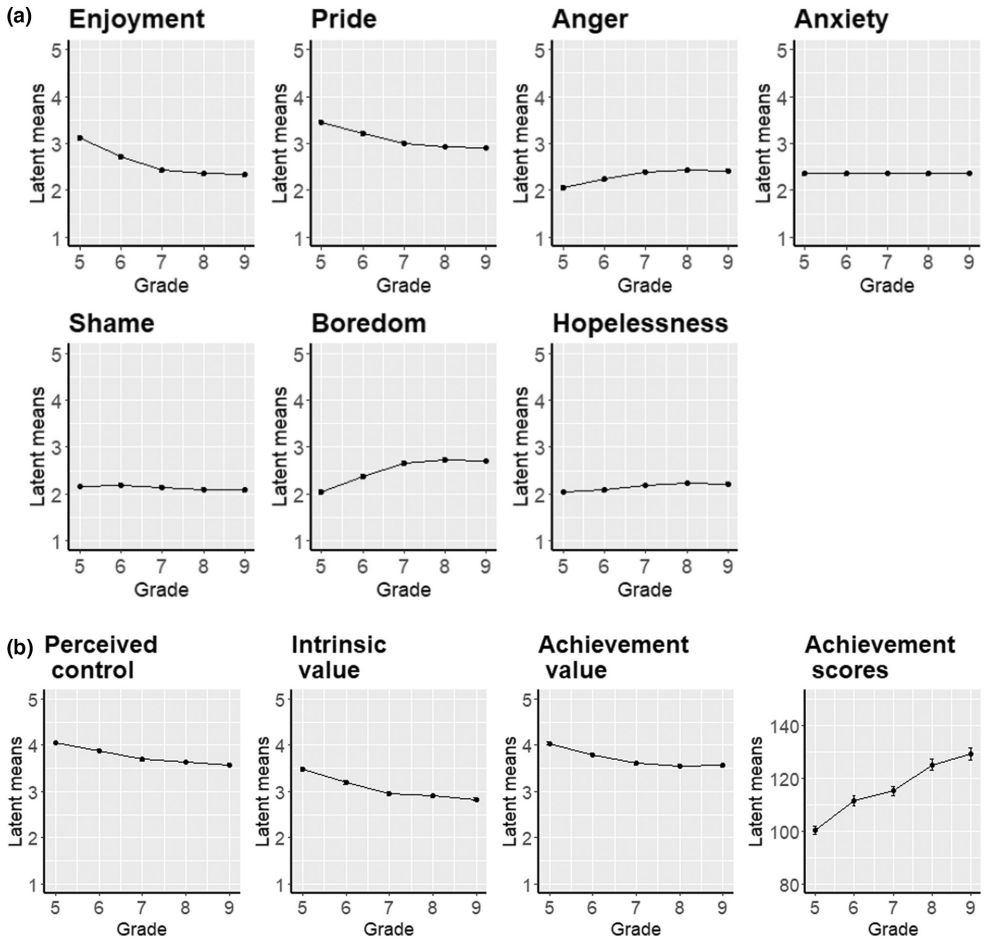

FIGURE 1 (a) Change trajectories of achievement emotions over 5 years. (b) Change trajectories of control–value beliefs and math achievement over 5 years. Note that the latent means are anchored at the first item of the scale.

findings (e.g., Watt, 2004), all control–value beliefs significantly declined with age. The effect sizes of the latent change scores were all large (Δ = −.93, −.80, −.83). As shown in Figure 1b, most of the change in control–value beliefs occurred from Grade 5 to Grade 7—the time when most achievement emotions also showed the biggest change (Figure 1a). We also examined the effects of the background variables on change trajectories of control–value beliefs (Table 4). School track was the only variable that had consistent effects on the slopes for all three control–value beliefs. Specifically, those in the highest academic track showed larger declines in the control–value beliefs. As for achievement emotions, gender and initial math grades also had significant associations with the intercept factors of control and intrinsic value. However, their slope factors were not significantly associated with gender or initial math grades.

