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Achievement emotions and arithmetic fluency – Development and parallel processes during the early school years

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ABSTRACT

This study investigated the developmental trajectories and interrelationships of mathematics-related achievement emotions and arithmetic fluency from first to third grade, and the effects of these on third grade mathematics performance. Participants were 232 Norwegian students. Students' emotions and arithmetic fluency were measured four times and mathematics performance once. Applying latent growth curve modeling, developmental patterns of decreasing enjoyment and increasing boredom were observed over time. The mean level of enjoyment remained fairly high, and of both boredom and anxiety quite low. Individual differences were observed in both the initial levels and development of all emotions and arithmetic fluency, indicating differences in developmental trajectories. Only the initial levels and rate of change in arithmetic fluency predicted mathematics performance at the third grade.

1. Introduction

Mathematics-related achievement emotions and mathematics achievement may be related in a potentially long-lasting, beneficial or detrimental cycle, as regards both academic careers and overall well-being (e.g., Camacho-Morles et al., 2021). However, there is a paucity of longitudinal studies investigating the development of these emotions as well as their relationships with mathematics performance during the early school years. Understanding the early developmental dynamics between achievement emotions and mathematics performance would have a significant impact on increasing knowledge about preventive and risk factors in mathematics development, to be taken into account in mathematics education. In the present study, we chart the levels, development, and interrelationships of mathematics-related achievement emotions (i.e., enjoyment, anxiety, and boredom) and arithmetic fluency over the course of the first three school years, and the influence of these factors on mathematics performance. The control-value theory of emotions (Pekrun, 2006), which suggests a reciprocal, feedback-loop relationship between achievement emotions and achievement outcomes (Pekrun & Perry, 2014), provides a theoretical basis to the investigation.

1.1. *Achievement emotions: enjoyment, anxiety, and boredom in mathematics*

The control-value theory of emotions (Pekrun, 2006; Pekrun & Perry, 2014) is a widely-used framework integrating emotions commonly experienced in learning contexts, their antecedents, and their outcomes. Within the theory, emotions directly related to achievement activities or outcomes that are judged on competence-related standards are defined as achievement emotions (Pekrun, 2006; Pekrun, Lichtenfeld, Marsh, Murayama, & Goetz, 2017). These emotions are guided, on the one hand, by individuals' (conscious or habitualised) appraisals of their

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competence to cope with the demands of a task or activity and potential to influence its outcome (i.e., their perceived level of control), and the subjective importance (i.e., value) of the activity or outcome, on the other (Pekrun, 2006; Pekrun & Perry, 2014). Achievement emotions are categorised according to a three-dimensional taxonomy, based on their object focus (achievement activities or outcomes), valence (positive or negative), and arousal level (activating or deactivating) (Pekrun, 2006; Pekrun, Frenzel, Goetz, & Perry, 2007, 2023).

Research examining the impact of emotions on studying and learning mathematics has traditionally focused on anxiety (Camacho-Morles et al., 2021; Namkung et al., 2019). However, recent studies have increasingly acknowledged the importance also of other achievement emotions, regarding motivation, behaviour, and learning, both generally (Fiedler & Beier, 2014; Lichtenfeld & Stupnisky, 2013; Pekrun & Linnenbrink-Garcia, 2014) as well as specifically within the domain of mathematics (e.g., Putwain, Becker, Symes, & Pekrun, 2018; Putwain, Pekrun, et al., 2018). In the present study, we focus on three emotions that represent the main dimensions of this taxonomy and have been found to be relevant for motivation, well-being, and achievement, namely, enjoyment (a positive, activating, activity-focused emotion), anxiety (a negative, activating, outcome-focused emotion), and boredom (a negative, deactivating, activity-focused emotion) (Pekrun, 2006; Pekrun et al., 2007).

Like their control and value antecedents, achievement emotions are considered to be domain-specific (Putwain, Pekrun, et al., 2018); also younger, primary-school students have been found to distinguish between emotions pertaining to different subjects (Raccanello, Brondino, Moè, Stupnisky, & Lichtenfeld, 2019). The present study is conducted in the domain of mathematics, due to the increasing importance of this domain for individuals' educational pathways and its role as a predictor of later educational outcomes (Putwain, Pekrun, et al., 2018; Widlund, Tuominen, Tapola, & Korhonen, 2020). More specifically, our focus is on arithmetic fluency development. Retrieving basic addition and subtraction facts in number range 1–20 (e.g., 4 + 7 or 13–5) accurately and quickly (i.e., fluently) from memory is a fundamental skill to master during the early years of schooling (Xu et al., 2021). Mastering of addition and subtraction facts well is also one of the learning goals in early grades mathematics (Utdanningsdirektoratet, 2020), and it not only helps the child to solve applied arithmetic problems with less cognitive effort, but has also been found to be associated with overall mathematics performance (Jordan, Hanich, & Kaplan, 2003). In the early stage of learning arithmetic facts, children rely mainly on counting-based strategies (Koponen, Aunola, Ahonen, & Nurmi, 2007). For example, they may use verbal number sequences and their fingers as memory aids in trying to find the correct answer for the calculation problem. Through practice, children start to use more advanced calculation strategies, such as counting on from a larger addend or using already known facts (e.g., doubles, such as 4 + 4), in solving unknown facts (Fuson, 1992). Using counting-based strategies, a child may find the correct answer for the calculation problem, but it takes more time compared to retrieving the fact from memory. The development of arithmetic fluency has shown to be rather stable over the early years of schooling (Sorvo et al., 2019), although individual differences are known to exist (Xu et al., 2021). Some children may struggle in learning these facts by heart, and this is indeed one of the main characteristics observed in children having mathematical learning difficulties (Geary, 2011). Therefore, we might also expect that children experience different emotions when learning arithmetic facts.

