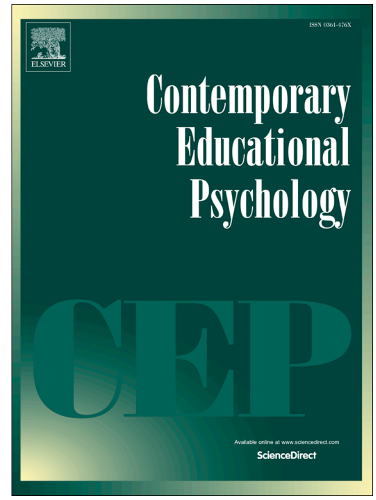
Accepted Manuscript



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PII: S0361-476X(18)30055-9
DOI: https://doi.org/10.1016/j.cedpsych.2018.10.002
Reference: YCEPS 1720

To appear in: *Contemporary Educational Psychology*

Received Date: 16 February 2018
Revised Date: 22 August 2018
Accepted Date: 3 October 2018

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Acknowledgments This research was funded by the Swiss National Foundation (SNF). We also thank the schools, teachers and students who participated in our study.

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Abstract

Based on self-determination theory and control-value theory, the present study examined the longitudinal and reciprocal relationships between students' self-determined motivation (intrinsic and identified motivation) and negative academic emotions (anxiety, anger, and boredom) in mathematics. In a longitudinal study, 348 seventh grade students (51.4% girls) completed three self-report measures (t0–t2) assessing their motivation and emotions at the beginning and end of seventh grade as well as at the end of eighth grade. Structural equation modelling in Mplus was used to test cross-lagged panel models of reciprocal effects between self-determined motivation and each emotion, controlling for prior achievement and gender. Over the course of seventh grade (t0–t1), exclusively unidirectional, negative effects between self-determined motivation and anger, anxiety, and boredom were found. The direction of the relationship was the same for all emotions in terms of the impact from students' emotions on their motivation from t0 to t1, with one exception that indicated the reverse association: there was a negative relation from intrinsic motivation to boredom. During the eighth grade (t1 to t2), the analyses revealed no further significant cross-lagged effects. Implications for educational practices and future research on motivation and emotion are discussed.

Keywords: motivation, self-determination theory, emotions, control-value theory, reciprocal relations

1. Introduction

There has been a growing awareness in recent years of the relevance of students' learning motivation for positive educational outcomes (Taylor et al., 2014). In addition, there has also been increasing interest in students' academic emotions (Pekrun & Linnenbrink-Garcia, 2014). During their academic careers, students are confronted with numerous educational challenges and consequently with both negative and positive emotional experiences. In the domain-specific analysis of adolescents' learning motivation and learning emotions, the subject area of mathematics is of particular interest: it is generally viewed as a challenging subject (Hannover & Kessels, 2004), it elicits negative emotions (Hagenauer, 2011), it features gender-specific discrepancies not only in motivation and emotions but also in achievement and self-concept (Frenzel, Pekrun, & Goetz, 2007a), and it seems especially prone to trigger boredom among students in lower achievement levels (Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010). The reciprocity in the relationship between students' emotions and achievement (Pekrun, vom Hofe, Blum, Frenzel, Goetz, & Wartha, 2007; Putwain, Becker, Symes, & Pekrun, 2018), as well as between their motivation and achievement in mathematics (Guay, Ratelle, Roy, & Litalien, 2010), has been explicitly studied in previous contributions, but the relationship between students' motivation and emotions in mathematics has yet to receive adequate attention. Although there is empirical evidence that students' emotions are correlated with their motivation, the questions remain (a) whether emotions and self-determined motivation influence each other reciprocally, and if so, (b) whether the two directions (motivation's impact on emotions versus emotion's impact on motivation) are equally strong or differ in intensity.

In this study, we explored the longitudinal reciprocal interplay between students' self-determined motivation and their negative emotions in mathematics. Investigating the relationships between these constructs is of relevance, as the research on learning emotions has developed almost completely independently of the research on self-determined motivation, although there is consensus that motivation and emotion are related (e.g., Abele-Brehm & Gendolla, 2000; Pekrun, 2013). Thus, bringing these two approaches together can equally enrich both research fields.

1.1 Self-Determination Theory of Motivation

Self-determination theory (SDT; Deci & Ryan, 2002; Ryan & Deci, 2017) defines various types of motivation, namely, forms of controlled and self-determined (autonomous) motivation ranging from amotivation (the state of lacking the intention to act) at one pole to intrinsic motivation (the most self-determined form of motivation) at the other (Ryan & Deci, 2000). Extrinsically motivated behaviours span the continuum between amotivation and intrinsic motivation. Whereas external and introjected regulations are primarily driven by external pressure and are thus controlled forms of motivation (e.g., students seeking to obtain rewards or to avoid punishment, guilt, or shame), identified regulation (e.g., students who do school work because they believe it to be important for their future prospects) represents a more autonomous or self-determined form of extrinsic motivation. Identified motivation shares many qualities with intrinsic motivation (e.g., students engaging freely in an activity due to the enjoyment and satisfaction it brings; Deci & Ryan, 2002; Ryan & Deci, 2017). Empirical research indicates that higher levels of self-determined motivation (i.e., intrinsic and identified motivation) are associated with various positive educational outcomes, such as better academic performance, more positive emotions, and improved self-concept (Deci, Vallerand, Pelletier, & Ryan, 1991; Ryan & Connell, 1989; Taylor et al., 2014). Because self-determined forms of motivation in particular are of fundamental importance for school learning—not only for educational outcomes but also in relation to the use of deep learning strategies, the self-regulation of learning, and lifelong learning (McCombs, 1991; Pekrun, 2013)—we focused on both self-determined forms of motivation, identified and intrinsic motivation, for the present study.