Next, we addressed whether control–value beliefs and achievement emotions co-develop. First, we assessed how the intercepts of the control–value beliefs were associated with the intercepts of the achievement emotions. The results were largely consistent with the CVT's predictions (Table 5). Specifically, higher intercepts of perceived control and intrinsic value were associated with higher intercepts of enjoyment and pride (partial *r*s = .56 to .70, *p*s < .01) and lower intercepts of all five negative emotions (partial *r*s = −.48 to −.11, *p*s < .01). Higher intercepts of achievement value were also associated with higher intercepts of the two positive emotions (partial *r*s = .31, .32, *p*s < .01) and lower intercepts of anger and boredom (partial *r*s = −.12, −.21, *p*s < .01). In contrast, higher intercepts of achievement value were associated with *higher* levels of anxiety and shame (partial *r*s = .06, .07, *p*s < .01). The hopelessness intercept was not significantly correlated with the intercept of the achievement value belief scores.

Second, we assessed the slope–slope associations (Table 5). Similar to the findings for the intercepts, larger decreases in perceived control and intrinsic value were associated with larger decreases in the two positive emotions (partial *r*s = .49 to .62, *p*s < .01) and greater increases in all five negative emotions (partial *r*s = −.49 to −.05, *p*s < .01), though the relation was weak for shame. For achievement value, larger decreases were associated with larger decreases of enjoyment and pride (partial *r*s = .32, 33, *p*s < .01) and larger increases in boredom and anger (partial *r*s = −.24, −.13, *p*s < .01). In addition, the slope of hopelessness was significantly

TABLE 4 Effects of students' background characteristics on the intercept and slopes of achievement emotions (unstandardized betas).

		Emotions							Control–value beliefs		
Dependent variable	**Predictors**	**Enjoyment**	**Pride**	**Anger**	**Anxiety**	**Shame**	**Boredom**	**Hopelessness**	**Perceived control**	**Intrinsic value**	**Achievement value**
Intercept factor	Family SES	.031 (.011)**	.03 (.011)**	.000 (.009)	.000 (.007)	.000 (.011)	−.005 (.012)	−.002 (.009)	−.001 (.007)	.011 (.013)	.015 (.009)
	Gender (male = 1)	.266 (.054)**	.315 (.049)**	−.042 (.047)	−.161 (.037)**	−.101 (.056)	.168 (.051)**	−.242 (.047)**	.153 (.028)**	.239 (.054)**	.014 (.04)
	Intelligence	−.049 (.026)	−.045 (.031)	.016 (.018)	−.018 (.015)	−.034 (.028)	.069 (.022)**	.021 (.018)	−.008 (.014)	−.021 (.026)	−.002 (.019)
	Initial math grade	−.275 (.037)**	−.25 (.034)**	.28 (.027)**	.292 (.023)**	.304 (.034)**	.167 (.029)**	.371 (.027)**	−.263 (.019)**	−.196 (.03)**	.000 (.027)
	Higher versus others	−.114 (.06)	−.082 (.039)*	.027 (.045)	.035 (.035)	−.024 (.046)	.027 (.054)	.05 (.044)	−.041 (.028)	−.097 (.04)*	.069 (.025)**
	Intermediate versus lower	−.054 (.034)	−.034 (.024)	−.016 (.024)	−.004 (.02)	−.023 (.024)	−.047 (.029)	−.009 (.026)	−.04 (.015)**	−.065 (.03)*	.021 (.016)
Slope factor	Family SES	−.016 (.011)	−.012 (.012)	.001 (.01)	.001 (.007)	.012 (.013)	−.002 (.011)	.002 (.011)	.009 (.01)	.005 (.017)	−.001 (.013)
	Gender (male = 1)	−.109 (.054)*	−.131 (.049)**	.004 (.05)	.058 (.044)	.115 (.058)*	.058 (.053)	.004 (.056)	.037 (.042)	−.028 (.06)	−.127 (.053)*
	Intelligence	.077 (.027)**	.032 (.036)	−.067 (.019)**	−.065 (.024)**	−.054 (.033)	−.037 (.026)	−.092 (.029)**	.064 (.022)**	.034 (.022)	−.044 (.024)
	Initial math grade	.086 (.033)**	.077 (.038)*	−.085 (.028)**	−.117 (.027)**	−.129 (.03)**	−.042 (.034)	−.119 (.032)**	.034 (.025)	−.007 (.035)	−.139 (.031)**
	Higher versus others	−.076 (.051)	−.042 (.046)	.055 (.034)	.002 (.03)	−.005 (.058)	.078 (.05)	.018 (.043)	−.083 (.033)*	−.106 (.036)**	−.093 (.026)**
	Intermediate versus lower	.001 (.028)	−.012 (.023)	.011 (.023)	−.007 (.022)	−.002 (.03)	.056 (.026)*	.016 (.027)	.017 (.019)	.007 (.026)	−.041 (.017)*

Note: Numbers in parentheses are standard errors. For math grades, lower numbers represented better grades. "Higher versus others" and "Intermediate versus lower" represent two contrasts to code school type.
Abbreviation: SES, socioeconomic status.
*$p < .05$; **$p < .01$.

