European Journal of Psychology of Education
https://doi.org/10.1007/s10212-020-00527-9

Emotional profiles regarding maths among primary school children – A two-year longitudinal study

Lourdes Mata[1] · Vera Monteiro[1] · Francisco Peixoto[1] · Natalie Nóbrega Santos[1] · Cristina Sanches[1] · Marta Gomes[1]

Received: 12 December 2019 / Revised: 23 December 2020 / Accepted: 28 December 2020
Published online: 18 March 2021

Abstract
Learning maths is challenging for many primary school students, and teachers must understand students' learning and emotional processes specific to learning maths. The current research, grounded in control-value theory, focused on achievement emotions regarding maths. Primary school students (N = 71) were studied with the primary objective of examining the longitudinal trajectories of achievement emotions of third graders over two years. The Portuguese Achievement Emotions Questionnaire for Elementary Students was administered biannually to assess enjoyment, anxiety, and boredom regarding maths. The results indicate that enjoyment decreased and boredom increased over time, revealing three emotional profiles: positive, negative and moderate. The positive profile showed the highest scores in maths achievement. Profile membership was moderately stable and became increasingly stable and structured. In examining the complexity of students' emotional profiles and processes, the importance of understanding them to enhance educational support, development, and learning was highlighted.

Keywords Achievement emotions · Academic achievement · Mathematics · Emotional profile · Cluster analysis

Introduction

Students' emotional experiences in the school environment play a central role in their development, adaptation and present/future success (Pekrun 2014a). Children's developmental characteristics and learning contexts determine the variety and strength of emotions experienced (Lichtenfeld, Pekrun, Stupnisky, Reiss, and Murayama 2012; Meyer and Turner 2006; Schutz, Hong, Cross, and Osborn 2006). However, few longitudinal studies have been developed and studies of primary school children's emotions are scarce. Therefore, the current research examined achievement emotions among primary school children in a longitudinal study with two complementary approaches: person-centred and variable-centred.

Emotions are multifaceted phenomena involving affective, cognitive, physiological, motivational and expressive processes (Pekrun 2014a). The different kinds of emotions relevant for students' learning are called achievement emotions (Pekrun 2014b) and emerge from activities

where success and/or failure can be obtained (e.g., enjoyment and pride when learning successfully; shame, boredom, and anxiety when failing to learn).

Control value theory (CVT) (Pekrun 2006) states that achievement emotions affect students' behaviour, performance and academic results because they activate subsequent actions and influence cognitive resources, learning strategies and engagement patterns in relation to learning situations (Pekrun 2006, 2013, 2014b).

Valence and degree of activation are posited by CVT as the most important dimensions to differentiate emotions and to understand their effects (Pekrun et al. 2007). Positive activating emotions (enjoyment, pride and hope) trigger cognitive resources, help focus attention, and strengthen interest and intrinsic motivation, facilitating learning and academic achievement (Pekrun 2006, 2009; Pekrun, Goetz, Frenzel, Barchfeld, and Perry 2011). Positive deactivating emotions (relief, contentment and relaxation) can weaken attention and effort in the moment but later support reengagement in learning activities and can have positive effects on academic performance (Pekrun et al. 2011). Negative deactivating emotions (e.g., boredom, hopelessness) can induce a decrease in cognitive resources and reduce physiological and cognitive activation, resulting in shallow information-processing, and leading to a decline in intrinsic and extrinsic motivation (Pekrun, Goetz, Daniels, Stupnisky, and Perry 2010; Pekrun and Perry 2014).

Interestingly, negative activating emotions (anxiety, anger, shame and frustration) can have various influences. For example, among more resilient students, anxiety can induce the motivation to study and promote engagement, (Pekrun 2014a; Pekrun et al. 2011); however, in some students, anxiety can have deleterious effects, being negatively related to interest, motivation, effort, self-regulation, use of strategy elaboration and achievement (Ahmed, van der Werf, Kuyper, and Minnaert 2013; Artino, La Rochelle, and Durning 2010; Pekrun et al. 2011), contributing to underachievement and low levels of performance.

Moreover, CVT states that the relationship between emotions and achievement is reciprocal and bidirectional (Pekrun 2006, 2014a). Recent research has confirmed these reciprocal effects over time: enjoyment and pride positively predicted achievement, and achievement positively predicted enjoyment and pride; anger, anxiety, shame, boredom and hopelessness negatively predicted achievement, and achievement negatively predicted these emotions (Pekrun, Lichtenfeld, Marsh, Murayama, and Goetz 2017).

Achievement emotions throughout the school years

Developmental characteristics (cognitive, linguistic, interpersonal and social) are important and influence the understanding and expression of all emotions, particularly achievement emotions (Bower 1992; Pekrun 2014a). Acculturation processes are essential to children's emotional development and responses when facing different situations of success and failure (Bower 1992). In the school context, peers and teachers are important elements of emotional experiences; they help children learn emotional regulation strategies (Frenzel, Pekrun, and Goetz 2007; Goetz, Pekrun, Hall, and Haag 2006; Linnenbrink-Garcia, Patall, and Pekrun 2016). Moreover, as students develop, they face new challenges, demands and goals, and experience new interpersonal relationships with teachers and colleagues (Daniels, et al. 2009; Tyson, Linnenbrink-Garcia, and Hill 2009). These changes in contexts, relationships and experiences may affect the diversity, intensity and type of emotions a student experiences (Goetz et al. 2006; Lichtenfeld et al. 2012; Meyer and Turner 2006; Schutz et al. 2006).

An interest in studying the different achievement emotions throughout schooling has emerged in recent years (Pekrun and Perry 2014). Most studies have used either cross-sectional (e.g., Monteiro et al. 2017; Raccanello, Brondino, and Bernardi 2013) or longitudinal methodologies (Ahmed et al. 2013; Mata et al. 2017; Pinxten, Marsh, Fraine, Noortgate, and Van Damme 2014; Wang, Chow, Hofkens, and Salmela-Aro 2015), focusing on students from fourth through eleventh grades. The findings of cross-sectional studies are in general agreement, revealing higher intensity of positive emotions (e.g., enjoyment, pride, and relief) for younger students and higher intensity of negative emotions (e.g., anger, boredom) for older students, in the domain both of mathematics (Monteiro et al. 2017; Raccanello et al. 2013) and language (Raccanello et al. 2013).

Longitudinal studies have investigated the development of achievement emotions among middle and high school students over one (Ahmed et al. 2013) or three years (Mata et al. 2017; Pinxten et al. 2014; Wang et al. 2015). All these studies found a decline in enjoyment as students got older, both towards school in general (Wang et al. 2015) and specifically in the domain of mathematics (Ahmed et al. 2013; Mata et al. 2017; Pinxten et al. 2014). Ahmed et al. (2013) and Mata et al. (2017) also found an increase in boredom with mathematics as students got older. Studies focusing on anxiety, on the other hand, reported mixed results: while Wang et al. (2015) observed that anxiety about school increased as students got older, Ahmed et al. (2013) found that anxiety about mathematics remained relatively stable over time, and Mata et al (2017) found that anxiety in the domain of mathematics decreased over time, both in the classroom and in test situations.

A four-year longitudinal study by Vierhaus, Lohaus, and Wild (2016) examining the trajectories of boredom and anxiety was the only one including participants who were in the beginning of early primary school (second graders). They found that enjoyment during classroom lessons was high and relatively stable from the second to fifth grades and then consistently decreased from the fifth to the seventh grade. On the other hand, boredom during lessons was low in the second grade, showed a continuous increase afterwards, and intensified substantially between the fifth and seventh grade. Thus, it may be inferred that there are specific periods of schooling where substantial emotional changes occur (Vierhaus et al. 2016).

In summary, research shows that positive and negative emotions follow different trajectories over time, but it also highlights the need to consider students' stage of schooling and the duration of the longitudinal period, to have an in-depth perspective on students' emotional changes in achievement situations over time. Additionally, results regarding anxiety have been inconsistent and complex, so the nature of changes in anxiety over time still needs to be clarified.

Person-centred approaches to the study of emotions

Usually, research on emotions utilizes methods classified as variable-centred approaches (Jarrell, Harley, and Lajoie 2016; Jarrell, Harley, Lajoie, and Naismith 2017; Raccanello, Rob, and Burro 2018). These approaches have the main goal of identifying and characterizing relationships between variables, and data obtained provide a general set of parameters to be interpreted (Howard and Hoffman 2017). Since data are also analysed and presented together, this approach provides a low level of specificity.

However, in more recent studies of emotions, complementary approaches have been used, and researchers are increasingly using a person-centred approach (e.g., Raccanello et al. 2018).

This approach makes the student the focus of the analysis, allowing insight into how psychological constructs are manifested within individuals, thus facilitating the identification of emotional profiles, as researchers are able to examine the intensity of each emotion (Jarrell et al. 2016). Although usually termed 'person-centred', this approach allows the researcher to specify the dynamics of subpopulations in a sample based on a set of similar features or variables (Howard and Hoffman 2017) and to compare differences between groups.

Still, studies using the person-centred approach to analyse students' emotions are few and fragmented, both in contexts and ages (university, secondary, primary students). Among university students, Jarrell et al. (2016, 2017), in a computer-based learning situation, and Robinson et al. (2017), in a classroom situation, identified different emotional profiles that included one positive profile (high levels of positive activated and positive deactivated emotions), one negative profile (high levels of negative deactivated emotion and the highest levels of negative activated emotion), and a low overall profile (moderate-low levels of all emotional variables). Robinson et al. (2017) also found a deactivated profile (moderate-high levels of positive deactivated and negative deactivated emotions). These emotional profiles were significant predictors of subsequent behavioural engagement, disengagement, achievement, perceived competence, and value appraisals, those students with the positive profiles being the ones presenting the most adaptive pattern.

Furthermore, regarding younger students, research using a person-centred approach is scarce (e.g., Ganotice, Datu, and King 2016; Raccanello et al. 2018). Ganotice et al.'s (2016) research with secondary school students examined whether it was possible to identify naturally occurring patterns of achievement emotions regarding maths classes and maths achievement (enjoyment, hope, pride, anger, anxiety, shame, hopelessness and boredom). The results identified four distinct emotional profiles, revealing that students felt complex patterns of achievement emotions: adaptive shame (the largest group with high levels of positive emotions and low levels of negative emotions except for shame, which was higher compared to the other profiles); moderate (moderate levels of positive and negative emotions); maladaptive (low levels of positive and high levels of negative emotions); and adaptive (high levels of positive emotions and low levels of negative emotions).