1.2 The Control-Value Theory of Academic Emotions

Students experience many different emotions in various academic settings in general (e.g., Hascher, 2010) and in response to challenging tasks specifically (Tulis & Fulmer, 2013). One of the most comprehensive theoretical frameworks describing the crucial role of emotions in the learning process is the control-value theory of achievement emotions (CVT; Pekrun, 2006; Pekrun, Frenzel, Goetz, & Perry, 2007). Within this framework, the critical emotions are those directly linked to academic learning, achievement activities, or achievement-related outcomes (Pekrun et al., 2007). These emotions can be positive or negative and may have differential effects on learning behaviour (Tulis & Fulmer, 2013). Positive or pleasant emotions are likely to support learning by fostering students' motivation, attention, engagement, or the use of learning strategies or self-regulated learning (Pekrun, 2014). For instance, enjoyment during learning tasks is considered a positive activating emotion that can increase students' interest; students overcome academic challenges more effectively when they enjoy what they are doing. Negative or unpleasant emotions also impact students' learning; for example, boredom, which has been identified as a negative emotion associated with disengagement and deactivation, typically reduces the use of deep learning strategies and promotes the shallow processing of information (Pekrun, 2014). Anger and anxiety are negative emotions that can have adaptive or maladaptive effects on learning processes; anxiety may motivate students to invest more effort in order to avoid failure, but high levels of anxiety can reduce students' interest and motivation as well as their engagement in and effort expended on challenging activities (Pekrun, 2014; Tulis & Fulmer, 2013).

1.3 Interplay Between Motivation and Emotions

In recent years, a growing body of research has suggested that emotions are positively related to students' engagement, learning, and achievement (Frenzel et al., 2007a,b; Pekrun, 2014; Pekrun, Goetz, Titz, & Perry, 2002). Within the framework of CVT, it is posited that students' achievement, their control-related appraisals (competence beliefs; e.g., self-concept), and their value appraisals (beliefs regarding the intrinsic or extrinsic value of a subject area; e.g., achievement outcomes) are among the most important determinants of their academic emotions. Emotions have been found to play a particularly essential role with regard to achievement but also with regard to motivation (Pekrun, 2014). According to CVT, the overall effects of emotions on learning outcomes and academic achievement are likely to depend on the set of motivational mechanisms triggered by various emotions (Peixoto, Sanches, Mata, & Monteiro, 2016). For instance, it is assumed that enjoyment is positively linked to learning and performance through the strengthening of motivation, meaning that the effects of students' emotions on achievement are mediated by their motivation, among other factors (e.g., the use of strategies). In contrast, negative emotions such as anxiety, anger, and boredom are generally expected to have a negative impact on students' learning processes as they decrease students' intrinsic motivation (Peixoto et al., 2016; Pekrun et al., 2007). To our knowledge, no study thus far has united CVT and SDT to empirically investigate the relationship and more specifically the direction of relationship between academic emotions and self-determined motivation over time. However, CVT has been combined with goal theory, another theoretical framework that is frequently implemented in motivation research (Goetz, Sticca, Pekrun, Murayama, & Elliot, 2016; Ntoumanis, 2001; Pekrun, Elliot, & Maier, 2009; Putwain, Larkin, & Sander, 2013). This theoretical strand is relevant to the present research in that the concept of mastery-goal orientation within goal theory has a strong conceptual overlap with self-determined motivation, in particular with intrinsic motivation. Students who pursue mastery goals primarily engage in learning because they want to understand things and acquire new knowledge and skills. Findings have shown that such students usually exhibit higher levels of learning enjoyment and lower levels of negative emotions such as boredom, anger, and anxiety (Pekrun et al., 2009).

Within the SDT framework, only a few studies (Isen & Reeve, 2005; Vandercammen, Hofmans, & Theuns, 2014) have focused on emotions as antecedents of motivation by investigating broad categories of positive versus negative affect. The results have indicated that positive affect is related positively to autonomous motivation, whereas there is no clear relationship between negative affect and autonomous motivation.

In sum, the link between self-determined motivation and academic emotions—in particular the link with students' negative emotions—has not yet been sufficiently investigated; however, the amount of empirical evidence confirming the reciprocal causations within the CVT framework between motivation and achievement (Guay et al., 2010), emotions and achievement (Pekrun et al., 2007, 2017), motivation and self-concept (Guay et al., 2010), and emotions and self-concept (Ahmed, Minnaert, Kuyper, & van der Werf, 2012; Peixoto et al., 2016) has been steadily increasing. In the present paper, we focused on the interplay of *negative* emotions and motivation for two reasons. First, with regard to the frequently explored positive emotion 'enjoyment', there is considerable overlap between the two constructs of intrinsic motivation and enjoyment, with enjoyment being one of the most direct self-reported measure of intrinsic motivation (Monteiro, Mata, & Peixoto, 2015). This often results in difficulties investigating the (longitudinal reciprocal) relationships between emotions and intrinsic motivation in a joint statistical model, as some degree of tautology in terms of construct operationalization is unavoidable. Second, there is a lack of studies that investigate the pattern between motivation and negative emotions.

1.4 The Present Study

The present study examined the reciprocal relationship between students' self-determined motivation and their negative emotions in relation to mathematics. In accordance with the theoretical frameworks of SDT and CVT, we expected self-determined motivation to be reciprocally linked to emotions such that self-determined motivation and anxiety, anger, and boredom would negatively predict each other over time.

Because prior research has shown that emotions and motivation are organized in a domain-specific way (Goetz, Frenzel, Pekrun, & Hall, 2006), the current paper specifically addresses students' self-determined motivation and emotions in the subject area of mathematics in early secondary education. The interplay was examined by addressing three negative emotions (anxiety, anger, boredom) that are relevant in mathematic instruction (Frenzel, Pekrun, & Goetz, 2007b).

2. Method

2.1 Participants and Procedure

The present study is part of the project entitled „Maintaining and fostering students' positive learning emotions and learning motivation in maths instruction during early adolescence", which was funded by the Swiss National Foundation. The sample consisted of 348 adolescents from 22 classes of the lowest achievement level,[1] with a mean age of 12.75 (*SD*

[1]After primary school, in the majority of the cantons, students are allocated into three different school tracks according to their intellectual ability, teachers' recommendations, and parental decisions: a basic-level track (*Realschule* = lower-achieving classes) that prepares students for vocational education and training, (2) an intermediate level track (*Sekundarschule*) that prepares students for more demanding occupational training or further education, and (3) and an upper-level track (*Gymnasium*) that prepares students for the university entrance qualifications (*Matura*; Guay et al., 2010).

= 0.64) at the beginning of seventh grade, who were followed until the end of eighth grade (three measurement points).