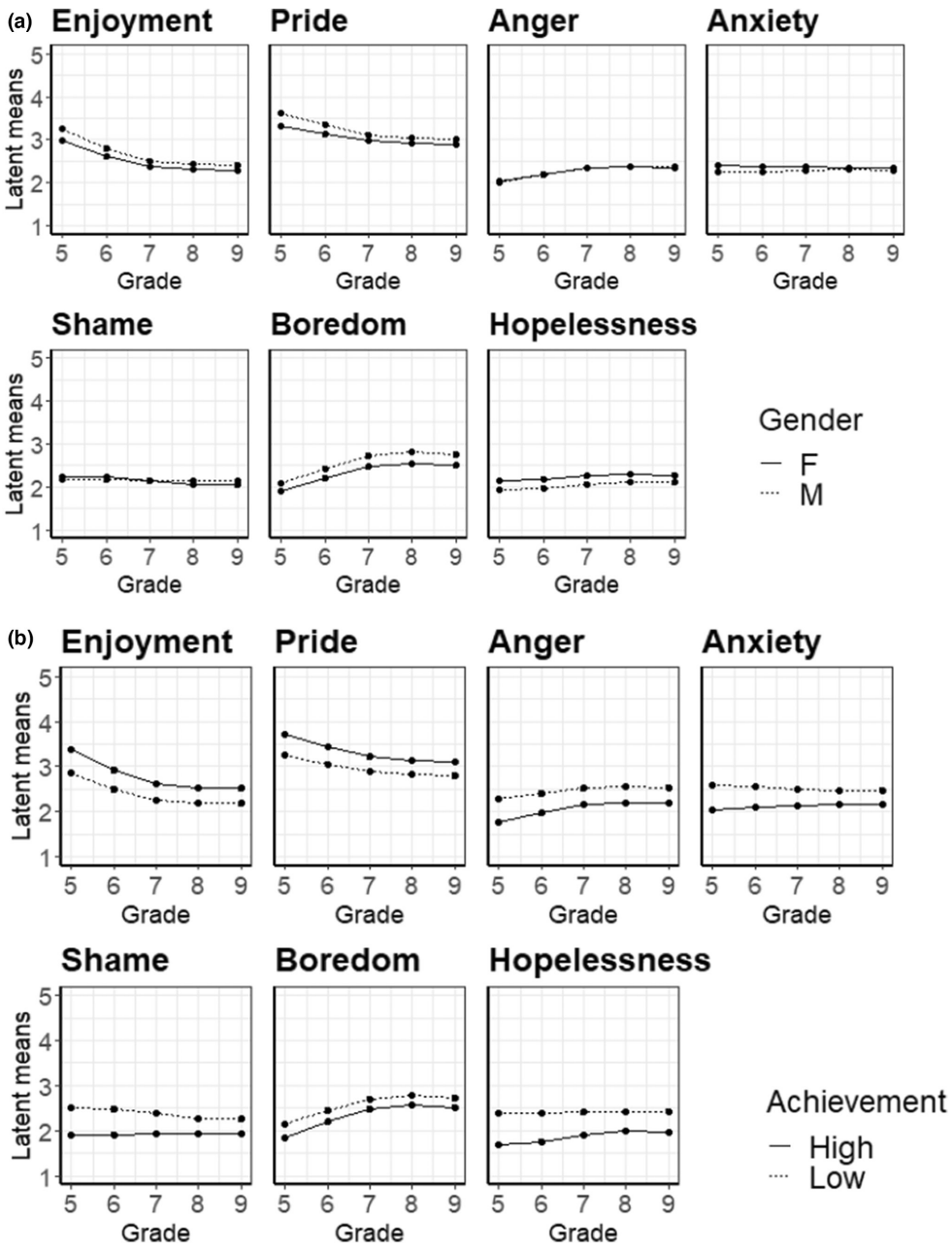

FIGURE 2 (a) Effects of gender and (b) effects of initial math grades on change trajectories of achievement emotions. (high and low represent 1 SD above and below the mean for initial math grades).

but weakly correlated with the slope of achievement value belief (partial $r = -.069$, $p < .01$). For anxiety and shame, the slopes were not significantly associated with the slope of achievement value, which does not appear consistent with the CVT's predictions that higher achievement value would be associated with stronger outcome emotions.