Enjoyment, or the excitement, pleasure, and satisfaction experienced in relation to a learning activity or task (Pekrun et al., 2007), is instigated by perceiving the task as personally valuable, and oneself as competent enough to cope with the demands it poses (Pekrun, 2006). Enjoyment is thought to preserve cognitive resources and focus attention on the task, and thus facilitate deep learning (Pekrun et al., 2017). It has been positively and reciprocally linked with mathematics achievement during the primary school years (Putwain, Becker, et al., 2018).

Anxiety, in turn, is seen as arising from uncertainty over one's capacity to ensure a desired outcome in a valued task or activity (Pekrun, 2006). Mathematics anxiety (MA) has long been considered to interfere with manipulation of numbers and mathematical problem-solving, and thus to be linked negatively with mathematics performance, in both academic and everyday situations (Richardson & Suinn, 1972). The level of MA has been thought to be initially low, but increasing over the school years (Dowker, Sarkar, & Looi, 2016), although empirical evidence for this development is sparse (Wang, Rimfeld, Shakeshaft, Schofield, & Malanchini, 2020). Among primary-school students, some studies have in fact shown anxiety to decrease over time (Gunderson, Park, Maloney, Beilock, & Levine, 2018; Sorvo et al., 2019), while others have shown no significant change (e.g., Ganley & McGraw, 2016).

Finally, boredom may stem from the combination of a lack of interest (i.e., low value) and either high or low perceived control (i.e., tasks may be lacking in challenge, or experienced as too difficult) (Pekrun et al., 2007). Academic boredom is seen as promoting avoidance motivation, as it is associated with the desire to withdraw or escape from the boredom-inducing activity (Pekrun, Goetz, Daniels, Stupnisky, & Perry, 2010). Younger students are thought to experience higher levels of enjoyment and lower levels of boredom towards schoolwork in general than older students (Lichtenfeld & Stupnisky, 2013). However, while boredom is considered to be commonly experienced in learning contexts (Goetz & Hall, 2014), it has been studied somewhat less than some other emotions (Vierhaus, Lohaus, & Wild, 2016), particularly among young students. In the few existing studies, negative reciprocal relationships have been observed between mathematics boredom and achievement (Putwain, Becker, et al., 2018).

Although boys and girls tend to perform at a similar level in mathematics in the early grades (Kersey, Braham, Csumitta, Libertus, & Cantlon, 2018), some gender differences in achievement emotions have been observed, in that girls have reported lower mathematics enjoyment (Lichtenfeld, Pekrun, Stupnisky, Reiss, & Murayama, 2012) and higher boredom (Lichtenfeld et al., 2012; Putwain, Becker, et al., 2018) than boys. However, although girls have been found to express more MA than boys, this difference may arise in adolescence (Dowker et al., 2016), as findings among primary-school students have been inconsistent: some studies have found no gender differences in MA (e.g., Kucian et al., 2018; Primi et al., 2020), whereas others have reported higher MA both among girls compared with boys (Gunderson et al., 2018; Lauer, Esposito, & Bauer, 2018) and boys compared with girls (Dowker, Cheriton, Horton, & Mark, 2019).

1.2. Present study

While achievement emotions have been widely studied, research carried out during the very first school years is rare. Some studies have focused on a single emotion (e.g., MA; Gunderson et al., 2018; Sorvo et al., 2019; Tomasetto, Morsanyi, Guardabassi, & O'Connor, 2021), others have examined a number of emotions, but cross-sectionally (Raccanello et al., 2019), while yet others have applied a longitudinal framework, but either over a fairly short time span (e.g., one school year; Putwain, Becker, et al., 2018; Putwain, Pekrun, et al., 2018) or domain-generally only (Vierhaus et al., 2016). The present study is one of only few to examine multiple emotions and their relationship with achievement in a domain-specific, longitudinal framework among primary-school students. Our research questions (RQ) and hypotheses (H) were as follows.

RQ1 How do mathematics-related emotions and arithmetic fluency change over time during the first three school years?

We expected (H1.1) relatively high levels of enjoyment and relatively low levels of anxiety and boredom on all grade levels, as well as moderate to high rank-order stability in all achievement emotions (Putwain, Becker, et al., 2018). We further expected enjoyment to manifest a decreasing trajectory, and boredom an increasing trajectory (Vierhaus et al., 2016), as the students progressed from first to third grade. We refrained from setting a specific assumption on the development of MA, as findings among this age group have been ambiguous, with both decrease (Gunderson et al., 2018; Sorvo et al., 2019) as well as no change observed (Ganley & McGraw, 2016).