This grade was targeted because it is considered a critical year in Switzerland, since it represents the transitional phase from primary to secondary school for most students (Fend, 1997). Of these 348 students, 179 were female (51.4 %) and 169 were male (48.6 %); 117 (33.6 %) had a migration background,[2] and 231 (66.4 %) did not. Students' mean socio-economic status (measured by the highest occupational status of their parents; HISEI) was 42.73 (*SD* = 14.26), which is below the average for Swiss students; however, it is within the expected range for students in basic-demand classes, given that students in this school type typically come from families with lower socio-economic status (Konsortium PISA.ch, 2014). Data collection was conducted by university research members during the students' regular mathematic instruction.

2.2 Measures

2.2.1 Students' self-determined motivation. In accordance with the SDT framework developed by Deci and Ryan (2002), students' self-determined motivation in the subject area of mathematics was measured in terms of the two motivational styles of intrinsic and identified regulation assessed in the German Self-Regulation Questionnaire (Gnambs & Hanfstingl, 2014; Müller, Hanfstingl, & Andreitz, 2007), an adapted version of the Academic Self-Regulation Questionnaire (Ryan & Connell, 1989) validated for German-speaking students. Intrinsic motivation was measured using five items (e.g., 'I work in mathematics because I want to learn new things', αt0/t1/t2 = .89/.86/.88) and identified

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[2] A quarter of the students with a migration background were first-generation students (i.e., students and their parents born outside of Switzerland). Three-quarters of the students were second-generation students (students born in Switzerland with foreign-born parents). Over 70% of the students with a migration background were from south-eastern European countries (e.g., Albania, Croatia, Macedonia, Bosnia, Turkey); approx. 10% each were from South-European countries (Italy, Spain, Portugal), German-speaking countries (Germany, Austria, Luxemburg), or from other countries (Latin American and African countries).

motivation using four items (e.g., 'I work in mathematics because it will give me better career choices', αt0/t1/t2 = .82/.83/.83). Answers were given on a five-point response scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*[3]).

2.2.2 Students' academic emotions. Students' academic emotions in mathematics were assessed using an abbreviated version of the Achievement Emotions Questionnaire—Mathematics[4] (AEQ-M; Pekrun, Goetz, & Frenzel, 2005), an instrument specifically developed for the domain-specific assessment of emotions in students between grades 5 and 10. Students' anxiety in mathematics was assessed with six items (e.g., 'I feel nervous in mathematics class', αt0/t1/t2 = .86/.84/.84), their anger with four items (e.g., 'Because I'm angry, I get restless in math class', αt0/t1/t2 = .82/.83/.83), and their boredom with three items (e.g., 'Math class bores me', αt0/t1/t2 = .77/.87/.84). All items were rated on a five-point response scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*).

2.2.3 Students' gender and prior mathematics achievement as control variables. Students' gender was coded as female (0) and male (1). Students' mathematic performance at the beginning of seventh grade was assessed using a standardized achievement test from the Swiss HarmoS[5] project. The average standard score is scaled to a mean of 500 (*SD* = 100;

[3] All items are documented in https://www.researchgate.net/profile/Timo_Gnambs/publication/256636350_A_Differential_Item_Functioning_Analysis_of_the_German_Academic_Self-Regulation_Questionnaire_for_Adolescents/links/00b49539f57c4d90cd000000.pdf.
[4] Items are documented in http://repositorio.ispa.pt/bitstream/10400.12/3739/1/EJDP_201_20%20MAY.pdf

[5] In Switzerland, the main responsibility for education lies with the cantons, which has resulted in 26 separate versions of school curricula nationwide. In an attempt to harmonize compulsory education in Switzerland, the Swiss Conference of Cantonal Ministers of Education initiated the HarmoS project, establishing comprehensive competency levels in specific core areas—including mathematics—for compulsory schools in Switzerland. With HarmoS, for the first time, standards determined a framework for a new curriculum (*Lehrplan 21*) in mathematics to unify the curricula of the 21 German-speaking cantons (Guay et al., 2010). Based on these standards and curricular objectives, mathematics achievement tests were designed for students in grades 2, 6, and 9; the tests include both closed- and open-ended tasks from each competence field in the heuristic matrix of the curriculum (numbers and operations; shape and space; sizes and mass; functional relationships; data and

Wälti, 2014). The mean achievement score for the students in the present sample was 432 (*SD* = 60.02), which is within the expected range for students in this school type in the canton of ‘Canton’ (Bauer, Ramseier, & Blum, 2014).

2.3 Data Analysis

2.3.1 Missing data. In Switzerland, students are assigned to different achievement levels at the end of primary education (sixth grade). The study targeted students that were assigned to the lowest achievement level (= risk group regarding motivational decline); however, due to the permeability of the Swiss school system on secondary education, better achieving students can leave the level during the seventh grade. Typically, such changes occur during the first weeks and months of seventh grade .Thus, we only included students that remained in low-achieving mathematic classes and excluded those that were ‘promoted’ to a higher achieving level in the first weeks of secondary education. Therefore, the data for the present study included 348 students from an initial sample of 415 students who remained in the low-achieving track and completed both surveys in seventh grade (t0 and t1). Values of missing students at measurement point t2 (grade 8) were estimated (missing in total: 23 % for the dependent variables at t2) using Multiple Imputation in SPSS (Version 24). The pooled means, pooled standard errors, and pooled intercorrelations were calculated based on the imputed data set (five imputations). Measurement invariance and the cross-lagged models were done in Mplus (Muthén & Muthén, 1998-2012) using Full Information Maximum Likelihood (FIML) as the missing imputation method. The MLR (maximum likelihood parameter estimator) was utilized which is robust to non-normality and non-independence of the indicators.

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randomness). For the present study, the achievement test designed for students at the end of grade 6 was used to assess the participants at the beginning of seventh grade.