There were additional significant associations between the intercept and the slope factor scores (Table 5). For example, higher intercepts of enjoyment were associated with a greater decrease in intrinsic value, and higher intercepts of intrinsic value were associated with a larger decline in enjoyment (partial $rs = -.18, -.29$, $ps < .01$). However, these associations may simply reflect regression to the mean. In fact, the intercept factors of enjoyment and those of intrinsic value were highly correlated ($r = .70$). Due to regression to the mean (Table 3), those with higher initial enjoyment also showed a larger decrease in enjoyment ($r = -.62$). Thus, the intercept scores of intrinsic value should be correlated with the slope scores of enjoyment even when there were no direct associations between them; therefore, we do not discuss the slope–intercept associations when the intercepts of the variables were strongly correlated.

TABLE 5 Partial correlations across the intercept/slope estimates of achievement emotions, control-value beliefs and achievement scores controlling for the background characteristics.

	Intercept							Slope						
	Enjoyment	Pride	Anger	Anxiety	Shame	Boredom	Hopeless	Enjoyment	Pride	Anger	Anxiety	Shame	Boredom	Hopeless
Perceived control														
Intercept	.578**	.582**	−.439**	−.435**	−.296**	−.29**	−.479**	−.175**	−.075**	.018	.011	.116**	.003	−.071**
Slope	.043*	.097**	−.11**	−.168**	−.162**	−.036	−.17**	.486**	.526**	−.417**	−.401**	−.186**	−.25**	−.49**
Intrinsic value														
Intercept	.698**	.557**	−.417**	−.248**	−.107**	−.445**	−.268**	−.285**	−.105**	.078**	.033	.041*	.058**	−.027
Slope	−.182**	−.066**	.056**	−.001	−.019	.109**	−.018	.621**	.496**	−.333**	−.173**	−.05**	−.35**	−.214**
Achievement value														
Intercept	.314**	.323**	−.115**	.064**	.067**	−.212**	.012	−.118**	−.075**	.002	−.016	−.047*	.001	−.019
Slope	.054**	.091**	−.081**	−.039*	−.018	−.073**	−.081**	.319**	.334**	−.129**	−.022	−.024	−.243**	−.069**
Achievement scores														
Intercept	.164**	.144**	−.19**	−.209**	−.193**	−.096**	−.206**	.023	.034	−.051**	−.044*	.043	−.034	−.075**
Slope	.083**	.085**	−.146**	−.152**	−.157**	−.132**	−.153**	.154**	.154**	−.158**	−.162**	−.074**	−.121**	−.199**

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

TABLE 6 Interaction between control and value in the intercepts and slopes of achievement emotions (estimates represent standardized betas).

	Intercept		Slope	
	Estimates	*SE*	Estimates	*SE*
Intrinsic value × control				
Enjoyment	1.136**	.125	0.033	.035
Pride	0.871**	.163	−0.012	.037
Anger	−0.297	.207	0.103*	.044
Anxiety	−0.554**	.211	−0.07	.058
Shame	−0.689**	.206	−0.125*	.050
Boredom	0.062	.264	0.052	.050
Hopelessness	−0.128	.196	−0.006	.051
Achievement value × control				
Enjoyment	0.635**	.231	0.058	.034
Pride	0.788**	.166	0.108**	.037
Anger	−0.707*	.299	0.026	.028
Anxiety	−1.018**	.258	−0.129**	.035
Shame	−0.972**	.238	−0.139**	.041
Boredom	−0.102	.331	0.093*	.041
Hopelessness	−1.058**	.278	−0.076*	.033

Note: Values reported under "Intercept" represent how the intercepts of the value-by-control interactions are associated with the intercepts of the achievement emotions. Values reported under "Slope" represent how the slopes of the value-by-control interactions are associated with the slopes of achievement emotions. SE represents standard errors.
*$p<.05$; **$p<.01$.