Regarding arithmetic fluency, we expected (H1.2) the initial level to be rather low, as in the beginning of schooling, many students are still using slower counting-based strategies than more fluent fact retrieval strategies, but assumed to detect significant development in terms of mean-level increase from first to third grade (Koponen, Aunola, & Nurmi, 2019). We anticipated high rank-order stability (Sorvo et al., 2019) as well as significant variance (i.e., individual differences) in performance at each timepoint (Zhang et al., 2020).

RQ2 How are changes in mathematics-related emotions and arithmetic fluency associated with each other?

We expected (H2.1) mathematics enjoyment to be related negatively to MA and boredom, and the latter two, in turn, to be related to each other positively (Raccanello et al., 2019). Regarding arithmetic fluency, we assumed a positive relationship within measurement points with enjoyment (Camacho-Morles et al., 2021), and negative with anxiety (Sorvo et al., 2019) and boredom (Camacho-Morles et al., 2021). Since we are not aware of direct previous evidence regarding the parallel processes of change, only the following assumptions were made, based on findings on concurrent correlations or longitudinal predictions. We assumed (H2.2) change in enjoyment to be inversely related to change in boredom (Putwain, Becker, et al., 2018), and changes in boredom and anxiety to be positively related (Lichtenfeld et al., 2012).

RQ3 How do changes in mathematics-related emotions and arithmetic fluency predict curriculum-based mathematics performance in the third grade?

We expected (H3.1) the level of arithmetic fluency to be the most important predictor of mathematics performance (Geary, 2011; Jordan et al., 2003). We also assumed (H3.2) a positive prediction from the level of enjoyment, and negative from the level of anxiety and boredom (Putwain, Becker, et al., 2018; Tomasetto et al., 2021). Due to paucity of previous studies, however, we refrained from setting hypotheses on predictions of changes in the achievement emotions and arithmetic fluency on mathematics performance.

RQ4 Are there gender differences in achievement emotions, arithmetic fluency, and third grade curriculum-based mathematics performance?

Due to the inconsistency of previous findings on the role of gender in achievement emotions (e.g., Dowker et al., 2019; Lauer et al., 2018; Primi et al., 2020), we did not set specific hypotheses on these relationships. Regarding gender differences in arithmetic fluency and mathematics performance, we expected boys and girls to perform on similar levels and show similar development at this age (H4) (Kersey et al., 2018).

2. Method

2.1. Participants and procedure

Participants were students ($N = 266$; $M_{age} = 6$ y 9 m, $SD_{age} = 3.43$ months at start of data collection; girls 45.5%) from 12 classes in five primary schools in the metropolitan area of Oslo, Norway. As most schools in Norway, the participating schools are run by the municipal education authority. Before the data collection, an ethical approval was applied for and granted by the Norwegian Centre for Research Data, and consent for voluntary participation from parents and teachers were collected accordingly. We used the parents' highest educational level, reported by parents in a questionnaire, as a proxy for socio-economic status. Of the parents of the participating children, 50.0% of mothers and 51.3% of fathers held a Master's degree. Higher educational level is more typical in the metropolitan area compared to the rest of the country in Norway (Statistics Norway, 2022).

Data collection began in the spring term (March–April 2019) of the first grade (t1) and continued in the autumn term (October–November 2019) of the second grade (t2). Data collection planned for the spring term of the second grade was cancelled due to the Covid-19 pandemic. However, further data were collected during the autumn (October–November 2020; t3) and spring terms (April–May 2021; t4) of the third grade. One school with 29 children was unable to participate at t3 and t4 due to Covid-19, and in addition, five children were unable to complete all testing. Thus, our final sample included 232 students from four schools. Little's MCAR, conducted on all relevant variables, gave χ^2 (2128) = 2221.398, $p = .078$, indicating missing data was missing completely at random.

The students were tested as part of a larger data collection in the iSeeNumbers project focusing on children's early numeracy development. At time points t1–t3, the students were tested in small groups by trained research assistants. At t4, visitors were not allowed at schools due to Covid-19 restrictions, and testing sessions were instructed online via Teams by one trained research assistant, with the teacher ensuring that the children were following the instructions in the classroom. Teams allowed for an audio and video connection for communicating with the teacher and students. No technical issues affecting the implementation of tasks and quality of data were experienced. Data regarding students' emotions and arithmetic fluency were collected in separate sessions, with data on emotions typically collected first, and 15-min breaks given between the sessions.

2.2. Measures

2.2.1. Achievement emotions

Three achievement emotions (enjoyment, anxiety, boredom) were measured at each time point using a Norwegian translation of the Achievement Emotions Questionnaire-Elementary School (AEQ-ES; Lichtenfeld et al., 2012). Only the subscales pertaining to classroom experiences and homework were utilised, due to the lack of formal testing in Norwegian schools during the first school years. The questionnaire comprised 20 items, with enjoyment measured with six items (e.g., "*I enjoy doing math*"), and anxiety (e.g., "*When I think about math class, I get nervous*") and boredom (e.g., "*I find doing math boring*") with seven items each. The items were rated on a 5-point Likert-type scale, with the anchor values depicted by pictures of children's faces showing increasing emotional intensity.