2.3.2 Preliminary analysis: Measurement invariance. Measurement invariance is critical for any comparison of the same construct across time (Little, 2013). The purpose is to ensure that the measurement properties of latent variables remain stable over time in order to avoid mistaking changes in measurement properties for hypothesized changes in the construct (Newsom, 2015). Analyses were performed using the structural equation modelling in Mplus (Version 7.3). Following the general procedures recommended by Little (2013), the present study applied a sequential testing procedure starting with the least constrained solution to measure invariance across the three measurement points for students' self-determined motivation (intrinsic and identified motivation), anxiety, anger, and boredom. The result of this first step was a configural invariance model, a model with no constraints on any of the parameters (i.e., all parameters are freely estimated). In the second step, metric invariance (weak factorial invariance) was estimated, enforcing equal factor loading between the three measurement points. In the third step, scalar invariance (strong factorial invariance) was estimated, combining the restrictions from the weak invariance model with the additional constraint of equal item intercepts between the three measurement points.

Following the recommendations of Cheung and Rensvold (2002) and Chen (2007), the change in two fit indices—the comparative fit index (CFI) and the root mean square error of approximation (RMSEA)—between nested models was investigated in order to determine the plausibility of the assumption of invariance. If the change in CFI is not more than .01 (Cheung & Rensvold, 2002) and the change in RMSEA is less than .015 (Chen, 2007), the assumption of invariance is tenable (Little, 2013).

2.3.3 Main analysis. To examine reciprocal relationships between students' self-determined motivation and emotions in mathematics over the course of two school years (grades 7 and 8), six autoregressive, bivariate, cross-lagged structural equation models for both self-determined forms of motivation (intrinsic and identified motivation) and each emotion were specified using the structural equation modelling in Mplus (Muthén & Muthén, 1998-2012). All models included control variables with each time point being regressed on gender and on mathematic achievement (from the beginning of seventh grade) [6]. All models specified latent factors and included correlated residuals for the individual items. Models 1a and 1b tested the longitudinal reciprocal relationship between mathematics *anxiety* and intrinsic (1a) and identified (1b) motivation; Models 2a and 2b tested the longitudinal reciprocal relationship between *anger* in mathematics and intrinsic (2a) and identified (2b) motivation; and Models 3a and 3b tested the longitudinal reciprocal relationship between *boredom* in mathematics and intrinsic (3a) and identified (3b) motivation. The cross-lagged models were computed using Mplus (Version 7.3, Muthén & Muthén, 1998-2012). Model fit was assessed by several commonly used fit indices: the CFI, the Tucker-Lewis Index (TLI), the RMSEA, and the standardized Root Mean Squared Residual (SRMR). A good level of fit is indicated when RMSEA and SRMR are less than 0.06 and when CFI and TLI values exceed 0.95. The fit of a model is considered acceptable when RMSEA and SRMR are less than 0.08 and CFI and TLI fall between 0.90 and 0.95 (Hu & Bentler, 1999).

To account for the multilevel-structured data (students in classes within schools), we used the Mplus command ‘Type = Complex’, which takes the non-independence of observations into account when calculating standard errors and chi-square tests (Muthén & Muthén, 1998-2012).

3. Results

3.1 Preliminary Results

[6] We calculated all models without controlling for gender and prior mathematics achievement. There were no differences in the detected effects with regards to significance. Because the data of the present study is part of an intervention project, the analyses were additionally calculated controlling for the participation in the intervention (dummy variable = intervention: yes/no). There were no differences in the detected effects with regards to significance.

Prior to analysing the structural, cross-lagged panel models, we examined the measurement models for all variables separately and their invariance across the three measurement points. In the first step, configural invariance was estimated (without constraints on factor loadings, or intercepts). The fits for all models (intrinsic and identified motivation, anxiety, anger, and boredom) were satisfactory, confirming identical factor structures over the three measurement points (see Table 1). In the second step, we estimated metric invariance, enforcing equal factor loadings across the three measurement points. The fits for all models were also satisfactory here; Δ CFI was not more than .01 and Δ RMSEA not more than .015. Thus, the assumption of metric invariance was confirmed for all variables across the two measurement points.

Although metric invariance is sufficient for the interpretation of structural relationships among variables, we also estimated models assuming scalar invariance by equally constraining all factor loadings, and intercepts. The fits of the models for all variables were satisfactory. Even though for identified motivation and anxiety the change in CFI was slightly over .01 (.014), the assumption of scalar invariance across the three measurement waves is overall supported by the data.

[Please insert Table 1 here]

3.2 Descriptive Results

Pooled means, standard errors, and inter-correlations between students' self-determined motivation and emotions in mathematics at the three measurement occasions are presented in Table 2. Mean scores for anxiety and boredom in mathematics at the beginning of seventh grade were higher than for anger. Whereas anxiety declines over the course of the two school years, boredom seems to stay relatively high. The correlations between self-determined motivation and emotions in mathematics at the three measurement points were all significant (except for self-determined motivation at the beginning of seventh grade [t0] and anxiety [t0-t2]), and all were in the expected direction. More importantly, the cross-temporal correlations between self-determined motivation and emotions were all significant (except again between motivation at t0 and anxiety at t0–t2), indicating the need to examine reciprocal effects over time.

[Please insert Table 2 here]

3.3 Cross-Lagged Effects Between Intrinsic/Identified Motivation and Emotions

3.3.1 Cross-lagged effect between intrinsic/identified motivation and anxiety. Across the three measurement points, there were weak to non-existing negative correlations between students' self-determined motivation (intrinsic and identified motivation) and anxiety in mathematics (see Table 2). The fit of the cross-lagged models (Models 1a and 1b; see Figures 1a and 1b) was satisfactory for both intrinsic motivation and anxiety (χ^2 (546) = 882.126, p = .0000; CFI = .925, TLI =.919, RMSEA = .042, SRMR =.061) as well as for identified motivation and anxiety (χ^2 (448) = 721.109, p = .0000; CFI = .924, TLI =.916, RMSEA = .042, SRMR = .062). The path relating prior intrinsic and identified motivation (t0) to subsequent anxiety (t1) was not significant. Thus, students' intrinsic and identified motivation in mathematics at the beginning of seventh grade did not predict students' anxiety towards mathematics at the end of seventh grade (controlling for autoregressive effects). However, the path relating prior anxiety (t0) in mathematics to subsequent intrinsic and identified motivation (t1) was significantly negative: the more students experienced anxiety in mathematics at the beginning of seventh grade, the lower students' self-determined motivation was at the end of seventh grade. For t1 to t2, no cross-lagged effects could be detected.