Interactions between control–value beliefs in growth curves of achievement emotions

The results described so far were not always consistent with the predictions from CVT. To examine whether the effects of interactions between control and value can account for these inconsistencies, we next explored the control-by-value interactions (Table 6). First, we examined how the control-by-value interactions in the intercept factors are associated with the intercepts of achievement emotions. We found significant interaction effects of perceived control and intrinsic value on the two positive emotions (βs = 1.14, 0.87; ps < .01) and two of the negative outcome emotions (anxiety and shame; βs = −0.55, −0.69; ps < .01). There were also significant interactions between control and achievement value for the two positive emotions (βs = 0.64, 0.79; ps < .01) and for the negative emotions (βs = −0.71 to −1.06; ps < .01) except boredom. To identify the interaction patterns, we estimated the effects of value on emotions when perceived control was low (−1 SD), average (0 SD) and high (+1 SD; Table S6). The results indicate that stronger intrinsic value at the first wave was associated with stronger enjoyment and pride and weaker anxiety and shame—especially when adolescents perceived higher (relative to lower) control. Those with stronger achievement value

also reported stronger positive emotions and weaker negative emotions—particularly when they perceived higher (relative to lower) control.

Next, we examined how the control-by-value interactions of the slope factors are associated with the slopes of achievement emotions. In line with CVT's predictions (Table 6), there were significant interaction effects of control and achievement value for the three negative outcome emotions (βs = −0.13, −0.14, −0.08; ps < .05), as well as the positive outcome emotion pride (β = 0.11, p < .01). Specifically, adolescents who maintained higher levels of achievement value over time showed a larger increase in anxiety, shame, and hopelessness—especially when they showed a larger drop in perceived control (Table S6). In addition, an increase in achievement value was associated with an increase in pride especially when perceived control was maintained. The interaction between slopes of achievement value and perceived control was not significant for enjoyment and anger (ps > .05).

Relations between growth curves of achievement emotions and academic achievement

Finally, we addressed whether the development of achievement emotions is associated with growth of academic achievement. First, we estimated a latent basis model for the achievement scores from Grade 5 to Grade 9 (Table 3; Figure 1b). The estimates confirm previous findings that achievement scores showed a sharp increase (Murayama et al., 2013). We next estimated factor scores for the intercept and slope of achievement and correlated them with the intercept and slope factor scores for achievement emotions while controlling for background variables (Table 5). The intercepts of achievement were significantly correlated with the intercepts for all achievement emotions (e.g., achievement intercept and enjoyment intercept, partial r = .16, p < .01). The slope scores for achievement were also significantly correlated with the slope scores of all achievement emotions. Specifically, the slopes of positive emotions were positively correlated with the growth of achievement scores (partial rs = .15, 15, ps < .01), and those of negative emotions were negatively correlated with the growth of achievement scores (partial rs from −.20 to −.07, ps < .01). Thus, those who showed a larger growth of achievement scores were more likely to show larger increases (or smaller decreases) in positive emotions and smaller increases in negative emotions.

In addition, the intercepts of all achievement emotions correlated significantly with the slopes of the achievement scores. Specifically, higher initial positive emotions (enjoyment and pride; partial rs = .08, .09, ps < .01) and lower negative emotions (anger, anxiety, boredom, shame, and hopelessness; partial rs = −.13 to −.16, ps < .01) were associated with a larger growth in math achievement over the subsequent years. In contrast, the intercepts of achievement scores were not consistently related to the slopes of the emotions.

DISCUSSION

Despite the awareness that achievement emotions play a key role in students' academic success and well-being, the longitudinal development of adolescents' achievement emotions is not clearly understood. Therefore, the present study aimed to comprehensively examine the change trajectories of adolescents' achievement emotions and associated factors by focusing on seven key achievement emotions in mathematics.