2.2.2. Arithmetic fluency

Arithmetic fluency was measured at each time point as addition and subtraction facts using two subtests from a Norwegian standardised test Regnefaktaprøven [Test of arithmetic facts] (Klausen & Reikerås, 2016). Both the addition and subtraction subtest comprise 45 calculation problems per page, arranged in three columns. One page includes either addition or subtraction facts, which are presented horizontally (e.g., 9 + 3 or 12–4) within the number range 1–20. The child had 2 min for each subtest to solve as many calculation problems as possible. The same test could be used at all time points, to follow children's arithmetic fluency development. One point was given for a correct answer and zero for an incorrect answer. A sum score for arithmetic fluency including addition and subtraction was formed, the maximum score thus being 90 points.

2.2.3. Mathematics performance

Mathematics performance was measured once (t4), with a curriculum-based mathematics test (Mononen, 2021) developed in the project, as no such test was available at the time of the study. This paper-pencil group-based test included 49 items from the topics of numbers (number sequences, comparison of multi-digit numbers), measurement (volume, length, money), calculations (multiplication facts, addition and subtraction algorithms) and fractions, and corresponded to the third-grade learning goals in the Norwegian mathematics curriculum (Utdanningsdirektoratet, 2020). Each correctly solved item gave one point, the maximum score being 49.

2.3. Analyses

Factor structure and longitudinal measurement invariance were tested by running a series of confirmatory factor analyses (CFAs). Preliminary analyses revealed severe skewness and kurtosis (i.e., absolute values > 3.0 and > 10.0, respectively; Kline, 2005) in the distribution of particularly the anxiety items. Hence, to reduce bias in estimates, the items of all achievement emotions were considered as ordered-categorical, and the tests of longitudinal measurement invariance were done using the weighted least squares means and variance adjusted (WLSMV) estimator, following guidelines for working with ordered-categorical indicators by Liu et al. (2017). In brief, a baseline configural model of the same pattern of factor loadings across time is initially tested, and if this provides a good model fit, one can proceed to evaluate metric invariance (factor loadings constrained to be equal across time) and scalar invariance (threshold level of moving from one response category to the next constrained to be identical for each indicator) models. Testing and establishing longitudinal measurement invariance for ordered-categorical indicators has been relatively sparsely discussed in literature (Liu et al., 2017; Sass, Schmitt, & Marsh, 2014). In the present study, we follow the suggestion of Liu et al. (2017) and report the results of the chi-square difference test ($\Delta\chi^2$), obtained using the DIFFTEST option in Mplus. Further, we also report changes in the comparative fit index (ΔCFI), with the recommended cut-off point of .002 suggested for use with ordered-categorical indicators (Meade, Johnson, & Braddy, 2008), as it has been found to be more sensitive to a lack of invariance also in smaller (<300) sample sizes than the likelihood-ratio tests (i.e., $\Delta\chi^2$).

Change over time in the three achievement emotions and arithmetic fluency was analysed with latent growth curve modeling (LGCM). The analyses were carried out in stages, so that separate univariate LGCMs were first carried out for each variable; then, parallel processes LGCM (i.e., a model with more than one concurrent trajectory of change) was estimated to examine how changes over time in the four constructs were related to each other; and finally, gender was added as a covariate, and performance in a curriculum-based mathematics task at the end of the third grade as an outcome.

Descriptive statistics and correlations of the observed variables were calculated using SPSS 26. LGCM was conducted using Mplus statistical software version 8.6 (Muthén & Muthén, 1998–2017). For evaluating model fit, we used the χ^2 statistic, the root mean square of error approximation (RMSEA; values < 0.08 showing acceptable, and <0.06 good fit to the data), comparative fit index (CFI; values > 0.90 showing acceptable, and >0.95 excellent fit to the data), and standardised root mean squared residual (SRMR; recommended value < 0.08) (Hu & Bentler, 1999).

2.4. Preliminary results and longitudinal measurement invariance

The expected three-factor structure, corresponding to enjoyment, anxiety, and boredom, was tested with cross-sectional CFA, with an adequate model fit, χ2 (2418) = 2752.768, p < .001; RMSEA = 0.024 (90% CI 0.019, 0.029); CFI = 0.986; SRMR = 0.077, and significant factor loadings for all items at all time points. Due to the full model being computationally extremely intensive, measurement invariance of the three-factor model was examined and established separately for each emotion with longitudinal CFAs (for unstandardised factor loadings of final invariance models, see, Supplementary Materials Table 1). The criteria for scalar invariance were fulfilled (see, Supplementary Materials Table 2), enabling meaningful comparison of latent means over time.

3. Results

3.1. Initial levels, stability, and development of achievement emotions and arithmetic fluency

An inspection of the mean levels (RQ1) showed a high level of mathematics enjoyment at the first measurement point, and low of boredom and, especially, anxiety (see, Table 1). The respective rank-order stabilities of mathematics enjoyment and boredom, examined by means of Pearson correlations between time points, were similar, with correlations ranging from r = 0.45–0.68 between consecutive time points, whereas anxiety appeared somewhat less stable, with a range of r = 0.20–0.43 between consecutive time points.