[Please insert Figures 1a and 1b here]

3.3.2 Cross-lagged effect between intrinsic/identified motivation and anger. Across the three measurement points, there were weak to moderate negative correlations between students' intrinsic and identified motivation and anger in mathematics (see Table 2). The fit of the cross-lagged panel models (Models 2a and 2b; see Figures 2a and b) was satisfactory for both intrinsic motivation (χ^2 (361) = 555.446, p = .0000; CFI = .948, TLI =.941, RMSEA = .040, SRMR =.058) and identified motivation (χ^2 (281) = 454.660, p = .0000; CFI = .937, TLI =.927, RMSEA = .043, SRMR =.057). The path relating prior intrinsic and identified motivation (t0) to subsequent anger in mathematics (t1) was not statistically significant. Thus, students' self-determined motivation in mathematics at the beginning of seventh grade did not predict anger in mathematics at the end of seventh grade (controlling for autoregressive effects). However, the path relating prior experienced anger in mathematics (t0) to subsequent intrinsic and identified motivation (t1) was significantly negative. For t1 to t2, no significant reciprocal effects could be detected for intrinsic or identified motivation.

[Please insert Figures 2a and 2b here]

3.3.3 Cross-lagged effect between intrinsic/identified motivation and boredom. Across the three measurement points, there were moderate to strong negative correlations between students' self-determined motivation and boredom in mathematics (see Table 2). The fit of the cross-lagged panel model (Model 3, see Figure 3) was satisfactory for both intrinsic motivation (χ^2 (282) =415.965, p = .0000; CFI = .959, TLI =.953, RMSEA = .037, SRMR =.051) and identified motivation (χ^2 (211) =324.092, p = .0000; CFI = .952, TLI =.943, RMSEA = .040, SRMR =.050). For seventh grade (t0–t1), the direction of relationship between motivation and boredom depended on the form of motivation. Whereas prior intrinsic motivation negatively predicted students' subsequent boredom in mathematics, prior boredom in mathematics negatively predicted students' identified motivation at the end of seventh grade. For eighth grade, no significant reciprocal effects could be detected for intrinsic or identified motivation.

[Please insert Figures 3a and 3b here]

4. Discussion

The main purpose of the present study was to investigate the longitudinal reciprocal interplay between adolescents' self-determined motivation (i.e., intrinsic and identified motivation) and negative emotions (anxiety, anger, and boredom) in mathematics, controlling for prior mathematics achievement and gender. Based on self-determination theory (Deci & Ryan, 2002) and control-value theory (Pekrun, 2006), we assumed that self-determined forms of motivation would be reciprocally associated with various negative emotions typically experienced in relation to the subject area of mathematics (anxiety, anger, and boredom). It was expected that self-determined motivation and anxiety, anger, and boredom would negatively predict each other over time.

Even though the results of the bivariate correlations revealed significant cross-temporal relationships between the variables, the hypothesis that a reciprocal relation would exist between self-determined motivation and negative emotions in mathematics had to be dismissed. Only unidirectional effects between the two self-determined forms of motivation and anger, anxiety, and boredom were found from the beginning to the end of seventh grade (t0–t1). While intrinsic motivation at t0 predicted subsequent boredom at t1, students' emotions at t0 impacted on their intrinsic and identified motivation at t1. This finding is in line with the results of Peixoto et al. (2016), who suggested that negative emotions such as anxiety, anger, and boredom are likely to have a negative impact on students' self-determined motivation. However, against expectations, in the second year of secondary education (t1–t2), no further effects could be identified. This finding is surprising and needs to be explored in future studies as no clear explanation can be provided for this result based on the current data set. However, one tentative explanations for this finding can be given.

We investigated the relation between negative emotions and self-determined motivation, which is likely to be more ambiguous as the association between positive emotions (such as enjoyment) and self-determined motivation (e.g., Hagenauer & Hascher, 2010). The finding might be explained with CVT, which differentiates not only between pleasant and unpleasant emotions but also between activating and deactivating emotions. In the case of anxiety, it cannot be definitively identified as either ‘activating’ or ‘deactivating’ without taking the intensity of the experienced motivation and emotion into account. As with the relationship with achievement, low to moderate anxiety can lead to increased investment and to better learning outcomes (Zeidner, 2014). Another co-occurrence of intrinsic/identified motivation and anxiety might be expected if students significantly value learning due to its perceived importance for their future (occupational) life (indicating high identified motivation) and experience anxiety, in particular when students perceive the situation as uncontrollable and are at risk of not achieving their desired goals (Zeidner, 2014). In such a case, the correlational pattern between identified motivation and anxiety would be positive, whereas for a student with high(er) control beliefs the correlational pattern would be negative (high identified motivation—low anxiety), which might explain the weak correlations. Evidence for the co-occurrence of identified motivation and anxiety can also be drawn from current research that has shown that identified motivation in mathematics is reactive to intervention and can rather easily be triggered through ‘relevance interventions’ (Brisson et al., 2017; Gaspard et al., 2015), whereas a reduction of anxiety potentially needs more time and sometimes even requires a therapeutic approach (e.g., Stallard et al., 2012; Zeidner, 2014). Even though these weak or nearly non-existing correlations between anxiety and intrinsic/identified motivation are unexpected, they are somewhat in line with more recent studies (Ariani, 2017; Gogol, Brunner, Martin, Preckel, & Goetz, 2017). For instance, regarding the lack of correlation between anxiety and intrinsic motivation, Ariani (2017) argued that because anxiety most likely results from students’ desire to perform well and get good grades and to show of one’s ability to others, anxiety is rather related to extrinsic forms of motivation (i.e., introjected and external motivation) than intrinsic motivation. This might be specifically true for subjects that are of high importance for educational trajectories such as mathematics.

The results for anger are similar to the relation between self-determined motivation and anxiety: prior anger negatively predicted later intrinsic/identified motivation but not vice versa, and the effect could only be found in grade 7. Thus, intrinsic and identified motivation does not seem to protect against the experience of anger. It can also be argued that for students who are motivated in a self-determined way, the quality of mathematic instruction is of importance; thus, they are more alert if the instruction does not meet their expectations and goals, which in turn can lead to anger. However, it was also found that the relation between anger and goal orientation is different for mastery and performance goal orientation (Baudoin & Galand, 2017). Thus, future studies on student anger could take the quality instruction as a mediator variable into account, detangle the causes of anger, and identify whether anger is attributed to the action or the result or to the self or others (Pekrun, 2006).