Overall change trajectories of achievement emotions in mathematics

The first goal of the present study was to examine the overall change trajectories of the seven achievement emotions in mathematics during adolescence. Using the latent basis model, we analyzed trajectories of positive activity emotion (enjoyment), positive outcome emotion (pride), negative activity emotions (anger and boredom), and negative outcome emotions (anxiety, shame, and hopelessness) in over 3,000 German adolescents from Grades 5 to 9. Our results indicate that as adolescents progress through grades, on average, enjoyment and pride decrease and anger and boredom increase. The average level of hopelessness also increased with age, although the increase was smaller than the increase in anger and boredom. However, not all negative emotions showed mean increases—anxiety did not significantly change, and shame *decreased*. Thus, while the average level of negative activity emotions increased during adolescence, negative outcome emotions showed mixed patterns.

The overall decrease in enjoyment and increase in boredom is aligned with existing findings on emotions in mathematics and other subjects (Ahmed et al., 2013; Grazia et al., 2021; Hagenauer & Hascher, 2010; Meyer & Schlesier, 2021; Vierhaus et al., 2016). The lack of significant changes in anxiety is also consistent with recent findings based on large-scale longitudinal data on math anxiety in the USA (Wang et al., 2021). The present study extends the existing literature by showing that negative outcome emotions (e.g., anxiety and shame) versus negative activity emotions (e.g., anger and boredom) show different patterns of change during adolescence. The decrease in pride differs from the findings by Sainio et al. (2021), who reported that pride in mathematics did not change from Grade 6 to Grade 7 when students experienced a school transition after Grade 6. However, other studies found a decrease in pride in adolescents who did not undergo a school transition (as those in the PALMA study; Ahmed et al., 2013; Meyer

& Schlesier, 2021). These results suggest that, without a school transition, adolescents on average experience a decrease in pride, at least in mathematics.

Background characteristics and change trajectories of achievement emotions

In addition to the overall change pattern of achievement emotions, we found large variances in the intercepts and slopes of the achievement emotions; that is, there were considerable individual differences in the initial levels and subsequent changes in achievement emotions. Next, we explored the effects of gender, family SES, school track, and initial grades on such individual differences. As expected, initial math grades were positively correlated with the two positive emotions and negatively correlated with the five negative emotions, as adolescents reported them in the first wave. We also found significant effects of gender on the initial levels of achievement emotions, in support of previous studies (Else-Quest et al., 2010).

It has long been suggested that initial inequalities in educational settings (e.g., gaps due to SES, health, and cognitive abilities) are amplified over time ("the rich get richer"; Kuo et al., 2021; Murayama et al., 2013). This Matthew Effect suggests that gender gaps in achievement emotions can widen, such that boys experience even more positive emotions in mathematics than girls over time. In contrast, in the present study, although there were gender differences in the initial levels of achievement emotions, they did not necessarily increase over time. We also found that adolescents with lower initial grades experienced a smaller increase (or larger decrease) in most negative emotions (apart from boredom) and a smaller decrease in the two positive emotions. Thus, our results suggest that the Matthew Effect may not be strong for achievement emotions.

It should be noted that previous research with the PALMA dataset shows that gender differences in math interest increase during adolescence (Frenzel et al., 2010). Although the analysis method was different from the present study, it appears that achievement emotions show less profound gender gaps than math interest. One potential explanation is that gender gaps in interest and achievement emotions are caused by different factors. For example, recent research indicates that children endorse gender stereotypes about interest (e.g., "boys are more interested than girls in math") more strongly than those about abilities, which are closely related to perceived control (e.g., "boys are better at math than girls"; Master et al., 2021). Goetz et al. (2013) suggested that the effects of students' gender on their achievement emotions are mediated by effects of gender on perceived control. Future research should examine how these mechanisms differentially shape gender differences in interest and achievement emotions.

Role of control–value beliefs in the development of achievement emotions

Another objective of this study was to investigate whether adolescents' perceived control and value beliefs play a role in explaining interindividual differences in the initial levels and change trajectories of achievement emotions. Our results indicate that at the first wave, adolescents who perceived higher control and higher intrinsic value reported stronger positive emotions and weaker negative emotions. Furthermore, those who perceived higher achievement value at the first wave were more likely to report stronger positive emotions and weaker negative activity emotions (anger and boredom), but stronger negative outcome emotions (anxiety and shame). These results are consistent with CVT's proposition that negative activity emotions and negative outcome emotions show different relations with achievement value (Pekrun, 2006, 2021; Pekrun et al., 2023).