The results further indicated that those with adaptive shame and adaptive profiles had the highest levels of autonomous and controlled motivation, the highest scores on most of the engagement outcomes (i.e., valuing school, emotions regarding school), and the highest maths grades. Those with a moderate profile had lower levels of autonomous and controlled motivation and lower maths grades compared to all other profiles. Those with maladaptive profiles had the lowest levels of controlled motivation, lower maths grades, and had the highest scores on intention to leave school. Therefore, students with different profiles exhibited not only distinct motivational outcomes, but also different levels of achievement (Ganotice et al. 2016).

The study by Raccanello et al. (2018) included fourth-, seventh- and eleventh-graders. The authors used a qualitative mode of data collection (i.e., free responses) to tap spontaneous emotions referred to by students (enjoyment, hope, relief, relaxation, anxiety, anger, shame, boredom and sadness) in the domains of literacy and maths. Three different profiles were identified: happy (higher levels of enjoyment, followed by boredom); relaxed (higher levels of relaxation and enjoyment); and depressed (prevalence of sadness and lower levels of anxiety and enjoyment), which was the least prevalent profile. Profile membership was independent of grade, domain (school subject) and gender.

Despite the diversity of contexts (e.g., computer-based learning, classroom), methods (e.g., questionnaire, interview) and participants' ages (e.g., adults, adolescents, children), all the aforementioned studies using a person-centred approach were able to identify complex emotional profiles. The profiles identified in these person-centred studies contained not just one, but a specific combination of emotions experienced with diverse levels of intensity. Furthermore, despite all the different emotions analysed, some similarities can be found among these identified profiles: positive emotions were the most frequent overall and always emerged in at least one type of profile (e.g., happy, positive emotion, adaptive shame); a negative emotions profile was always identified (e.g., depressed, negative, maladaptive); and the other profiles were usually characterized as being low or moderate in terms of emotional expression/intensity/score (e.g., moderate, moderate-low, low). Notwithstanding, the similarities, each context introduced unique outcomes, showing that the person-oriented approach can bring new insights to our current knowledge about students' emotional experiences and their potential effects.

Current research

The aforementioned studies provided some empirical information about the development of achievement emotions in school-aged students, highlighting that emotions are subject-specific. However, some important aspects still need deeper analysis. Firstly, few longitudinal studies have been developed; secondly, the study of primary school children's achievement emotions is underrepresented, not only in longitudinal studies but also in person-centred approaches; thirdly, few studies have simultaneously used variable- and person-centred approaches; fourthly, as far as we know, there has been no research using a person-centred approach in a longitudinal study with primary school children.

Therefore, the current research was developed with primary school children and only analysed their emotions regarding maths because emotions are domain-specific (e.g., Goetz, Frenzel, Pekrun, Hall, and Ludtke 2007) and maths is an important field of knowledge for our everyday lives, independent of career paths (OECD 2014). This study examined three different emotions (enjoyment, anxiety and boredom), which are frequently experienced in achievement settings (Pekrun, Goetz, Frenzel, Barchfeld and Perry 2011; Pekrun et al. 2002).

This research had three main aims:

1. To examine the longitudinal trajectories of achievement emotions regarding maths over a two-year period starting in third grade. A decrease in enjoyment and an increase in boredom related to maths over time was expected. There were no expectations regarding anxiety, as previous findings are not consistent (e.g., Ahmed et al. 2013; Monteiro et al. 2017; Raccanello et al. 2013).
2. To use a person-centred approach to examine how achievement was associated with these profiles. It was expected to identify different profiles with specific emotional constellations similar to what was found both with older students (e.g., Ganotice et al. 2016; Raccanello et al. 2018) and younger children (e.g., Raccanello et al. 2018). Higher levels of achievement in maths were expected for those students with more positive emotional profiles.
3. The third aim was to analyse the stability and variability of the identified emotional profiles over a two-year period. No expectations were anticipated regarding this aim, as

there has not yet been any study on young children's emotional profiles using a longitudinal perspective.

Material and methods

Participants

Participants were 82 Portuguese students from five classes in four private schools in Lisbon. Data presented in this study were part of a broader longitudinal mixed methods research project intended to explore the effects of teachers' assessment on students' achievement, motivation, and emotions. For the purpose of this project, it was necessary to ensure that the teacher remained with the same class for two years, a prerequisite that is hard to fulfil in public schools, where teachers and students frequently change each school year. Therefore, the option was to conduct the study in private schools to ensure continuity and avoid, as much as possible, experimental mortality. For this study, we analysed quantitative data from two assessments per year during the students' third- and fourth-grade years (2016–2018). At the first time point (in January of third grade, hereinafter G3T1) and the second time point (in June of third grade, G3T2), there were 82 participants (56% boys, 44% girls; $M_{age} = 8.07$, $SD = 0.34$). At the third time point (in January of fourth grade, G4T3), four participants had left the school, and at the fourth time point (in June of fourth grade, G4T4), seven participants were not present. Those 11 students were excluded from the longitudinal study because of incomplete data. Therefore, a total of 71 students (57.7% boys, 42.3% girls; $M_{age} = 8.07$, SD = 0.26) were eligible for data analysis.

Measures

To assess achievement emotions regarding maths, we used the Portuguese version of the Lichtenfeld et al. (2012) Achievement Emotions Questionnaire for Elementary Students (AEQ-ES-P) by Sanches et al. (2020). For the validation of the Portuguese version, the usual translation and back-translation procedures were used, with the reformulation of some items to make their sense clear in Portuguese. Globally the items and structure of the original instrument were maintained. This questionnaire is composed of 28 items that measure three achievement emotions: enjoyment (9 items), boredom (7 items), and anxiety (12 items) regarding maths. These were analysed in three different academic settings: while attending classes (e.g., 'I find maths classes so boring that I would rather do something else'), while doing homework (e.g., 'I enjoy maths homework so much that I don't want to stop doing it'), and while taking tests (e.g., 'I get very nervous during maths tests'). Items were answered on a five-point Likert scale (1 = not at all; 5 = very much), where each answer had graphical representations of faces that showed various levels of emotional intensity. There were two different types of questionnaire: one for male students (with boys' faces) and another for female students (with girls' faces). The instrument showed good reliability in the present study at all the time points ($\alpha \geq 0.88$, see Table 1). Previous studies had demonstrated its temporal stability ($r \geq 0.58$) and its invariance across gender and grades (Sanches et al. 2020).

We used two different information resources from pupils' assessments to measure their achievement:

Table 1 Descriptive statistics of all variables related to students' emotions and performance in maths

Time point	Variable	*M*	SD	*Sk*	*Ku*	α
G3T1: 3rd Grade January	Enjoyment	3.51	0.98	-0.4	-0.5	.93
	Anxiety	2.32	0.74	0.5	0.7	.88
	Boredom	2.08	1.06	1.0	0.3	.95
	Test scores	0.03	0.98	-0.1	-0.9	-[a]
	Grade	0.00	0.85	-0.4	-0.9	.90
G3T2: 3rd Grade June	Enjoyment	3.40	0.97	-0.4	-0.6	.93
	Anxiety	2.19	0.79	0.9	0.6	.90
	Boredom	2.05	0.89	1.1	1.2	.91
	Test scores	0.04	0.95	-0.2	-0.2	- [a]
	Grade	0.01	0.87	-0.6	-0.6	.93
G4T3: 4th Grade January	Enjoyment	3.25	0.87	-0.1	-0.5	.90
	Anxiety	2.11	0.69	0.5	-0.5	.90
	Boredom	2.14	0.90	0.6	-0.3	.92
	Test scores	0.05	0.98	-0.4	-0.7	- [a]
	Grade	0.08	0.85	-0.8	-0.2	.93
G4T4: 4th Grade June	Enjoyment	2.93	0.91	0.2	-0.1	.94
	Anxiety	2.26	0.80	0.4	-0.6	.92
	Boredom	2.46	1.00	0.6	-0.1	.95
	Test scores	0.10	0.95	-0.5	-0.4	- [a]
	Grade	0.08	0.87	-0.5	0.0	.96

Note: sk = skewness; ku = kurtosis; [a] one item measure

1) Grade reports. There are three terms in a school year. In the first cycle of basic education, student assessment includes an internal summative assessment at the end of every term, and this assessment is the special responsibility of the class form teacher. This is an overall assessment of academic behaviour and students' learning in each of the basic maths competence requirements for that school grade: numbers and operations, geometry, problem-solving and data organization. The purpose of this form of assessment is classification and certification, as specified through qualitative grades: *very good, good, satisfactory* and *unsatisfactory*. To measure achievement in this research, this qualitative assessment of all participants was collected in the second (G3T1 and G4T3) and third terms (G3T2 and G4T4) of the school year when students were in grades 3 and 4. This grade reports measure presented good reliability at all the time points ($\alpha \geq = 0.90$, see Table 1).
2) Test scores. Before the end of each term, teachers usually employ a final test as a tool to obtain information about the successful fulfilment of the learning objectives for each term. These tests were unique and different for each class because they were designed individually by each teacher. They included several maths tasks for students to complete. Students received qualitative grade marks according to their performance: 1 = unsatisfactory (less than 50% of the tasks were correct), 2 = satisfactory (between 50 and 69% correct); 3 = good (between 70 and 89% correct) and 4 = very good (more than 90% correct).. These students' qualitative grades in mathematics were also collected for our research in the second and third terms of the school year when students were in grades 3 and 4.

Students' gender (coded 0 for male and 1 for female) and numeric reasoning served as control variables and were included as covariates in the analyses. Numeric reasoning (NR) was assessed through a subscale of the Portuguese Scale of Cognitive Level (Escala Colectiva de

Nível Intelectual, ECNI) developed by Miranda (1983). This subscale consists of eight items with numerical series that students must complete (one point per correct answer). The subscale presents adequate levels of internal consistency (KR20 = 0.76).

Data collection procedures

The students and their parents were informed of the purpose of the study and provided informed consent for their participation. Participation was voluntary and confidentiality was guaranteed. The questionnaires were administered when the students were in the third and fourth grades, twice per academic year, once in January and once in June. Students were taught to use the five-point response scale using three sample items unrelated to achievement emotions. A trained researcher read each item aloud to mitigate participants' individual literacy difficulties. The questionnaires, which took approximately 15–20 min to complete, were administered to small groups (four–five students) during a class period. The grade reports and the test results in the domain of maths were subsequently collected from the teachers' records. At the primary level, grades in the Portuguese educational system are qualitative; in the schools participating in this study, a four-point scale (1 = unsatisfactory, 2 = satisfactory, 3 = good, and 4 = very good) or a five-point scale (1 = unsatisfactory, 2 = satisfactory, 3 = good, 4 = very good, and 5 = excellent) was used. As teachers were different and the scales they used to classify students were not all the same, all maths grades from the teachers' reports and students' tests were converted to a z-scored scale for each class, which gave us a context-free evaluation that captures the individual performance of the students relative to their class mean and standard deviation (Cross 1995; Stake 2002).