With regards to boredom, the pattern needs further explanation as the effects are different for the two forms of self-determined motivation. The relationship of *intrinsic* motivation with boredom follows the pattern of anxiety and anger with prior boredom predicting intrinsic motivation at the end of seventh grade. Identified motivation, however, was not predicted by boredom but proven as a predictor itself. The question that arises is whether this finding is specific for the emotion of boredom. Boredom is a deactivating emotion with manifold causes and is frequently experienced in school (Pekrun et al., 2014); thus, it can be harmful to intrinsic motivation represented by learning enjoyment. The impact on identified motivation with boredom can be interpreted as a regulation strategy, that is, to cognitively reframe the less interesting mathematic learning into an activity relevant for future individual development (Schutz, Davis, Decuir-Gunby, & Tillman, 2014). Nevertheless, this explanation leaves open why these effects wane for grade 8.

More generally, future research needs to investigate whether there are different patterns of relationships between various forms of motivation and discrete emotions (Baudoin & Galand, 2017). For example, the relationship between motivation and negative emotions may be moderated/mediated by other key motivational constructs such as students' self-concept. Additionally, in order to better understand students' emotional and motivational experiences in the subject area of mathematics, future studies are needed that not only further investigate domain-specific reciprocal relations between the factors but also within a certain domain by taking the situational context into account more thoroughly. Students might experience feelings of anxiety, anger, or boredom with respect to different tasks or topics within the subject area of mathematics, which suggests more complex relations between students' emotions and motivation in mathematics regulated by the situational context. In order to capture these dynamics, experience-sampling studies or alternatively studies using classroom video observations accompanied with stimulated recall interviews might provide a promising way for future research that aims to capture the emotion-motivation link in students' learning experience (e.g., Goetz, Bieg & Hall, 2016; Goetz, Frenzel, Stoeger, & Hall, 2010). Complementary, empirical research regarding the relations between motivation and emotion in other subjects could be helpful to understand domain-specific patterns in mathematics.

4.1 Limitations

The present study was subject to certain limitations. First, the sample only consisted of seventh-grade students who were placed (and remained) in low-achieving mathematics classes after primary school. Thus, the results may not be generalizable to students in other mathematics achievement levels. Second, the sample for this study was limited in size, and therefore the extent to which it is representative of the larger student population is unclear.[7] Third, the present study did not consider potential moderators or mediators in the relationship between self-determined motivation and emotions. There is some controversy regarding the determination of causal processes on the basis of longitudinal structural equation analyses, since a third variable may well exist that can explain the linkage between the variables (Pekrun, Hall, Goetz, & Perry, 2014). Consequently, it would be important in future research to include additional variables in the prediction of the interrelationship between motivation and emotions. Fourth, despite narrowing students' motivation and emotions down to the subject area of mathematics, it has to be considered that even within a given domain, motivational and emotional patterns potentially vary depending on the topic (e.g., geometry, algebra, statistics) as well as the situation (e.g., tests, class, homework). The applied emotion scales consisted of rather global items referring to mathematics classes in general. It is important to further examine students' emotions in various educational settings (Gogol et al., 2017). Future research should therefore refer to specific mathematical domains, topics, tasks, or situations. Finally, cross-lagged models are critically discussed in the methodological literature regarding their power to detect 'causal effects'. According to Hamaker, Kuiper, and Grasman (2015), such models fail to adequately account for within-person effects and have thus been considered inefficient in terms of revealing causal (true) effects. Instead, they propose random intercept cross-lagged panel models (RI-CLPM) that might be more frequently applied in future research as a possible alternative to the traditional way of calculating cross-lagged panel models. However, with regard to the research on emotion and motivation, the used cross-lagged panel models enable the results of our study

[7] Minimum detectable effect sizes were computed using G*Power 3.1. The smallest effect size that can be detected with 80 power at the 0.05 level of statistical significance and the sample size of N = 348 of the present study is 0.13.

to be directly linked to various relevant other studies in the field on emotions and motivation in education that also executed CLPM in its traditional way (e.g. Bakadorova & Raudfelder, 2017; Pekrun et al., 2017).

4.2 Implications

Students' self-determined motivation and their emotions are relevant for various educational outcomes. To facilitate the understanding of how motivation affects subsequent emotions and vice versa, the present study examined the longitudinal relationships between students' self-determined motivation and three frequently experienced negative emotions in mathematics: anxiety, anger, and boredom. Although we could not detect strong interrelations over time, the associations were found within each measurement point on a bivariate level. In general, the relation seemed to be more salient from emotion to motivation compared to the other direction. Thus, in order to support self-determined motivation, it would be crucial to reduce students' experience of negative emotions such as anxiety, anger, and boredom by for instance arousing the controllability of the learning situation, enhancing students interest in mathematics, and highlighting the relevance of mathematics. More generally, we suggest designing intervention programmes in a comprehensive manner that addresses both motivation and emotions. Both motivation and emotion theories should be incorporated in a meaningful way, as each framework offers unique insights and implications for the improvement of students' learning in mathematics in terms of the quality of motivation and the experience of a positive emotional pattern.