Univariate LGCMs were estimated for the three achievement emotions and arithmetic fluency. Due to changes in the planned data collection caused by the Covid-19 pandemic, measurement points were unevenly spaced, in that t1 and t2, and t3 and t4 were approximately six months apart, whereas t2 and t3 were approximately 12 months apart. We therefore fixed t1 and t2 at zero and one, respectively, and t3 and t4 at three and four, respectively (Preacher, Wichman, MacCallum, & Briggs, 2008). This model fit the data acceptably for all three achievement emotions: enjoyment χ^2 (5) = 12.201, p = .032; RMSEA = 0.079 (90% CI 0.021, 0.136); CFI = 0.967; SRMR = 0.062; MA χ^2 (5) = 2.659, p = .752; RMSEA = 0.000 (90% CI 0.000, 0.064); CFI = 1.000; SRMR = 0.035; boredom χ^2 (5) = 8.129, p = .149; RMSEA = 0.052 (90% CI 0.000, 0.114); CFI = 0.983; SRMR = 0.038. However, this model did not describe the data well as regards arithmetic fluency, χ^2 (5) = 45.804, p < .001; RMSEA = 0.188 (90% CI 0.140, 0.239); CFI = 0.940; SRMR = 0.046. A model allowing deviation from linearity where t1 was fixed at zero and t4 at one, with t2 and t3 allowed to be freely estimated, showed a good fit to the data, χ^2 (3) = 1.586, p = .662; RMSEA = 0.000 (90% CI 0.000, 0.086); CFI = 1.000; SRMR = 0.007, and was consequently used in further analyses.

The results of the univariate LGCM (see, Table 2) revealed a significant overall decrease (M = −0.15, p < .01) of mathematics enjoyment and increase (M = 0.07, p = .01) in mathematics boredom, whereas the levels of MA remained low and did not change significantly during the three years (see, Fig. 1). However, significant individual differences in both the initial levels and the slopes were observed in all achievement emotions (see, Table 2).

As to arithmetic fluency (RQ1), the mean level at t1 was rather low, with correlations ranging from r = 0.78–0.84 between consecutive time points showing relatively high rank-order stability (see, Table 1). Univariate LGCM revealed significant increases in arithmetic fluency over time (M = 26.00, p < .01); significant individual differences in initial levels and slopes were observed also here, indicating differences between the students' skill levels and developmental trajectories (see, Table 2).

3.2. Interrelationships of achievement emotions and arithmetic fluency

To examine the interrelationships between achievement emotions and arithmetic fluency (RQ2), a parallel processes model was estimated. Model fit was initially inadequate, χ^2 (90) = 377.228, p < .001; RMSEA = 0.117 (90% CI 0.105, 0.130); CFI = 0.851; SRMR = 0.061. Based on modification indices, the residual covariances of the respective enjoyment and boredom variables within each measurement point were included, resulting in a good model fit, χ^2 (86) = 143.537, p < .001; RMSEA = 0.054 (90% CI 0.038, 0.069); CFI = 0.970; SRMR = 0.052. The latent correlations between all initial levels and slopes are given in Table 2.

Table 1
Correlations and descriptive statistics.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1 Enj. t1	–																
2 Enj. t2	.45**	–															
3 Enj. t3	.45**	.62**	–														
4 Enj. t4	.38**	.47**	.65**	–													
5 Anx. t1	−.10	−.09	−.08	.01	–												
6 Anx. t2	−.11	−.25**	−.10	−.08	.42**	–											
7 Anx. t3	−.02	−.14*	−.14*	−.04	.22*	.20**	–										
8 Anx. t4	.02	.03	.07	−.11	.25**	.21**	.43**	–									
9 Bor. t1	−.72**	−.43**	−.39**	−.33**	.25**	.21**	.01	.02	–								
10 Bor. t2	−.38**	−.80**	−.52**	−.39**	.16*	.38**	.13	.03	.50**	–							
11 Bor. t3	−.36**	−.52**	−.78**	−.56**	.08	.13	.20**	.04	.42**	.52**	–						
12 Bor. t4	−.33**	−.45**	−.57**	−.81**	.06	.14*	.11	.22**	.39**	.46**	.68**	–					
13 AF t1	.13	.12	.20**	.05	−.22**	−.19**	−.22**	−.21**	−.22**	−.14*	−.11	−.05	–				
14 AF t2	.12	.22**	.22**	.10	−.12	−.15*	−.24**	−.16*	−.18**	−.19**	−.15*	−.06	.78**	–			
15 AF t3	.12	.25**	.28**	.12	−.19**	−.24**	−.28**	−.12	−.20**	−.26**	−.22**	−.12	.69**	.79**	–		
16 AF t4	.10	.26**	.26**	.19**	−.15*	−.21**	−.24**	−.18**	−.17*	−.25**	−.21**	−.21**	.65**	.75**	.84**	–	
17 Math. Perf.	−.04	.12	.13	.08	−.15*	−.20**	−.23**	−.17*	−.04	−.12	−.10	−.14*	.47**	.47**	.50**	.61**	
M	3.38	3.32	3.00	2.83	1.24	1.23	1.28	1.23	1.96	1.88	2.01	2.21	10.23	18.79	28.72	36.39	34.71
SD	1.23	1.25	1.20	1.17	0.44	0.49	0.62	0.49	1.11	1.07	1.10	1.20	7.80	10.66	13.74	16.93	9.19
Obs. Range	1.00–5.00	1.00–5.00	1.00–5.00	1.00–5.00	1.00–3.40	1.00–5.00	1.00–5.00	1.00–4.80	1.00–5.00	0.71–5.00	1.00–5.00	1.00–5.00	0–48	1–75	1–73	2–89	5–48
Skewness	−0.27	−0.23	0.09	0.16	2.41	4.20	3.85	3.87	1.22	1.25	1.18	1.02	1.47	1.20	0.71	0.54	−1.03
Kurtosis	−0.98	−1.15	−1.13	−1.15	6.27	24.54	17.24	19.49	0.56	0.51	0.48	−0.03	3.20	2.77	0.46	0.32	0.87
McDonald's ω	.880	.925	.920	.935	.781	.832	.844	.884	.910	.919	.935	.956	.899	.959	.977	.982	.910