Data analysis procedures

Variable-centred analyses

To examine the changes in achievement emotions over time, analyses of variance (ANOVA) for repeated measures were conducted. Greenhouse–Geisser correction was used when the sphericity assumption had been violated. Values for skewness and kurtosis for all variables (Table 1) were within the acceptable limits for the planned analyses (Hair et al. 2014).

Structural equation modelling (SEM) was used to evaluate the longitudinal reciprocal effects between emotions and achievement. Since there was substantial correlation between the emotion variables, we used separate discrete emotion models to examine the links between emotion and achievement: one for enjoyment, one for anxiety and one for boredom. For each emotion, we estimated two models: one for grades and one for test scores as the achievement measure. All the models represent a cross-lagged format, as represented in Fig. 1, where emotions are posited to influence achievement, and achievement, in turn, to influence emotion. Numeric reasoning and gender were included as covariates in the analysis. All variables were modelled as manifest variables and all reported models were tested with correlations among latent constructs measured at the same wave. The models were tested using Mplus (v. 8), harnessing the complex survey data option with the robust maximum likelihood (MLR) estimator to compute standard errors and chi-squared test of model fit, taking into account the non-independence of observations due to cluster sampling, with students clustered in classes (Muthén and Muthén 1998–2018). To evaluate model fit, we used the following set of goodness-of-fit indices and cut-off criteria for acceptable fit: root mean square error of

approximation (RMSEA < 0.06 to 0.080), comparative fit index (CFI > 0.95), and Tucker–Lewis index (TLI > 0.95) (Schreiber et al., 2006).

Person-centred analyses

To complement this analysis, we also used a person-centred approach to focus on each individual student's achievement emotions and their dynamic interplay (Corpus and Wormington 2014).

A cluster analysis was conducted to generate homogeneous profiles based on the different combinations of achievement emotions. I-states as objects analysis (ISOA) were also used, as suggested by Bergman, Nurmi, and von Eye (2012), to capture the natural occurrences of these combinations at all time points. ISOA treats each student's data from a single time point as a discrete unit, and the use of ISOA is only appropriate to study short-term emotional changes over the course of one school year, since it is unclear whether posterior changes reflected differences in the emotional profiles or differences in the cluster solutions (Bergman et al. 2012). Therefore, data from the four assessments were separated into 284 i-states. Specifically, the four time points data for each participant were temporarily separated and treated as unrelated data points (i-states). Once the data were clustered, the i-states were reorganized to represent individual students across time.

The i-states data were used in a two-step analysis using a combination of hierarchical and non-hierarchical clustering methods, as recommended by Hair et al. (2014). The input variables (enjoyment, boredom and anxiety) were examined for substantial multicollinearity: the variance inflation factor (VIF) ratio was 3.4, and tolerance values were greater than 0.30, so no serious multicollinearity issues were found (Hair et al. 2014). Additionally, after removing three univariate outliers (with values more than 3 SD below or above the mean), the hierarchical method Ward's linkage (with squared Euclidean distance as a measure of similarity) was used as the first step to identify and compare several possible cluster solutions (Hair et al. 2014). The optimal cluster solution was chosen based on its parsimony, distinctness and the percent variance calculated for each of the constituting achievement emotions. As a second step, a non-hierarchical k-means clustering procedure was used to fine-tune these cluster solutions (Hair et al. 2014).

Since cluster algorithms are influenced by the order of cases in the data, to assess the stability of the cluster solutions, multiple combinations of random sorts of the data were used, followed by k-means cluster analysis and the similarity of the resulting clustering studied.

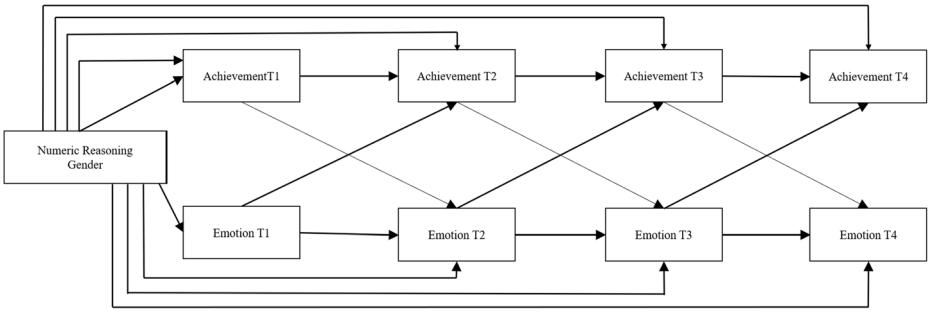

Fig. 1 Basic structure of cross-lagged reciprocal effects model. Numeric reasoning and gender were included as individual covariates in the analysis

Furthermore, a double-split cross-validation procedure was used to ensure the stability and replicability of the cluster solution (Hair et al. 2014). The sample was randomly split into two groups, and the full two-step procedure was applied to each half. Cohen's kappa was used to compare the cluster solutions of each half with the original cluster. Based on previous research, results were considered acceptable when the averages of the two resulting kappas were greater than 0.60 (Hayenga and Corpus 2010). A second and third validation procedure were performed to verify that the cluster solutions were appropriate for data from both the third and fourth grades, and from both boys and girls. Instead of splitting the i-states randomly, data from students' grade and gender were used to generate the two halves and after this we continued with the aforementioned validation procedure.

After cluster validation — and once the final solution was chosen — the i-states were reorganized to represent cases of individual participants, each case with repeated measures of the emotional cluster (i.e., each participant with four cluster memberships, one for each time point). Then multivariate analysis of variance (MANOVA) was then used to explore whether the students' profile membership was related to their maths achievement (both test scores and grade reports as correlated dependent variables). Roy's largest root test was used when the assumptions regarding validity of the ANOVA procedures were met (independence, normality, and equality variance–covariance matrices), in this specific case, this test provides advantages related to the power of the test when compared to other ANOVA test options available in SPSS (Hair, Black, Babin, and Anderson 2014) — and Pillai's trace criterion was used if these same assumptions were not met. Finally, chi-squared tests were used to examine the stability and change in profile membership over time. We used partial eta squared and Cramér's V as measures of effect size, interpreted as suggested by Maroco (2014): small ≤ 0.05 medium > 0.05 and large > 0.25 for partial eta squared; and small ≥ 0.05, medium ≥ 0.15, and large ≥ 0.25 for Cramér's V.

Results

Descriptive analyses

Descriptive statistics and correlation analyses at all time points are presented in Tables 1 and 2. Results showed that, at all time points, enjoyment levels were above the midpoint of the scale, while anxiety and boredom levels were below the midpoint of the scale, indicating a predominance of positive over negative emotions. Furthermore, enjoyment was negatively related to anxiety and boredom, and anxiety was positively related to boredom. Correlation coefficients indicated that the temporal stability of the variables from G3T1 to G4T4 was relatively high ($r > 0.50$ for enjoyment, $r > 0.59$ for anxiety, and $r > 0.37$ for boredom). Moreover, anxiety was negatively related to achievement (both test scores and grade reports) at all time points, except in G4T4; on the other hand, enjoyment and boredom were related to achievement (both test scores and grade reports) only at G4T4. Finally, boredom showed a negative relationship with achievement through students' grade reports at G3T1.

In Table 2 we show that students' numeric reasoning abilities were associated with test score results (at G3T1, G3T3 and G3T4) and with teachers' summative assessment (at all time points). We also observed a significant correlation between numeric reasoning and enjoyment at G3T4.

Table 2 Intercorrelations among students' measured emotion variables regarding maths

Time point	Variable	NR	1	2	3	4	5	6	7	8	9	10	11	12
G3T1:	1 Enjoyment	.11	1											
3rd Grade – January	2 Anxiety	-.01	-.45**	1										
	3 Boredom	-.10	-.84**	.51**	1									
	Test scores	.29**	.20	-.23*	-.20									
	Grade	.42**	.20	-.40**	-.26*									
G3T2:	4 Enjoyment	.18	.66**	-.40**	-.58**	1								
3rd Grade – June	5 Anxiety	-.04	-.29*	.59**	.25*	-.46**	1							
	6 Boredom	-.07	-.56**	.41**	.54**	-.83**	.54**	1						
	Test scores	.19	.25*	-.37**	-.34**	.20	-.34**	-.18						
	Grade	.33**	.28*	-.47**	-.35**	.25*	-.42**	-.22						
G4T3:	7 Enjoyment	.13	.48**	-.30*	-.32**	.50**	-.26*	-.38**	1					
4th Grade – January	8 Anxiety	-.15	-.15	.44**	.08	-.30*	.70**	.27*	-.40**	1				
	9 Boredom	-.09	-.33**	.26*	.31**	-.36**	.23	.37**	-.76**	.37**	1			
	Test scores	.28*	.32**	-.31**	-.33**	.22	-.35**	-.20	.18	-.25*	-.14			
	Grade	.39**	.21	-.32**	-.21	.08	-.28*	-.05	.13	-.23*	-.04			
G4T4:	10 Enjoyment	.27*	.59**	-.42**	-.44**	.50**	-.19	-.32**	.66**	-.25*	-.53**	1		
4th Grade – June	11 Anxiety	-.18	-.13	.41**	.04	-.27*	.56**	.18	-.40**	.69**	.27*	-.29*	1	
	12 Boredom	-.08	-.49**	.41**	.44**	-.40**	.25*	.41**	-.57**	.28*	.59**	-.75**	.27*	1
	Test scores	.45**	.24	-.33**	-.26*	.18	-.32**	-.16	.30*	-.37**	-.29*	.45**	-.20	-.34**
	Grade	.40**	.29*	-.43**	-.34**	.23	-.34**	-.17	.20	-.27*	-.13	.43**	-.17	-.28*

* $p < .050$; ** $p < .001$

NR—numeric reasoning

Variable-centred analyses

Figure 2 compares enjoyment, anxiety, and boredom levels, as well as test scores and grade reports, between time points. The repeated measures ANOVA on emotions revealed a significant main effect of time for enjoyment, $F(2.68,187.42) = 11.92$, $p < 0.001$, $\eta_p^2 = 0.15$, and for boredom $F(2.68,187.63) = 5.02$, $p = 0.003$, $\eta_p^2 = 0.07$. Furthermore, enjoyment levels remained relatively stable from G3T1 to G4T2, with a significant decrease, medium size effect, at G4T3, $F(1,70) = 4.19$, $p = 0.044$, $\eta_p^2 = 0.06$, and again with a large effect from G4T3 to G4T4, $F(1,70) = 32.91$, $p < 0.001$, $\eta_p^2 = 0.32$. The pattern was similar for boys and girls.