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Table 1

Summary of Goodness of Fit for Models—Longitudinal Measurement Invariance (t0, t1, and t2)

	Model	χ^2	df	*p*	RMSEA	CFI	SRMR	$\chi^2\Delta$	*p*	Δ RMSEA	Δ CFI
Intrinsic Motivation											
1	M1 Configural	122.986	72	0.0002	0.045	0.982	0.03				
2	M2 Metric	134.226	80	0.0001	0.044	0.981	0.038	11.24	0.1885	0.001	0.001
3	M3 Scalar	157.407	88	0	0.048	0.976	0.038	23.181	0.0031	-0.004	0.005
Identified Motivation											
1	M1 Configural	72.304	39	0.0009	0.05	0.982	0.032				
2	M2 Metric	78.513	45	0.0015	0.046	0.982	0.042	6.209	0.4002	0.004	0
3	M3 Scalar	110.55	51	0	0.058	0.968	0.044	32.037	0.0000	-0.012	0.014
Anxiety											
1	M1 Configural	266.447	114	0	0.062	0.948	0.049				
2	M2 Metric	296.958	124	0	0.063	0.941	0.059	30.511	0.0007	-0.001	0.007
3	M3 Scalar	348.759	134	0	0.068	0.927	0.061	51.801	0.0000	-0.005	0.014
Anger											
1	M1 Configural	92.963	39	0	0.063	0.97	0.04				
2	M2 Metric	112.455	45	0	0.066	0.962	0.048	19.492	0.0034	-0.003	0.008
3	M3 Scalar	136.559	51	0	0.069	0.952	0.046	24.104	0.0005	-0.003	0.01
Boredom											
1	M1 Configural	44.199	15	0	0.075	0.978	0.033				
2	M2 Metric	46.181	19	0.0005	0.064	0.98	0.037	1.982	0.7391	0.011	-0.002
3	M3 Scalar	53.474	23	0.0003	0.062	0.977	0.037	7.293	0.1212	0.002	0.003

Table 2

Means (M), Standard Errors of Means (SEM), and Inter-Correlations for Students' Intrinsic and Identified Motivation and Emotions

Variables	*M*	*SEM*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Intrinsic motivation t_0	3.03	.05	–														
2. Intrinsic motivation t_1	3.00	.05	.51**	–													
3. Intrinsic motivation t_2	2.91	.05	.30**	.42**	–												
4. Identified motivation t_0	4.04	.04	.41**	.24**	.15**	–											
5. Identified motivation t_1	4.01	.04	.25**	.43**	.20**	.42**	–										
6. Identified motivation t_2	4.05	.04	.15**	.16**	.29**	.30**	.42**										
7. Anxiety t_0	2.13	.05	-.09	-.12*	-.08	-.04	-.14**	-.14*	–								
8. Anxiety t_1	1.79	.04	-.10	-.14*	-.09	.02	-.10	-.07	.37**	–							
9. Anxiety t_2	1.82	.04	.02	-.07	-.03	.00	-.10	-.12*	.28**	.36**	–						
10. Anger t_0	1.93	.05	-.24**	-.25**	-.16**	-.18**	-.20**	-.19**	.71**	.33**	.22**	–					
11. Anger t_1	1.79	.05	-.20**	-.33**	-.22**	-.07	-.25**	-.14**	.30**	.58**	.23**	.40**	–				
12. Anger t_2	1.90	.04	-.07	-.13*	-.24**	-.10	-.13*	-.30**	.20**	.28**	.50**	.28**	.38**	–			
13. Boredom t_0	2.10	.05	-.36**	-.22**	-.14**	-.28**	-.23**	-.21**	.53**	.21**	.18**	.64**	.30**	.18**	–		
14. Boredom t_1	2.06	.05	-.30**	-.37**	-.24**	-.11*	-.21**	-.13*	.26**	.45**	.15**	.36**	.76**	.31**	.37**	–	
15. Boredom t_2	2.12	.05	-.17**	-.26**	-.40**	-.12*	-.19**	-.33**	.15*	.17**	.32**	.20**	.35**	.66**	.19**	.41**	–

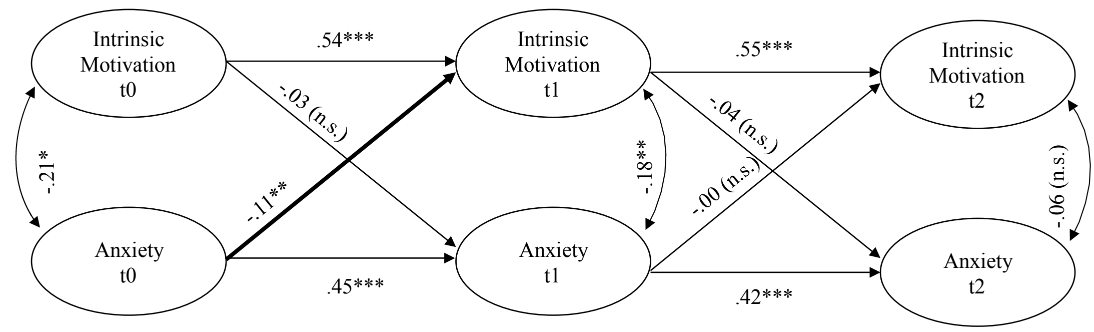
***p* < .01; ****p* < .001; 1–3: min = 1. max = 5; 4–145 min = 1. max = 4.

Note. Data provided for the means, standard errors of means, and correlations have been inputted using multiple imputations in SPSS.

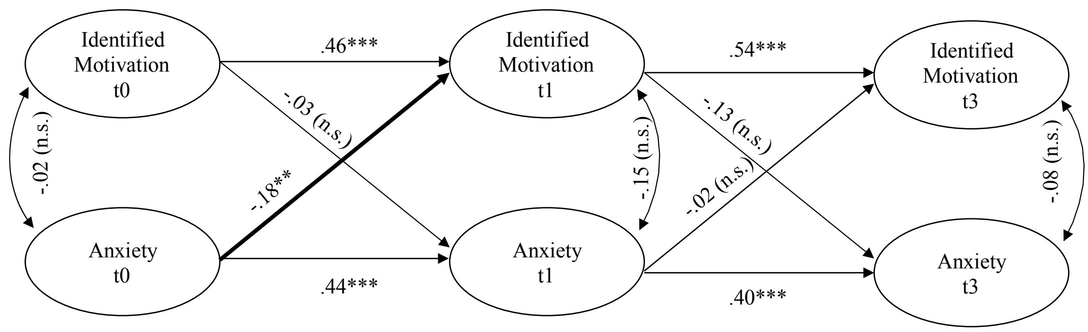
Figures 1a and 1b

Results of the cross-lagged panel analysis between (a) intrinsic motivation and anxiety, and (b) identified motivation and anxiety. $^{+}p < .10$; $*p < .05$; $**p < .01$; $***p < .001$.