Note. Enj. = Enjoyment; Anx. = Anxiety; Bor. = Boredom; AF = Arithmetic Fluency; Math. Perf. = Mathematics Performance (3rd grade); t1–t4 = Time 1 – Time 4. $^{**}p < .01$; $^{*}p < .05$.

The initial level of mathematics enjoyment correlated negatively with the initial levels of anxiety and boredom, whereas the initial levels of anxiety and boredom were positively correlated. Further, also the slope of enjoyment was negatively related to the slopes of anxiety and boredom, and positive correlations were observed between the slopes of anxiety and boredom. However, the initial level of enjoyment and the slope of anxiety were positively related, whereas negative correlations were observed between the initial level of anxiety and the slope of boredom, and, conversely, the initial level of boredom and the slope of anxiety.

Regarding arithmetic fluency, its initial level correlated positively with the initial level of enjoyment, and negatively with the initial levels of anxiety and boredom. There was also a small positive correlation between the initial level of arithmetic fluency and the slope of boredom. The slope of arithmetic fluency, in turn, was positively related to the initial level of mathematics enjoyment, and negatively to the initial levels of anxiety and boredom. Finally, the initial level and slope of arithmetic fluency were positively correlated.

3.3. *Predictions on mathematics performance and gender effects*

Finally, we examined the predictive effects of the levels of and changes in emotions and arithmetic fluency on third grade mathematics performance (RQ3), while controlling for the effects of gender (RQ4). The final model fit the data adequately, χ^2 (102) = 174.665, $p < .001$; RMSEA = 0.055 (90% CI 0.041, 0.069); CFI = 0.966; SRMR = 0.049. The only predictors of mathematics performance were the initial level ($\beta = 0.44$, $p = .003$) and slope ($\beta = 0.37$, $p < .001$) of arithmetic fluency.[1] Compared with boys, girls reported higher initial levels of mathematics enjoyment ($\beta = -0.35$, $p = .027$), whereas boys reported higher initial mathematics boredom ($\beta = 0.50$, $p = .001$). All effects are given in Table 3.

4. Discussion

We examined, over the first three school years, (i) how mathematics-related emotions and arithmetic fluency change over time; (ii) how changes in mathematics-related emotions and arithmetic fluency are associated with each other; (iii) how these changes may predict mathematics performance at the end of the third grade; and (iv) possible gender differences in achievement emotions, arithmetic fluency, and third-grade curriculum-based mathematics performance. In sum, we found young students to experience high enjoyment and low anxiety and boredom in mathematics learning, with enjoyment decreasing and boredom increasing over the years. Students started with rather low arithmetic fluency in the first grade and improved significantly in their skills over time. Individual differences were observed in both the initial levels and rate of change of all three achievement emotions as well as arithmetic fluency. Only the initial levels and rate of change in arithmetic fluency predicted mathematics performance. Regarding gender differences, girls reported higher initial levels of mathematics enjoyment, whereas boys reported higher initial mathematics boredom.

The relatively high level of enjoyment and low of boredom (H1.1) closely reflect previous findings among similar or slightly older age groups (Lichtenfeld, Pekrun, Marsh, Nett, & Reiss, 2022; Putwain, Becker, et al., 2018). The initial level of anxiety was similar or even lower than the moderate levels previously observed among this age group or slightly older students (Gunderson et al., 2018; Lichtenfeld

[1] Given the possibility of multicollinearity due to high correlations between enjoyment and boredom, we ran additional models, one without enjoyment and one without boredom, to test whether such modifications influenced the effects. Neither the initial level nor change in enjoyment and boredom predicted mathematics performance, thus supporting the validity of the effects in the full model.

Table 2
Means, variances, and bivariate latent correlations for initial levels and slopes.