The results for anxiety revealed no main effect of time, $F(2.59, 181.18) = 2.21$, $p = 0.097$, $\eta_p^2 = 0.03$. Nevertheless, the contrast analysis showed a significant increase, with a medium size effect, from G4T3 to G4T4, $F(1,70) = 4.33$, $p = 0.041$, $\eta_p^2 = 0.06$. The results for boredom revealed a slight increase from G3T1 to G4T3, which was not significant, and a significant difference between G4T3 and G4T4, $F(1,70) = 15.68$, $p < 0.001$, $\eta_p^2 = 0.18$) with a medium size effect. The pattern was similar for boys and girls.

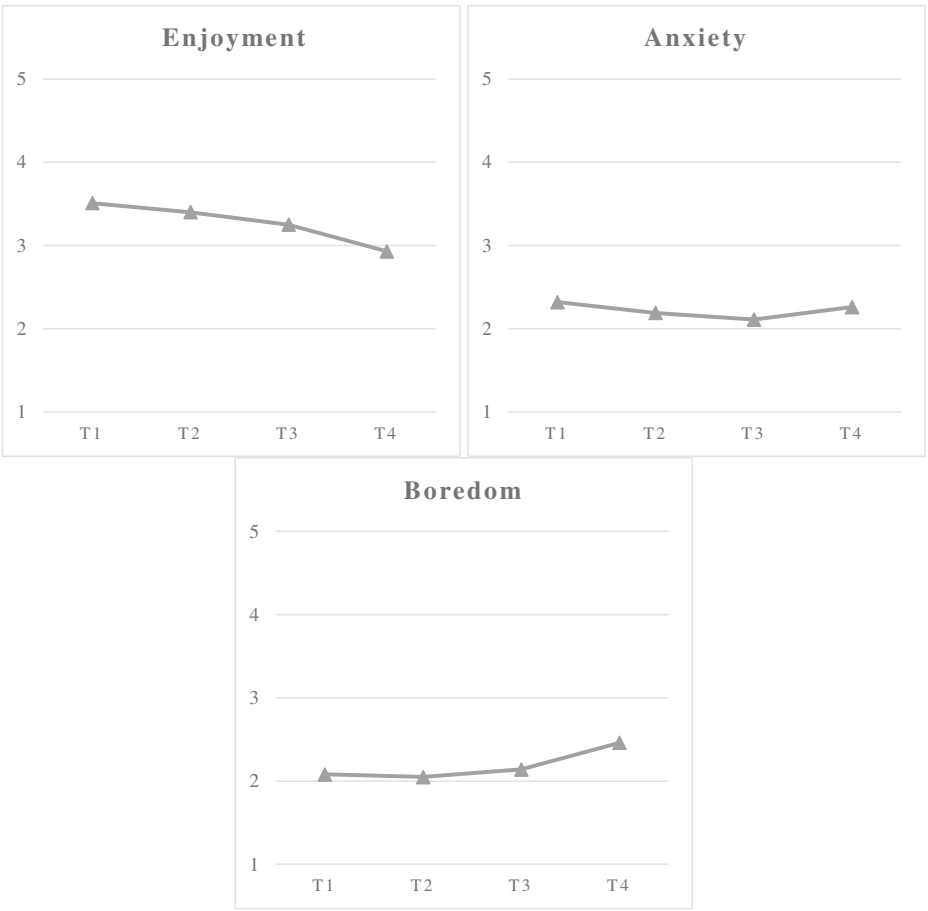

Fig. 2 Changes in achievement emotions from G3T1 to G4T4

To test the longitudinal causal relationship between the variables at stake, three models were tested for test scores and grade reports. The models tested for grade reports did not fit the data accurately (see Table 3). In contrast, models for test scores did present an acceptable fit, especially after removing non-significant covariances, covariate effects, and correlations among latent constructs measured in the same wave (Table 3, parsimonious models). Final models are presented in Fig. 3.

In all the models presented in Fig. 3, path coefficients between moderate (> 0.30) and high (> 0.50) stability were observed for achievement and for emotions. Although not all the paths were significant, the models provided some support for the reciprocal effect model. Maths enjoyment, boredom and anxiety at time points one and three predicted later test scores at time points two and four, and maths achievement at time point two – influenced subsequent maths enjoyment, boredom, and anxiety at time point three. The presence of non-significant paths despite their similar estimation values is probably related to the sample size, since we observed large standard errors and therefore higher confidence intervals, which decrease the precision of our results (Hair et al. 2014).

Numeric reasoning had small positive effects on grade and test scores at time points one and four. Numeric reasoning also influenced maths enjoyment at T4. Gender had small significant effects on all emotions at time point one and at time point four. Girls reported lower levels of enjoyment at T1, and T4, higher levels of anxiety at T1 and higher levels of boredom at T4. There were no significant correlations between gender and numeric reasoning.

Person-centred analyses

Description of the final cluster solution

Two univariate outliers were removed for the cluster analyses, resulting in 282 i-states. A three-cluster solution was chosen that explained 63 per cent, 52 per cent and 68 per cent respectively of the variance in the constituting dimensions (enjoyment, anxiety, and boredom), thereby surpassing the 50 per cent threshold suggested by similar studies (Hayenga and Corpus 2010; Vansteenkiste, Sierens, Soenens, Luyckx, and Lens 2009). This cluster solution proved to be

Table 3 Reciprocal effects model for emotion and achievement: Fit indices

Achievement	Model	χ^2			CFI	TLI	RMSEA			SRMR
		Value	df	*p*			Value	95% IC	*p*	
Test scores	Enjoyment	218.14	42	<.001	.922	.836	.098	[.032,.154]	.093	.095
	Enjoyment (parsimonious)	210.64	44	<.001	.948	.908	.070	[.000,.126]	.279	.089
	Anxiety	266.73	42	<.001	.972	.942	.066	[.000,.129]	.279	.095
	Anxiety (parsimonious)	200.19	42	<.001	.972	.957	.048	[.000,.110]	.481	.073
	Boredom	200.19	42	<.001	.913	.817	.099	[.033,.155]	.091	.085
	Boredom (parsimonious)	200.19	42	<.001	.972	.957	.048	[.000,.108]	.483	.087
Grade scores	Enjoyment	375.48	42	<.001	.946	.886	.113	[.055,.167]	.039	.086
	Enjoyment (parsimonious)	374.48	42	<.001	.938	.896	.108	[.055,.157]	.038	.089
	Anxiety	416.27	42	<.001	.939	.871	.127	[.074,.180]	.013	.100
	Anxiety (parsimonious)	416.27	42	<.001	.932	.889	.118	[.070,.165]	.014	.104
	Boredom	398.12	42	<.001	.926	.845	.136	[.085,.188]	.006	.078
	Boredom (parsimonious)	398.12	42	<.001	.924	.867	.126	[.078,.174]	.008	.080

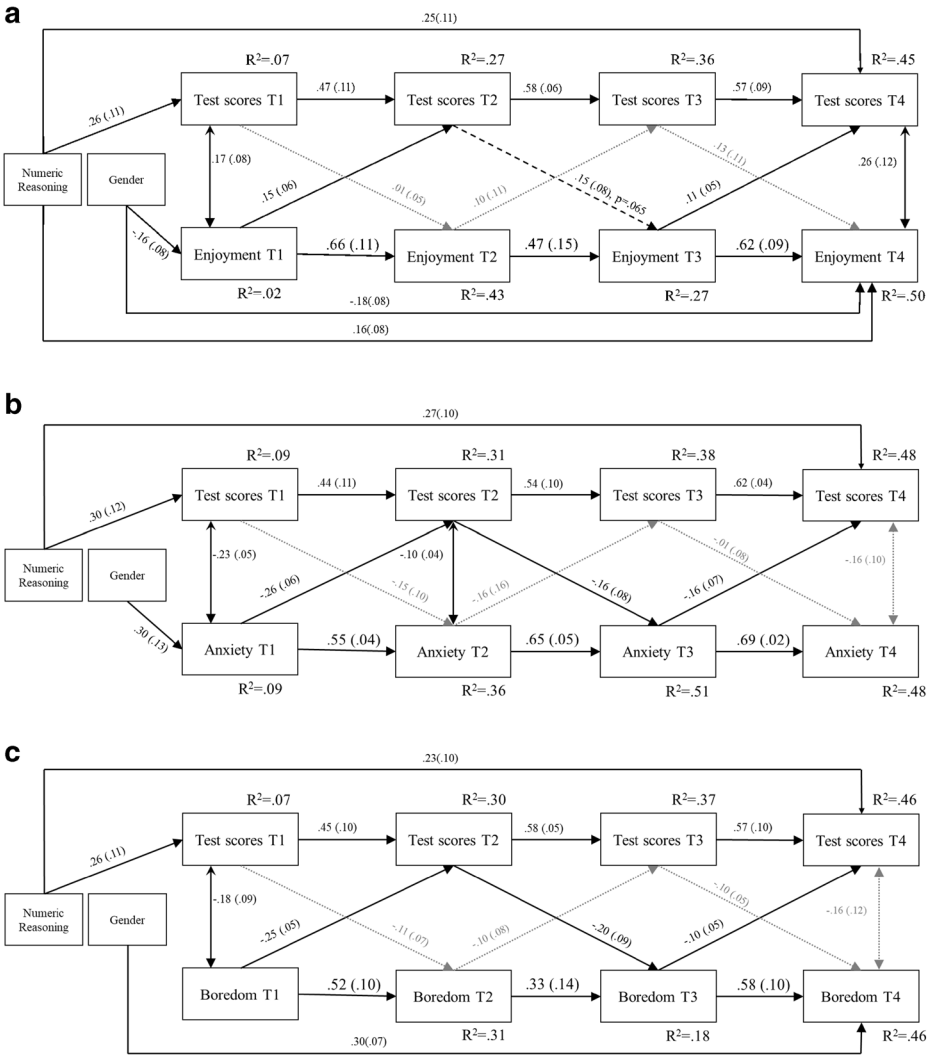

Fig. 3 Reciprocal effect model for emotion and test scores. Coefficients presented are standardized, standard errors are presented between curved brackets. Dotted lines represent non-significant coefficient. Panel A: Model for enjoyment. Panel B: Model for anxiety. Panel C: Model for enjoyment

very stable in the resampling of the dataset ($\kappa > 0.90$) and replicable using two randomly selected halves ($\kappa = 0.93$), third and fourth grade halves ($\kappa = 0.96$), and halves of girls and boys ($\kappa = 0.85$).