(a) Intrinsic Motivation and Anxiety

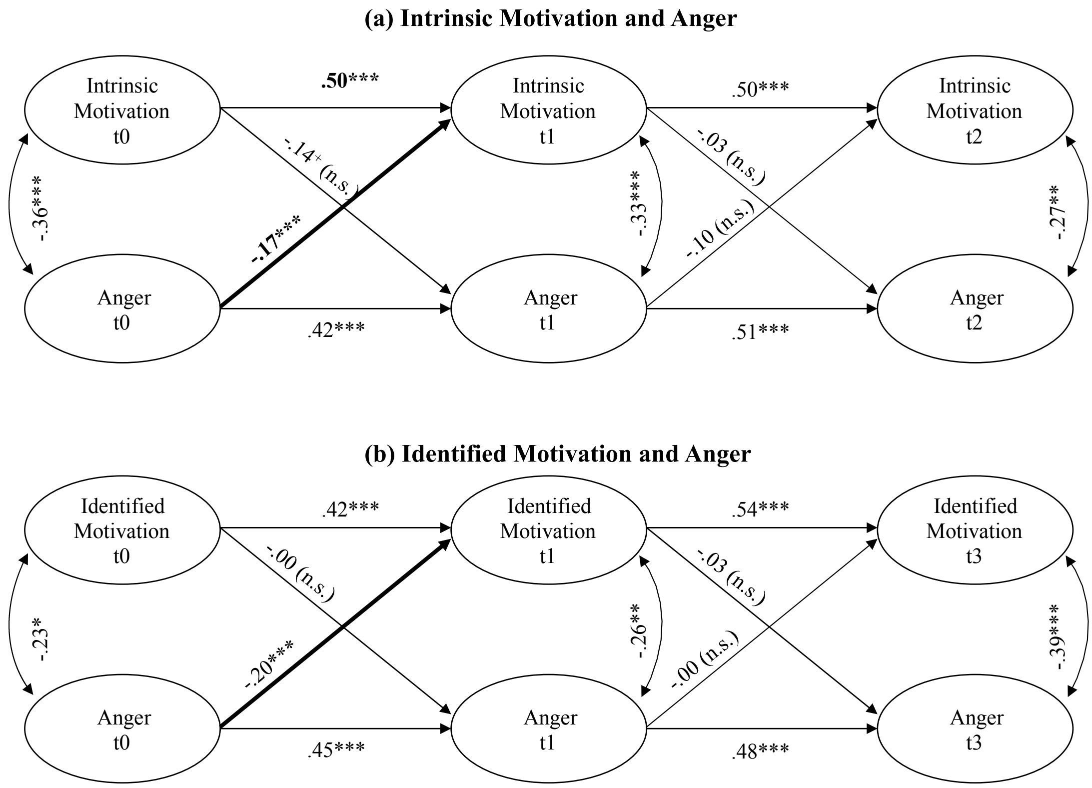


(b) Identified Motivation and Anxiety



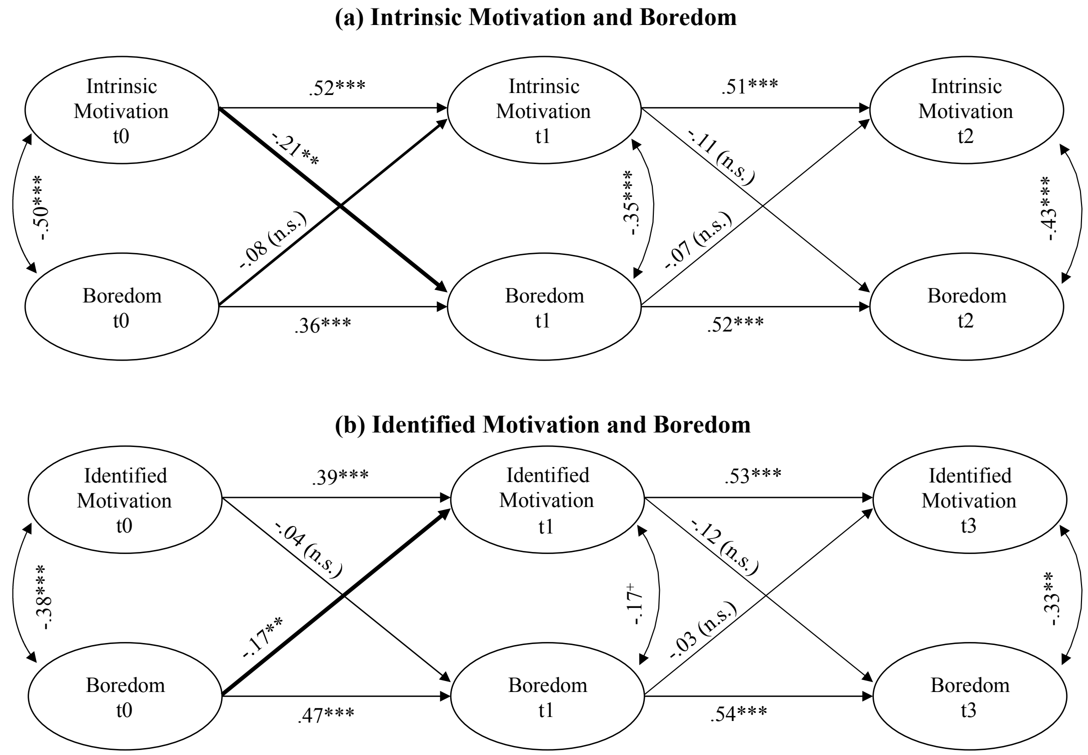
Figures 2a and 2b

Results of the cross-lagged panel analysis between (a) intrinsic motivation and anger, and (b) identified motivation and anger. $^{+}p < .10$; $*p < .05$; $**p < .01$; $***p < .001$



Figures 3a and 3b

Results of the cross-lagged panel analysis between (a) intrinsic motivation and boredom, and (b) identified motivation and boredom. $^{+}p < .10$; $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$



Highlights

- Relations between intrinsic/identified motivation and negative emotions in mathematics were examined.
- Students' emotions and motivation in lower secondary education were linked over time.
- Anxiety and anger negatively predicted intrinsic and identified motivation in grade 7.
- Boredom negatively predicted identified motivation, whereas intrinsic motivation negatively predicted boredom in grade 7.