In addition to the results for the first wave, we found that adolescents' perceived control, intrinsic value, and achievement value significantly declined as they advanced through the grades. These findings are consistent with prior evidence that both control and value beliefs decline during adolescence (e.g., Metsäpelto et al., 2017; Watt, 2004). Such declines were associated with change trajectories of achievement emotions. Specifically, those who showed a larger decline in perceived control and intrinsic value were more likely to experience a larger decrease in the two positive emotions and a larger increase in all five negative emotions. In addition, those with a larger decline in achievement value were more likely to experience a greater decrease in enjoyment and pride, and a greater increase in anger, boredom, and hopelessness. In contrast, the slopes of anxiety and shame were not significantly related to the slopes of achievement value.

According to CVT, negative outcome emotions arise when learners perceive low control and high achievement value. Thus, the links of the slope for achievement value with the slopes for anger and boredom are not predicted by CVT; the theory leaves it open if these links exist or not. In addition, at first sight, the lack of a significant relation between the slopes of anxiety and shame and achievement value does not appear consistent with CVT. However, CVT proposes that anxiety and shame primarily relate to the importance of failure (which was not separately assessed in the present analysis). Furthermore, the theory proposes that control and value appraisals interact in their effects on achievement emotions.

Indeed, as expected from CVT, our subsequent analyses revealed significant effects of the interactions between control and achievement value on negative outcome emotions. Specifically, those with stronger achievement value were more likely to show higher anxiety, shame, and hopelessness at the first wave especially when their control was low. In addition,

adolescents developed stronger anxiety, shame, and hopelessness over time when their achievement value was maintained and perceived control decreased. Adolescents who maintained achievement value were also less likely to show a decline in pride over time when they maintained perceived control. In contrast, the interaction effects of slopes of control and achievement value were not significant for enjoyment and anger (both of them are activity emotions). Thus, the findings highlight the importance of considering the effects of interactions between control and value in understanding the mechanisms behind the development of achievement emotions. Taken together, our results support CVT (Pekrun, 2006, 2021; Pekrun et al., 2023) and suggest that students' appraisals of control and value drive the development of achievement emotions over a multiyear time span.

While our results on achievement value were largely consistent with CVT, some of the results were not expected based on CVT. For example, CVT predicts an interaction between intrinsic value and control for activity emotions. However, we found significant interactions between the intercepts of intrinsic value and perceived control for the intercepts of outcome emotions (pride, anxiety, and shame). In addition, the interactions between the slopes of intrinsic value and control were not significant for the slopes for enjoyment and boredom (i.e., activity emotions); these results diverge from previous research with primary school children (Putwain et al., 2018). In addition, intrinsic value had strong main effects on all achievement emotions (Table 5), which is different from recent findings with undergraduate students (Pekrun et al., 2023). Thus, the effects of intrinsic value on achievement emotions may be different during adolescence. Future research is needed to examine how intrinsic value interacts with control in affecting emotions across different age groups.

Development of achievement emotions and academic achievement

This study also provides evidence for the co-development of achievement emotions and academic achievement. Unlike relations with control–value beliefs, relations with achievement were organized along the valence dimension, with different associations for positive and negative emotions. In general, larger growth in academic achievement was positively correlated with smaller decreases (or larger increases) in the two positive achievement emotions and with smaller increases (or larger decreases) in all negative achievement emotions. In addition, students with higher levels of positive emotions in the first wave were more likely to show greater growth in math achievement. In comparison, those with higher levels of negative emotions were more likely to show smaller growth in achievement. These results are in line with previous longitudinal research demonstrating reciprocal relations between achievement and achievement emotions (e.g., Forsblom et al., 2021; Pekrun et al., 2017). These valence-specific effects are also consistent with CVT (Pekrun, 2006, 2021). Our results further support this theory and suggest that different negative emotions (e.g., anger and anxiety) can be induced by different control–value appraisals, but that all of them may be associated with negative downstream impacts on academic achievement.

Limitations and future directions

This study is the first to comprehensively examine the growth trajectories of different achievement emotions during adolescence. The analysis is based on a large representative sample from a multi-wave study and a robust analytic methodology. Nevertheless, several important limitations should be considered and can be used to derive directions for future research.