The means of the achievement emotions z-scores were interpreted in line with González, Paoloni, Donolo, and Rinaudo (2012): values below -1 were considered very low; from -1 to -0.50 low; from -0.49 to 0.49 average; from 0.50 to 1 high; and greater than 1 very high. Therefore, the final cluster solution included:

1) A negative emotional profile (66 i-states, 23.4%), characterized by low levels of enjoyment ($M_{z\text{-scores}} = -1.28$ and $M_{scale} = 2.09$), average levels of anxiety ($M_{z\text{-score}} = 0.26$ and $M_{scale} = 2.44$), and very high levels of boredom ($M_{z\text{-score}} = 1.36$ and $M_{scale} = 3.48$).

2) A positive emotional profile (115 i-states, 40.8%), characterized by high levels of enjoyment ($M_{z\text{-scores}} = 0.74$ and $M_{scale} = 4.04$), and low levels of anxiety ($M_{z\text{-scores}} = -0.80$ and $M_{scale} = 1.59$) and boredom ($M_{z\text{-scores}} = -0.72$ and $M_{scale} = 1.42$). This was the largest profile at G3T1, G3T2 and G4T3.
3) A moderate emotional profile (101 i-states, 35.8%), that reported high levels of anxiety regarding maths, yet lower than the midpoint of the scale ($M_{z\text{-scores}} = 0.66$ and $M_{scale} = 2.76$), and average levels of enjoyment ($M_{z\text{-scores}} = -0.10$ and $M_{scale} = 3.24$) and boredom ($M_{z\text{-scores}} = 0.01$ and $M_{scale} = 2.15$). This was the largest profile at G4T4.

Results were analysed for systematic differences in gender across profiles at the four time points. No significant differences were found between the two genders. Figure 4 presents the final cluster solution and the z-scores for each emotion.

Emotional profiles and academic achievement

The MANOVA revealed that, after controlling for students numeric reasoning, a significant effect of emotional profile on achievement was introduced at G3T1 ($F(2,67) = 11.27$, Roy's $\lambda = 0.34$, $p < 0.001$, $\eta_p^2 = 0.25$), G3T2 ($F(2,66) = 3.24$, Roy's $\lambda = 0.10$, $p = 0.045$, $\eta_p^2 = 0.09$), and G4T4 ($F(2,62) = 3.77$, Roy's $\lambda = 0.12$, $p = 0.029$, $\eta_p^2 = 0.11$), all with medium size effects.

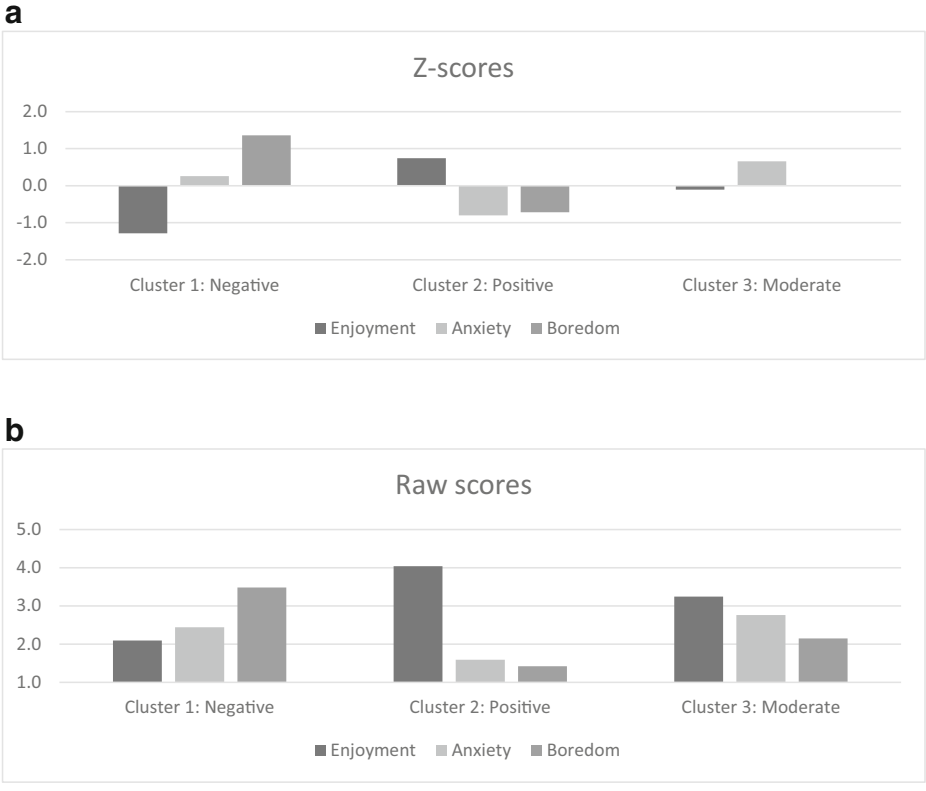

Fig. 4 Cluster profiles of achievement emotions regarding maths and the students' z-scores (Panel A) and raw scores (Panel B) for each emotion

At these time points, the negative profile underperformed the positive in both test scores (p_{T1} = 0.014, p_{T2} = 0.039, p_{T4} = 0.033) and grade reports (p_{T1} < 0.001, p_{T2} = 0.055, p_{T4} = 0.038; see Table 4). At G3T1, the moderate profile also underperformed the positive profile (p = 0.015) and outperformed the negative profile (p = 0.045) in grade reports. No significant effect of emotional profile on achievement was identified at G4T3 ($F(2,68) = 2.64$, Roy's $\lambda = 0.08$, p = 0.079, $\eta_p^2 = 0.07$), probably because the observed power of the test was very low ($\pi = 0.51$). The lower power could be related to an increase in the measurement error at time point 3, since the eta partial squared indicated a medium-sized effect. It was at this time point that the enjoyment and boredom scales presented the lowest test–retest correlation with the previous time points (Fig. 5).

Profile stability

Changes in profile membership are displayed in Fig. 3. Overall, the profiles were moderately stable, while still showing a significant variability: from G3T1 to G3T2, most students remained in the same profile (57.5%; $\chi^2(4) = 20.70$, $p < 0.001$, $V = 0.38$); the variability further decreased from G3T2 to G4T3 (38.0% changed; $\chi^2(4) = 25.50$, $p < 0.001$, $V = 0.42$), and continued to decrease from G4T3 to G4T4 (only 31.0% changed; $\chi^2(4) = 44.77$, $p < 0.001$, $V = 0.56$). The effect size of the relationship between the previous profile and the next, increased over time, indicating an improvement in stability over time. Furthermore, 35.2 per cent of the students (n = 25) stayed on the same profile across all time points.

Between G3T1 and G3T2, we found the highest stability in the positive profile and the lowest in the moderate profile (70% and 42% respectively remained in the same profile). Adjusted standardized residuals indicated that students in the positive profile were less likely to change to the negative profile than to maintain their profile or change to the moderate profile, and students in the negative profile were less likely to change to the positive profile, than to maintain their profile or change to the moderate profile (only 10% and 13% changed to these clusters, respectively).

In contrast, between G3T2 and G4T3, the highest stability was found in the moderate profile, and the lowest in the negative profile (67% and 59% respectively remained in the same profile). Adjusted standardized residuals indicated that students in the moderate and negative

Table 4 Students' achievement levels by emotional profiles regarding maths

Time Points	Profile	n	Test scores		Grade reports	
			M	*SD*	*M*	*SD*
G3T1: 3rd Grade—January	Negative	15	-0.52	1.02	-0.67	0.92
	Positive	30	0.28	0.88	0.40	0.58
	Moderate	26	0.05	0.97	-0.08	0.82
G3T2: 3rd Grade—June	Negative	17	-0.37	1.16	-0.30	0.86
	Positive	32	0.26	0.85	0.26	0.76
	Moderate	21	-0.23	0.80	-0.20	0.96
G4T3: 4th Grade—January	Negative	18	-0.18	1.13	-0.02	0.91
	Positive	27	0.37	0.81	0.33	0.72
	Moderate	26	-0.12	1.00	-0.12	0.91
G4T4: 4th Grade—June	Negative	16	-0.36	1.05	-0.33	0.94
	Positive	23	0.41	0.81	0.38	0.71
	Moderate	26	0.12	0.93	0.00	0.93

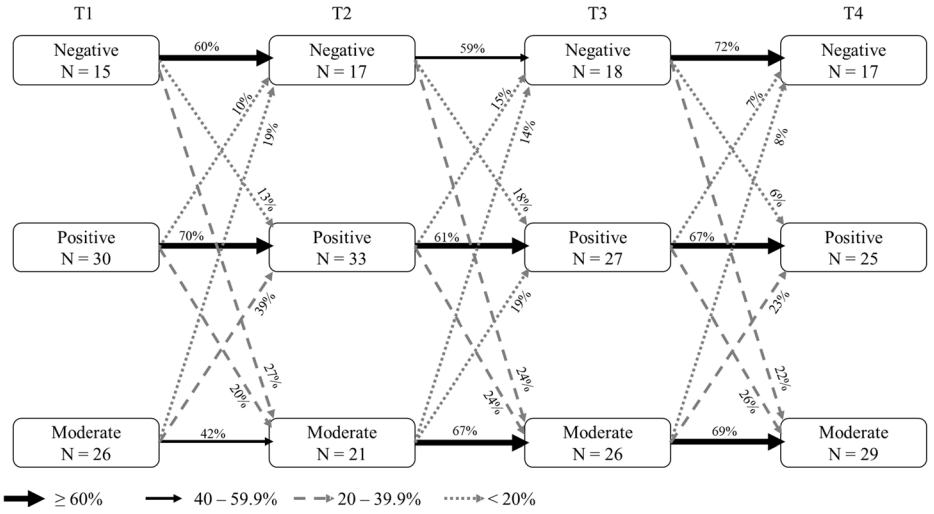

Fig. 5 Changes in students' profile membership from G3T1 to G4T4

profiles were less likely to change to the positive profile (14% and 18%, respectively) and students in the positive profile were less likely to change to the moderate profile (24% changed).