	Variable	*M*	*S*	Initial Level				Slope		
				Enjoyment	Anxiety	Boredom	AF	Enjoyment	Anxiety	Boredom
Initial Level	Enjoyment	3.43**	0.77**	–						
	Anxiety	1.24**	0.11′	−.32** (.12)	–					
	Boredom	1.87**	0.60**	−.85** (.04)	.55** (.13)	–				
	AF	10.65 **	54.06**	.24** (.09)	−.30** (.07)	−.30** (.07)	–			
Slope	Enjoyment	−0.15**	0.03*	−.19 (.17)	.29 (.20)	.22 (.16)	−.11 (.15)	–		
	Anxiety	−0.00	0.01*	.28* (.11)	−.46 (.28)	−.43** (.12)	−.05 (.11)	−.41* (.20)	–	
	Boredom	0.07**	0.04**	.03 (.15)	−.38* (.16)	−.20 (.15)	.20' (.11)	−.76** (.11)	.63** (.20)	–
	AF	26.00**	123.96**	.28** (.10)	−.21** (.08)	−.30** (.09)	.43** (.10)	.13 (.12)	−.00 (.12)	−.08 (.11)

Note. AF = Arithmetic Fluency. Standard errors of latent correlations are given in brackets after the estimate. ** $p \leq .01$; * $p \leq .05$; ' $p < .10$.

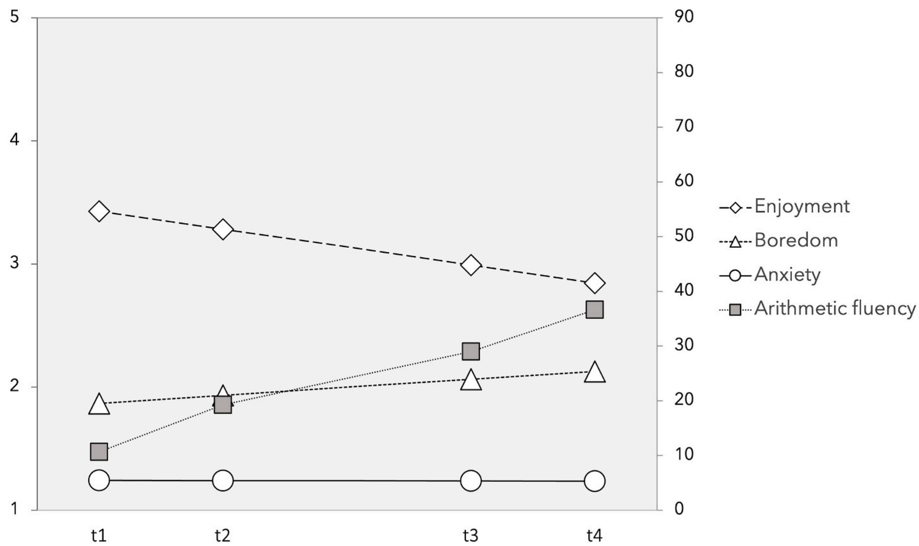

Fig. 1. Estimated means of the developmental trajectories of mathematics-related achievement emotions (left y-axis) and arithmetic fluency (right y-axis) from the spring of grade 1 (t1) to the spring of grade 3 (t4). Uneven temporal spacing of time points reflects the time lag between measurements.

et al., 2022; Sorvo et al., 2019; Tomasetto et al., 2021). Furthermore, the level of anxiety remained virtually unchanged over time, reflecting some previous findings (Ganley & McGraw, 2016; Lichtenfeld et al., 2022). The low levels of anxiety may to some extent be traceable to teaching practices and educational cultures, as testing, a prominent source of MA (Szczygieł & Pieronkiewicz, 2021), is virtually non-existent in the first years of Norwegian schooling. The decrease of mathematics enjoyment and increase of boredom, in turn, was in line with our expectations and some previous results (Vierhaus et al., 2016), as well as theoretical considerations (see, Lichtenfeld et al., 2022). However, it should be noted that although reduced, the level of enjoyment remained reasonably high throughout the three years, whereas boredom and anxiety remained low.

The difference in the relative timing of the changes in mathematics enjoyment and boredom – enjoyment decreased particularly between the autumn of the second grade and the autumn of the third grade, while boredom increased particularly over the course of the third grade – suggests that although strongly inversely correlated, they are separate processes, not merely “reverse sides of the same coin”. The reduction in enjoyment and increase of boredom may, on the one hand, be at least in part due to mathematics becoming more challenging from grade to grade, and students’ self-assessment of their abilities more realistic (Fredricks & Eccles, 2002). On the other hand, this development may result from students with good arithmetic skills not finding the syllabus challenging enough (Pekrun et al., 2007).

The rank-order stabilities of enjoyment (r = 0.45–0.65) and boredom (r = 0.50–0.68) were relatively strong, in line with previous observations (Lichtenfeld et al., 2022; Putwain, Becker, et al., 2018), suggesting that these emotional responses to mathematics become fairly established quite early on in students’ academic careers. In other words, the students who enjoy mathematics the most (or indeed, least) remain the same over time, as do those who find it most boring. Conversely, the rank-order stability of anxiety was only moderate (r = 0.20–0.43) and weaker than in some recent studies (Gunderson et al., 2018; Lichtenfeld et al., 2022; Sorvo et al., 2019), especially between the autumn of the second and the autumn of the third grade. Although the skewness and rather limited variance in anxiety measurements might have reduced their correlations, it, nevertheless, appears that some initially more anxious students may become less so over time, and vice versa, and this dynamic warrants further study in future research.