First, although the results suggest that achievement emotions co-develop with control–value beliefs and achievement, the causality of these results is unclear, and hence, any inferences proposing a causal direction should be interpreted with caution. Related to this issue, we did not analyze all achievement emotions together because of difficulties in estimating models simultaneously when including all of them. While our approach to using factor scores has produced theoretically consistent results in previous studies on achievement emotions (Pekrun et al., 2017, 2019, 2023), the current results may not fully and accurately represent the relations of intercepts and slopes.

Second, this study relied on self-report measures of emotions experienced by students when attending classes, doing homework, and taking tests and examinations. Such retrospective measures do not necessarily reflect the dynamic change in emotions during single episodes of learning or test taking. Future research should combine retrospective self-report assessments with situational methods (e.g., experience sampling) to validate self-report measures and investigate how short-term fluctuations in achievement emotions contribute to the long-term developmental changes observed in this study. In addition, a recent study (Pekrun et al., 2023) suggests that achievement value can be empirically divided into the perceived importance of success and the perceived importance of failure. Further research is needed to identify the roles of each of the different facets of value in achievement emotions.

Third, this study is based only on data from the state of Bavaria in Germany. Our large sample was representative of the student population in that state. However, it is unclear how generalizable the results are to adolescents from other countries with different backgrounds.

For example, we found the most dramatic changes in achievement emotions and control–value beliefs between Grades 5 and 7, that is, shortly after students entered secondary school. However, the current data cannot tell us whether such large changes are due to the transition from primary to secondary schools or due to age. Furthermore, the present study focuses on emotions in mathematics. Future research should include other academic domains and examine the effects of cohort, school transitions, and cultural context.

Practical implications

The findings from the present study offer insights for practitioners and parents. First, the developmental changes documented in this study (i.e., reductions in average levels of positive emotions and increases in negative emotions) are clearly neither desirable for students' well-being nor conducive to their academic success. We observed that a decrease in positive emotions and an increase in negative emotions were associated with less growth in academic achievement. Moreover, a decrease in positive emotions experienced by students is not ideal for teachers' or parents' well-being. Our results add to the growing body of literature encouraging educators and parents to pay attention to adolescents' emotional responses to learning.

Second, the present study highlights the role of adolescents' control and value beliefs in developing achievement emotions. Among different facets of value, our results point to the importance of intrinsic value: Higher intrinsic value was predictive of stronger maintenance of all positive emotions and less development of all negative emotions. In contrast, high achievement value was associated with the development of negative emotions, such as anxiety and shame, especially when combined with low perceived control. Taken together, the present findings suggest the importance of fostering children's intrinsic value (e.g., their interest) in learning activities in educational settings.

Finally, this study highlights individual differences in the development of achievement emotions and control–value beliefs. As in previous studies, boys experienced more positive emotions, more control, and higher intrinsic value in mathematics than girls at the beginning of secondary school. In addition, students with lower academic grades showed weaker positive emotions, more negative emotions, and weaker control–value beliefs in mathematics at the beginning of secondary school. Despite these differences, gender and initial math grades had only weak effects on changes in achievement emotions and control–value beliefs. Nevertheless, it is important to note that we observed large gaps between high and low achievers in achievement emotions throughout the subsequent 5 years. These results suggest that it is important to pay attention to low-achieving students to reduce the gap between high and low achievers.

CONCLUSION

It is well known that adolescents tend to lose their self-confidence and intrinsic motivation as they advance through the school years (Metsäpelto et al., 2017; Miyamoto et al., 2020; Watt, 2004). These observations might suggest that adolescents simply feel less positive and more negative over time in education. In line with this intuition, we found a decrease in students' enjoyment of learning and pride in their achievement during adolescence. However, we also found more complex developmental patterns for negative emotions: On average, anger and boredom increased, but shame decreased, and the average levels of anxiety did not change. Our results suggest the importance of considering specific emotions (beyond the positive vs. negative valence divide) and distinct antecedents of each emotion to better understand the developmental changes in adolescents' emotions in educational settings.

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DATA AVAILABILITY STATEMENT

The data necessary to reproduce the analyses presented here are not publicly accessible. The analytic code necessary to reproduce the analyses presented in this paper is publicly accessible at the following URL: https://osf.io/vhrbx/. The materials necessary to attempt to replicate the findings presented here are not publicly accessible but available from the authors on request. The analyses presented here were not preregistered.

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SUPPORTING INFORMATION

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