Finally, between G4T3 and G4T4, it was found that the three profiles were very stable (67% remained in the same profile). Adjusted standardized residuals indicated that students in the negative and moderate (23.1%) profiles were less likely to change to the positive profile (5.6% and 23.1%, respectively), and students in the positive profile were less likely to change to the negative or moderate profiles (7.4% changed to negative; 22.2% changed to moderate).

Discussion

To accomplish the study's first aim of examining longitudinal trajectories of three emotions regarding maths, enjoyment, boredom, and anxiety were measured four times. Using a variable-centred approach, it was found that the variable of time had a significant effect on enjoyment and boredom, but not on anxiety, which remained stable across the four time points. However, enjoyment and boredom presented reversed emotional pathways: enjoyment decreased significantly and continuously, while boredom significantly increased. Overall, these results are similar to those identified in older students in both cross-sectional and longitudinal studies (Ahmed et al. 2013; Mata et al. 2017; Monteiro et al. 2017; Vierhaus et al. 2016), indicating that this pattern begins very early, even when students are at the beginning of their school process. Several reasons have been offered to explain these reverse patterns of positive and negative emotions throughout schooling, which are similar to the negative changes already identified in motivation research (Wigfield and Eccles 2000). The main arguments explaining these patterns pertain to participants' developmental characteristics and the characteristics of methods and topics in a given school (Mata et al. 2009; Pekrun 2006; Pekrun et al. 2017; Wigfield and Eccles 2000).

Arguments suggesting developmental characteristics propose that younger students have had fewer experiences, and their cognitive capabilities to analyse, compare, and evaluate

situations are less developed, which may interfere not only with their interpretation of situations but also their self-perception (Guay et al. 2010; Harter 2012; Wigfield 2000). Older children's self-assessments are more accurate and realistic; consequently, self-perceptions among younger children are more positive than those among older ones (Eccles, O'Neill, and Wigfield 2005; Mata et al. 2009; Wigfield and Eccles 2000). Therefore, since self-perceptions of ability interfere with perceived control, and the latter is positively related to students' enjoyment and negatively to their anxiety and boredom (Dettmers et al. 2011; Pekrun and Perry 2014; Sanches et al. 2020), this can explain why, when the students in this research were younger, they showed higher levels of positive emotions and lower levels of negative emotions.

Explanations concerning school methods and topics that consider the pedagogical dynamics and climate in a classroom can also explain the emotions felt by students, suggesting that school activities do not meet students' needs and interests (Mata et al. 2009; Wigfield 2000; Wigfield and Eccles 2000). Furthermore, when students perceive the school environment as controlling, this induces less cognitive activation, generating fewer positive emotions and more boredom because perceived control mediates the effects of environmental aspects on achievement emotions (Pekrun et al. 2007). Additionally, controlling environments inhibit students' sense of competence and autonomy, which are necessary to raise intrinsic motivation and positive emotions (Deci and Ryan 2000; Niemiec and Ryan 2009; Pekrun et al. 2007). Moreover, as students progress in their schooling, pedagogical practices are frequently not able to continue successfully to demonstrate the importance of the knowledge being taught, so students have difficulty comprehending its functionality and usefulness (Deci 2009; Ryan and Niemiec 2009). This can limit their understanding of the subjective importance of school activities and outcomes, which compromises their value appraisals related to school, affecting their emotions (Pekrun 2006).

Furthermore, although our results are similar to those in past research among older students (Ahmed et al. 2013; Mata et al. 2017; Monteiro et al. 2017), when comparing them with the results obtained by Vierhaus et al. (2016) with German primary school students, some differences are found regarding enjoyment: the German research revealed high and stable levels of enjoyment from second to fifth grade. In our research, Portuguese students showed a decreasing pattern from third to fourth grade, similar to what was found for older students in diverse studies (Ahmed et al. 2013; Mata et al. 2017; Pinxten et al. 2014). Moreover, the Portuguese third grade maths curriculum is very extensive, and there is considerable pressure involved in its fulfilment, so much so that Portuguese teachers have been advocating that it be revised to meet students' needs and capabilities. This could be one factor explaining the significant early decrease in enjoyment among Portuguese primary school students which was not present in the study by Vierhaus et al. (2016).

The results of our research also showed that anxiety remained stable through third and fourth grades. Ahmed et al. (2013) did not find differences in anxiety during the seventh grade, and Ma and Xu (2004) found that anxiety regarding maths was very stable from eighth to twelfth grade. However, past findings about school anxiety are not very consistent, as some other studies have reported mixed findings (e.g., Wigfield and Eccles 1989) or an increase in anxiety levels (Hill et al. 2016). Factors which may explain these differing results include participants' characteristics (e.g., achievement), context (e.g., class, test), time span, and political/cultural backgrounds. These different variables can explain the diversity in results, demonstrating that it is necessary to be careful when comparing results (Ahmed et al. 2013; Monteiro et al. 2017; Wang et al. 2015). Moreover, anxiety is a negative activated emotion,

and research has shown that it can have different influences on different groups of students: while anxiety can decrease cognitive resources and motivation, leading to underachievement (Ahmed et al. 2013; Artino et al. 2010; Pekrun et al. 2011), it can induce motivation and harder work to avoid failure (Pekrun et al. 2011).

The pattern of longitudinal associations between emotions and maths results showed effects of emotions on academic achievement during the same school year but not from one school year to another. The effects of achievement on emotions were only significant from one school year to another. Older students' enjoyment (Pekrun et al., 2017) positively predicts achievement, while anxiety and boredom negatively predict achievement. Reciprocally, performing well in school seems to foster enjoyment in the following year and reduce negative emotions at school, whereas performing poorly seems to increase negative emotions in maths classes.

A second aim of this research was to identify different emotion profiles using a person-centred approach to data analysis. This aim was achieved, making it possible to associate achievement with these profiles, thus providing a different and complementary perspective on academic emotions and how they occur among students. As hypothesized, it was possible to identify three different emotional profiles. Students in the negative emotional profile felt the highest levels of boredom, followed by anxiety, and exhibited the lowest levels of enjoyment. This was the smallest profile across all time points, comprising a quarter or less of the participants (21.1–25.4%). Students in the positive emotional profile felt the highest levels of enjoyment and the lowest levels of both boredom and anxiety, and this was the biggest profile in almost all time points (38–46.5%). Students in the moderate emotional profile felt moderate levels of enjoyment and boredom, and higher levels of anxiety (although below the midpoint of the scale). This was the biggest profile at the end of fourth grade (G4T4- 40.9%).

In other studies, different sets of emotions and methodologies were used, and other emotional profiles were identified. Nevertheless, there is a great similarity between our three profiles and some of the profiles identified in other studies with older students (e.g., Ganotice et al. 2016; Jarrell et al. 2016; Robinson et al. 2017). These profiles illustrate that students feel complex patterns of emotions regarding maths, demonstrating the importance of looking at the particular combination of emotions experienced by students—instead of focusing on one particular emotion, to better understand their characteristics and desire to act (Fernando, Kashima, and Laham 2014).

It is worth noting that most of the students showed positive or moderate emotional profiles, and about one in four of all the participants fitted the negative profile. Even so, it is important to highlight that the most prevalent emotion for these students was boredom which is a negative deactivating emotion usually associated with lower academic achievement (e.g., Ahmed et al. 2013; Pekrun et al. 2010, 2011). Relatedly, our results revealed a significant effect of profile membership on achievement in most cases: students in the negative profile underperformed compared to their peers in the positive profile, both in test scores and grade reports. Likewise, among the subsample of students who remained in the same profile across all time points, students with a negative profile always underperformed their peers with a positive profile in test scores and grade reports. These results are similar to those seen in research with older students, where profile membership was significantly associated with engagement and achievement (Ganotice et al. 2016; Robinson et al. 2017), and they are also consistent with our variable-centred results. There were no differences in profiles in terms of their make-up by gender, similar to what Raccanello et al. (2018) found, showing that the emotional constellations regarding maths are independent of some differences identified in

self-competence and self-efficacy, where boys usually present higher levels than girls (Ahmed et al. 2013; Bieg, Goetz, Wolter, and Hall 2015; Santos et al. 2019).

accomplish the third aim, we analysed the stability of membership of each emotional profile for these students throughout their third- and fourth-grade years. We found more than just an increase in boredom and a decrease of enjoyment, as observed in the variable-centred analysis. Among these primary school children, profile membership was moderately stable across all four time points. From one time point to the next, the majority of students (59–72%) remained in the same profile. The stability of these profiles highlights that a great many of these young students already have firm emotional constellations about maths. This emphasizes the importance of the first years of schooling for the development of affect regarding maths. Schools and teachers must be aware of the importance of their approaches and strategies to develop positive attitudes and affect regarding maths among their students.

Over time, more frequent changes occurred from positive and negative profiles to moderate ratings, and from moderate to positive. The highest volatility levels were observed at the beginning of the research (G3T1–G3T2), where 58 per cent of the students in the moderate profile moved to another profile. This was the greatest profile change observed through the two years of research, and the greatest change involved students moving to the positive profile. In the moderate profile, it seemed that the emotional constellation facilitated their positive change, because even with a moderate level of anxiety, these students expressed positive emotions, as their enjoyment levels were higher than their anxiety and boredom levels.

The opposite change, from positive to moderate, is also understandable, as it resulted from a decrease in enjoyment and an increase in negative emotions, which was shown in this research and reported in previous variable-centred research (Ahmed et al. 2013; Hill et al. 2016; Mata et al. 2017; Monteiro et al. 2017; Pinxten et al. 2014). Thus, the person-centred approach allows us to understand that different students, even with similar emotional constellations, may have diverse emotional pathways through their schooling.

Furthermore, the percentage of students who switched from one profile to another decreased over time, and, at the end of fourth grade, less than 31 per cent changed their emotional profile; this stability applied to all profiles. This increase in stability was impossible to observe in the variable-centred analysis. However, it may be inferred that emotions can change throughout schooling, not only in their frequency, as variable-centred research has highlighted (Ahmed et al. 2013; Mata et al. 2017; Monteiro et al. 2017; Pinxten et al. 2014), but also in their constellations. Additionally, these different emotional profiles seem to become increasingly stable and structured. To better understand these results, it is important for future studies to identify the characteristics of students who remain in the same profile and of those who change. A future analysis must consider both the specificity of each emotional profile and the other important variables for education and success, such as self-perception of competence, self-regulation and motivational characteristics of students.

This study has several limitations. The first concerns the approach and variables considered to study maths emotions and achievement. Different variables, such as the maths curriculum and the teachers' approach and skills in teaching and engaging students, can contribute to results and attitudes regarding maths. These and other contextual factors were not evaluated or considered in this study, although they should be explored in future research about this topic. Another limitation concerns the generalization of the results of the cluster analyses with young children and their longitudinal collected data. This was the first longitudinal study performed with a person-centred approach with young children, but the number of participants was not very large and therefore not representative of Portuguese primary school children, and these

students were questioned only about maths. To confirm these results and explore them in more depth, it is crucial to continue and enlarge this kind of research with a larger sample of primary school children, to study their emotions not only regarding maths but also regarding other school subjects, as emotions are domain-specific. Besides, as is known, age is an important variable to consider. Therefore, it is important to develop more studies with students of different ages to study the characteristics of these profiles and the transformation of such profiles over time. Moreover, research must analyse whether school or cycle transitions interfere with profile stability.

The third limitation is linked to the use of a self-reported instrument to tap emotions, which is susceptible to response bias. In future research, it is important to use complementary measures such as teachers' judgements about their students' emotions.

The fourth limitation is related to the emotions studied. Previous research has shown that emotions other than enjoyment, boredom and anxiety, are also important and are experienced in educational contexts (Ganotice et al. 2016; Pekrun 2006; Pekrun et al. 2011; Raccanello et al. 2018; Robinson et al. 2017). Thus, to better understand this process and its complexity, it is important that future studies introduce other positive and negative emotions with different characteristics (e.g., pride, shame, and anger) to diversify the emotional profile.

Conclusions

This study combined two different methodological approaches, person-centred and variable-centred, and was longitudinal, performed across two school years. The design allowed an in-depth and multifaceted understanding of the students' emotional processes in maths throughout primary school. The person- and variable-centred approaches complemented and supported each other's results. The analysis of clusters of students allowed us to identify groups of participants with a similar pattern in terms of some of their individual characteristics; it also allowed us to identify not only the proportion of the sample that showed each pattern, but also specific outcomes and characteristics for each of the patterns. In the future, as each student responds uniquely to the educational environment, it will be important to complement this approach with a within-person analysis to examine psychological processes within individuals (Murayama et al. 2017).

Although only three emotions were analysed, it was possible to identify different emotional profiles, highlighting the value of analysing different combinations of these emotions and the ways such combinations can be associated with academic achievement. Similar to research with older students (Jarrell et al. 2016; Robinson et al. 2017), our results showed that the interpretation of an emotional profile, rather than each emotion alone, allowed a more in-depth understanding of students' emotional relationship with maths and its connection with achievement. Results were different for students in the negative, positive, and moderate profiles, showing that a positive emotional profile was frequently associated with higher levels of achievement, especially when compared with the achievement of students in the negative profile.

The longitudinal person-centred approach allowed us to understand that students' emotional profile membership became more stable over time. In addition, the variety of profiles and their inter-profile movements were particularly interesting as they revealed a certain level of profile malleability. These results showed the nature of the students' emotional dynamic, which should be considered in intervention efforts and to optimise academic performance. Therefore, to nurture positive emotions, the learning context, the teacher's knowledge and

skills, and the teacher-student relationship can be crucial elements in the approach to the maths curriculum. These positive emotions are usually associated with task value and with students' confidence in their own ability to overcome challenges and solve tasks and problems (Pekrun 2006, 2014a). Hence, students' self-confidence and their perception of task value need to be intentionally considered in teachers' pedagogical interventions to promote positive emotions and engagement. Finally, the results highlighted the complexity of students' emotional profiles and processes throughout schooling, and the importance of understanding them to enhance educational support, development, and learning.

Funding FCT-Fundação para a Ciência e Tecnologia, PTDC/MHC-CED/1680/2014, UIDP/04853/2020 and UIDB/04853/2020.

6. References

Ahmed, W., van der Werf, G., Kuyper, H., & Minnaert, A. (2013). Emotions, self-regulated learning, and achievement in mathematics: A growth curve analysis. *Journal of Educational Psychology, 105*(1), 150–161. https://doi.org/10.1037/a0030160.

Artino, A. R., La Rochelle, J. S., & Durning, S. J. (2010). Second-year medical students' motivational beliefs, emotions, and achievement. *Medical Education, 44*(12), 1203–1212. https://doi.org/10.1111/j.1365-2923.2010.03712.x.

Bergman, L. R., Nurmi, J.-E., & von Eye, A. A. (2012). I-states-as-objects-analysis (ISOA): Extensions of an approach to studying short-term developmental processes by analyzing typical patterns. *International Journal of Behavioral Development, 36*(3), 237–246. https://doi.org/10.1177/0165025412440947.

Bieg, M., Goetz, T., Wolter, I., & Hall, N. C. (2015). Gender stereotype endorsement differentially predicts girls' and boys' trait-state discrepancy in math anxiety. *Frontiers in Psychology, 6,* 1404. https://doi.org/10.3389/fpsyg.2015.01404.

Bower, G. (1992). How emotions affect learning. In S. Christianson (Ed.), *The handbook of emotion and memory* (pp. 3–31). New Jersey: Lawrence Erlbaum Associates.

Corpus, J. H., & Wormington, S. V. (2014). Profiles of intrinsic and extrinsic motivations in elementary school: A longitudinal analysis. *Journal of Experimental Education, 82*(4), 480–501. https://doi.org/10.1080/00220973.2013.876225.

Cross, L. H. (1995). Grading students. *Practical Assessment, Research & Evaluation, 4*(8), 1–3.

Daniels, L. M., Stupnisky, R. H., Pekrun, R., Haynes, T. L., Perry, R. P., & Newall, N. E. (2009). A longitudinal analysis of achievement goals: From affective antecedents to emotional effects and achievement outcomes. *Journal of Educational Psychology, 101*(4), 948–963. https://doi.org/10.1037/a0016096.

Deci, E. L. (2009). Large-scale school reform as viewed from the self-determination theory perspective. *Theory and Research in Education, 7,* 244–252. https://doi.org/10.1177/1477878509104329.

Deci, E. L., & Ryan, R. M. (2000). The "What" and "Why" of goal pursuits: Human needs and self-determination of behavior. *Psychological Inquiry, 11*(4), 227–268. https://doi.org/10.1207/S15327965PLI1104_01.

Dettmers, S., Trautwein, U., Lüdtke, O., Goetz, T., Frenzel, A. C., & Pekrun, R. (2011). Students' emotions during homework in mathematics. Testing a theoretical model of antecedents and achievement outcomes. *Contemporary Educational Psychology, 36,* 25–35. https://doi.org/10.1016/j.cedpsych.2010.10.001.

Eccles, J. S., O'Neill, S., & Wigfield, A. (2005). Ability self-perceptions and subjective task values in adolescents and children. In K. Moore & L. Lipman (Eds.), *What do children need to flourish? Conceptualizing and measuring indicators of positive development* (pp. 237–249). New York: Springer.

Fernando, J. W., Kashima, Y., & Laham, S. M. (2014). Multiple emotions: A person-centered approach to the relationship between intergroup emotion and action orientation. *Emotion, 14*(4), 722–732. https://doi.org/10.1037/a0036103.

Frenzel, A. C., Pekrun, R., & Goetz, T. (2007). Perceived learning environment and students' emotional experiences: A multilevel analysis of mathematics classrooms. *Learning and Instruction, 17*(5), 478–493. https://doi.org/10.1016/j.learninstruc.2007.09.001.

Ganotice, F. A., Datu, J. A. D., & King, R. B. (2016). Which emotional profiles exhibit the best learning outcomes? A person-centered analysis of students' academic emotions. *School Psychology International, 37*(5), 498–518. https://doi.org/10.1177/0143034316660147.

Goetz, T., Frenzel, A. C., Pekrun, R., Hall, N. C., & Ludtke, O. (2007). Between- and within-domain relations of students' academic emotions. *Journal of Educational Psychology, 99*(4), 715–733. https://doi.org/10.1037/0022-0663.99.4.715.

Goetz, T., Pekrun, R., Hall, N., & Haag, L. (2006). Academic emotions from a social-cognitive perspective: Antecedents and domain specificity of students' affect in the context of Latin instruction. *British Journal of Educational Psychology, 76*(2), 289–308. https://doi.org/10.1348/000709905X42860.

González, A., Paoloni, V., Donolo, D., & Rinaudo, C. (2012). Motivational and emotional profiles in university undergraduates: A Self-Determination Theory perspective. *The Spanish Journal of Psychology, 15*(3), 1069–1080. https://doi.org/10.5209/rev_SJOP.2012.v15.n3.39397.

Guay, F., Chanal, J., Ratelle, C. F., Marsh, H., Larose, S., & Boivin, M. (2010). Intrinsic, identified, and controlled types of motivation for school subjects in young elementary school children. *British Journal of Educational Psychology, 80,* 711–735. https://doi.org/10.1348/000709910X499084.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2014). *Multivariate data analysis. Pearson New Pearson New* (International). Essex: Pearson Education Limited.

Harter, S. (2012). *The construction of the self: Developmental and sociocultural foundations* (2nd ed.). New York: Guilford Press.

Hayenga, A. O., & Corpus, J. H. (2010). Profiles of intrinsic and extrinsic motivations: A person-centered approach to motivation and achievement in middle school. *Motivation and Emotion, 34*(4), 371–383. https://doi.org/10.1007/s11031-010-9181-x.

Hill, F., Mammarella, I. C., Devine, A., Caviola, S., Passolunghi, M. C., & Szűcs, D. (2016). Maths anxiety in primary and secondary school students: Gender differences, developmental changes and anxiety specificity. *Learning and Individual Differences, 48,* 45–53. https://doi.org/10.1016/j.lindif.2016.02.006.

Howard, M. C., & Hoffman, M. E. (2017). Variable-centered, person-centered, and person-specific approaches: Where theory meets the method. *Organizational Research Methods, 21*(4), 846–876. https://doi.org/10.1177/1094428117744021.

Jarrell, A., Harley, J. M., & Lajoie, S. P. (2016). The link between achievement emotions, appraisals, and task performance: Pedagogical considerations for emotions in CBLEs. *Journal of Computers in Education, 3*(3), 289–307. https://doi.org/10.1007/s40692-016-0064-3.

Jarrell, A., Harley, J. M., Lajoie, S., & Naismith, L. (2017). Success, failure and emotions: Examining the relationship between performance feedback and emotions in diagnostic reasoning. *Educational Technology Research and Development, 65*(5), 1263–1284. https://doi.org/10.1007/s11423-017-9521-6.

Lichtenfeld, S., Pekrun, R., Stupnisky, R., Reiss, K., & Murayama, K. (2012). Measuring students' emotions in the early years: The Achievement Emotions Questionnaire-Elementary School (AEQ-ES). *Learning and Individual Differences, 22*(2), 190–201. https://doi.org/10.1016/j.lindif.2011.04.009.

Linnenbrink-Garcia, L., Patall, E. A., & Pekrun, R. (2016). Adaptive motivation and emotion in education: Research and principles for instructional design. *Policy Insights from the Behavioral and Brain Sciences, 3*(2), 228–236. https://doi.org/10.1177/2372732216644450.

Ma, X., & Xu, J. (2004). The causal ordering of mathematics anxiety and mathematics achievement: A longitudinal panel analysis. *Journal of Adolescence, 27*(2), 165–179. https://doi.org/10.1016/j.adolescence.2003.11.003.

Mata, L., Monteiro, V., & Peixoto, F. (2009). Motivação para a leitura ao longo da escolaridade [Reading motivation throughout schooling]. *Análise Psicológica,* 27(4)*,* 563–572. https://doi.org/10.14417/ap.248

Mata, L., Peixoto, F., Monteiro, V., & Sanches, C. (2017). Emoções face à matemática e progressão na escolaridade – Estudo longitudinal com alunos do 5º e do 7º anos de escolaridade [Emotions regarding mathematics and progression in schooling - Longitudinal study with 5th and 7th grade students]. *Análise Psicológica,* 35(2), 125–144. https://doi.org/10.14417/ap.1227

Maroco, J. (2014). *Análise estatística com o SPSS Statistics [Statistica analysis with SPSS Statistics]*. Pêro Pinheiro: Report Number.

Murayama, K., Goetz, T., Malmberg, L.-E., Pekrun, R., Tanaka, A., & Martin, A. J. (2017). Within-person analysis in educational psychology: Importance and illustrations. *British Journal of Educational Psychology Monograph Series II, 12,* 71–87.

Meyer, D. K., & Turner, J. C. (2006). Re-conceptualizing emotion and motivation to learn in classroom contexts. *Educational Psychology Review, 18*(4), 377–390. https://doi.org/10.1007/s10648-006-9032-1.

Miranda, M. J. (1983). *Manual da Escala Colectiva de Nível Intelectual (ECNI): Aferição para Portugal*. Lisboa: INIC.

Monteiro, V., Peixoto, F., Mata, L., & Sanches, C. (2017). Mathematics: I don't like it! I like it! Very much, a little, not at all... Social support and emotions in students from 2nd and 3rd cycles of education. *Análise Psicológica,* 35(3), 281–296. https://doi.org/10.14417/ap.1156

Muthén, L. K., & Muthén, B. O. (1998–2017). *Mplus statistical analysis with latent variables. User's guide* (8th Edition). Los Angeles: Muthén & Muthén.

Niemiec, C. P., & Ryan, R. M. (2009). Autonomy, competence, and relatedness in the classroom. Applying self-determination theory to educational practice. *Theory and Research in Education,* 7(2), 133–144. https://doi.org/10.1177/1477878509104318

OECD. (2014). *PISA 2012 results: What students know and can do – Students performance in mathematics, reading and science (Vol. 1* (revised). Paris: OECD Publishing.

Pekrun, R. (2006). The Control-Value Theory of achievement emotions: Assumptions, corollaries, and implications for educational research and practice. *Educational Psychology Review, 18*(4), 315–341. https://doi.org/10.1007/s10648-006-9029-9.

Pekrun, R. (2009). Global and local perspectives on human affect: Implications of the control value theory of achievement emotions. In M. Wosnitza, S. A. Karabenick, A. Efklides, & P. Nenninger (Eds.), *Contemporary motivation research: From global to local perspectives* (pp. 97–115). Cambridge: Hogrefe.

Pekrun, R. (2013). Emotion, motivation and self-regulation: Common principles and future directions. In N. C. Hall & T. Goetz (Eds.), *Emotion, motivation and self-regulation: A handbook for teachers* (pp. 168–187). Bingley: Emerald Group Publishing Limited.

Pekrun, R. (2014). Achievement emotions. In M. Furlong, R. Gilman, & E. S. Huebner (Eds.), *Handbook of positive psychology in schools* (pp. 146–164). New York: Taylor & Francis/Routledge.

Pekrun, R. (2014b). *Emotions and learning* (Educational Practices Series, Vol. 24). Geneva: UNESCO, International Academy of Education (IAE) and International Bureau of Education (IBE).

Pekrun, R., Frenzel, A. C., Goetz, T., & Perry, R. (2007). The control-value theory of achievement emotions: An integrative approach to emotions in education. In P. A. Schutz & R. Pekrun (Eds.), *Emotion in education* (pp. 13–36). Amsterdam: Academic Press.

Pekrun, R., Goetz, T., Daniels, L. M., Stupnisky, R. H., & Perry, R. P. (2010). Boredom in achievement settings: Exploring control-value antecedents and performance outcomes of a neglected emotion. *Journal of Educational Psychology, 102*(3), 531–549. https://doi.org/10.1037/a0019243.

Pekrun, R., Goetz, T., Frenzel, A. C., Barchfeld, P., & Perry, R. P. (2011). Measuring emotions in students' learning and performance: The Achievement Emotions Questionnaire (AEQ). *Contemporary Educational Psychology, 36*(1), 36–48. https://doi.org/10.1016/j.cedpsych.2010.10.002.

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self- regulated learning and achievement: A program of qualitative and quantitative research. *Educational Psychologist, 37,* 91–106. https://doi.org/10.1207/S15326985EP3702_4.

Pekrun, R., Lichtenfeld, S., Marsh, H. W., Murayama, K., & Goetz, T. (2017). Achievement emotions and academic performance: Longitudinal models of reciprocal effects. *Child Development, 88*(5), 1653–1670. https://doi.org/10.1111/cdev.12704.

Pekrun, R., & Perry, R. P. (2014). Control-Value Theory of achievement emotions. In R. Pekrun & L. Linnenbrink-Garcia (Eds.), *International handbook of emotions in education* (pp. 120–141). New York: Taylor & Francis/Routledge.

Pinxten, M., Marsh, H. W., De Fraine, B., Noortgate, W. V. D., & Van Damme, J. (2014). Enjoying mathematics or feeling competent in mathematics? Reciprocal effects on mathematics achievement and perceived math effort expenditure. *British Journal of Educational Psychology, 84*(1), 152–174. https://doi.org/10.1111/bjep.12028.

Raccanello, D., Brondino, M., & De Bernardi, B. (2013). Achievement emotions in elementary, middle, and high school: How do students feel about specific contexts in terms of settings and subject domains? *Scandinavian Journal of Psychology, 54*(6), 477–484. https://doi.org/10.1111/sjop.12079.

Raccanello, D., Rob, H., & Burro, R. (2018). Salience of primary and secondary school students' achievement emotions and perceived antecedents: Interviews on literacy and mathematics domains. *Learning and Individual Differences, 65,* 65–79. https://doi.org/10.1016/j.lindif.2018.05.015.

Robinson, K., Ranellucci, J., Lee, Y., Wormington, S., Roseth, C., & Linnenbrink-Garcia, L. (2017). Affective profiles and academic success in a college science course. *Contemporary Educational Psychology, 51,* 209–221. https://doi.org/10.1016/j.cedpsych.2017.08.004.

Ryan, R. M., & Niemiec, C. P. (2009). Self-determination theory in schools of education. Can an empirically supported framework also be critical and liberating? *Theory and Research in Education,* 7(2), 263–272. https://doi.org/10.1177/1477878509104331

Sanches, C., Monteiro, V., Mata, L., Santos, N., & Gomes, M. (2020). Psychometric properties of the Portuguese version of the Achievement Emotions Questionnaire for Elementary School. *Análise Psicológica, 38*(1), 127–139. https://doi.org/10.14417/ap.1671.

Santos, N. N., Mata, L., Monteiro, V., Sanches, C., & Gomes, M. (2019). Perceção de competência e desempenho na matemática em alunos do 1.º ciclo do ensino básico [Perceived competence and math achievement in elementary school students]. *Revista Portuguesa de Educação,* 32(1),108–124. https://doi.org/10.21814/rpe.14264

Schreiber, J. B., Nora, A., Stage, Fr., & K., Barlow, E. A., & King, J. . (2006). Reporting structural equation modeling and confirmatory factor analysis results: A review. *The Journal of Educational Research, 99*(6), 323–337. https://doi.org/10.3200/JOER.99.6.323-338.

Schutz, P. A., Hong, J. Y., Cross, D. I., & Osborn, J. N. (2006). Reflections on investigating emotion in educational activity settings. *Educational Psychology Review, 18*(4), 343–360. https://doi.org/10.1007/s10648-006-9030-3.

Stake, J. E. (2002). Making the grade: Some principles of comparative grading. *Journal of Legal Education, 52*(4), 583–618.

Tyson, D. F., Linnenbrink-Garcia, L., & Hill, N. E. (2009). Regulating debilitating emotions in the context of performance: Achievement goal orientations, achievement-elicited emotions, and socialization contexts. *Human Development, 52*(6), 329–356. https://doi.org/10.1159/000242348.

Vansteenkiste, M., Sierens, E., Soenens, B., Luyckx, K., & Lens, W. (2009). Motivational profiles from a self-determination perspective: The quality of motivation matters. *Journal of Educational Psychology, 101*(3), 671–688. https://doi.org/10.1037/a0015083.

Vierhaus, M., Lohaus, A., & Wild, E. (2016). The development of achievement emotions and coping/emotion regulation from primary to secondary school. *Learning and Instruction, 42,* 12–21. https://doi.org/10.1016/j.learninstruc.2015.11.002.

Wang, M.-T., Chow, A., Hofkens, T., & Salmela-Aro, K. (2015). The trajectories of student emotional engagement and school burnout with academic and psychological development: Findings from Finnish adolescents. *Learning and Instruction, 36,* 57–65. https://doi.org/10.1016/j.learninstruc.2014.11.004.

Wigfield, A. (2000). Facilitating children's reading motivation. In L. Baker, M. Dreher, & J. Guthrie (Eds.), *Engaging young readers—Promoting achievement and motivation* (pp. 140–158). New York: Guilford.

Wigfield, A., & Eccles, J. S. (1989). Test anxiety in elementary and secondary school students. *Educational Psychologist, 24*(2), 159–183. https://doi.org/10.1207/s15326985ep2402_3.

Wigfield, A., & Eccles, J. S. (2000). Expectancy-value theory of achievement motivation. *Contemporary Educational Psychology, 25*(1), 68–81. https://doi.org/10.1006/ceps.1999.1015.