Children’s arithmetic fluency improved from first to third grade as expected (H1.2). In the first grade, many children are still practising their addition and subtraction facts using error-prone and slow counting strategies, which was reflected as a rather low level of performance. Increase in the mean level performance from grade to grade indicates that children have learned to use more efficient calculation strategies, and eventually started to retrieve the facts from long-term memory (Koponen et al., 2019). As expected, significant individual differences were observed in the initial levels and rate of change in arithmetic fluency, suggesting differences in arithmetic skills are present (ten Braak, Lenes, Purpura, Schmitt, & Størksen, 2022; Zhang et al., 2020), and may begin to increase, early in the school years. The rank-order stability between consecutive time points showed to be rather high in arithmetic fluency (r = 0.78–0.84), reflecting prior studies (Sorvo et al., 2019; Zhang et al., 2020) and suggesting that high-scoring first-graders continue to do well over time, whereas students scoring lower in the first

Table 3
Standardised predictive effects with covariate and outcome.

Predictor	Enjoyment				Anxiety				Boredom				AF				Mathematics Performance	
	Initial level		Slope		Initial level		Slope		Initial level		Slope		Initial level		Slope			
	β (SE)	z	β (SE)	z	β (SE)	z	β (SE)	z	β (SE)	z	β (SE)	z	β (SE)	z	β (SE)	z	β (SE)	z
Gender	−.35 (.16)	−2.21*	.07 (.24)	0.27	.02 (.16)	0.12	−.13 (.19)	−0.67	.50 (.15)	3.47**	.23 (.20)	1.12	.21 (.14)	1.53	−.16 (.15)	−1.04	−.13 (.18)	−0.75
Enj. Initial																	−.05 (.20)	−0.24
Enj. Slope																	−.03 (.23)	−0.12
Anx. Initial																	−.21 (.19)	−1.13
Anx. Slope																	.16 (.33)	0.47
Bor. Initial																	.23 (.36)	0.64
Bor. Slope																	−.30 (.39)	−0.76
AF Initial																	.44 (.15)	2.95**
AF Slope																	.37 (.09)	3.86**
R^2	.03		.00		.00		.00		.06		.01		.01		.01			

Note. 0 = girl, 1 = boy. Enj. = Enjoyment; Anx. = Anxiety; Bor. = Boredom; AF = Arithmetic Fluency. $^{**}p \leq .01$; $^{*}p < .05$.

grade perform at a lower level also in the later grades. This was also supported by the positive relationship between the initial level and growth in arithmetic fluency.

Regarding the parallel processes, in agreement with our hypothesis (H2.1) and previous findings, we found the initial level of enjoyment to be negatively related with the initial levels of both anxiety (Raccanello et al., 2019) and boredom (Putwain, Becker, et al., 2018; Raccanello et al., 2019). Furthermore, changes (H2.2) in enjoyment on the one hand, and anxiety and boredom on the other, were inversely and significantly related – in other words, a decrease in enjoyment was linked with an increase in the other two emotions. This makes intuitive sense, as enjoyment is instigated by high control and value appraisals, whereas anxiety arises when perceived value is high but control is low, and boredom when both are low (Pekrun, 2006). In other words, a decrease in enjoyment signifies a reduction in experiences of control, value, or both, and reduced levels of control and/or value, in turn, are characteristic of anxiety and boredom.

Low control appraisals being characteristic of both anxiety and boredom (Pekrun, 2006) may also explain the positive connections we observed between their initial levels, in line with prior research (Lichtenfeld et al., 2022; Raccanello et al., 2019), as well as between their respective slopes. Although this finding suggests that children's anxiety and boredom may increase in parallel, we somewhat surprisingly also observed significant negative connections between the initial level of anxiety and the slope of boredom, and the initial level of boredom and the slope of anxiety. It hence appears that high MA early in a child's school career does not necessarily result in increased boredom, possibly due to differences in the respective relationships anxiety and boredom have with mathematics value. If mathematics is valued, but one is unsure of one's abilities, anxiety may ensue (Pekrun, 2006). Conversely, students' high boredom in the beginning stages of the school years may indicate low mathematics value (Putwain, Pekrun, et al., 2018), which, in turn, might explain the inverse connection with the development of MA. Also unexpected was the positive connection between initial level of enjoyment and increasing anxiety. Again, this may be connected to the perceived value of mathematics, in that some children who enjoy mathematics and consider it as personally valuable may also experience uncertainty and worry about their skill levels and ability to succeed in this valued domain (see, Pekrun, 2006). Another explanation might be that the overly positive appraisals young children often have of their own skills and abilities in a domain (Fredricks & Eccles, 2002) tends to change over time, as students develop a more realistic view both of the demandingness of mathematics as a subject domain, and their own abilities in it. This, in turn, could conceivably result in increased anxiety.

In line with our expectations and reflecting previous research, all achievement emotions were linked with arithmetic fluency – mathematics enjoyment positively (Camacho-Morles et al., 2021), and anxiety (Gunderson et al., 2018; Sorvo et al., 2019) and boredom (Camacho-Morles et al., 2021) negatively – already in the spring of the first grade. The initial levels of the emotions were also similarly related to the change in arithmetic fluency, reflecting previous findings in which earlier mathematics enjoyment and boredom have predicted subsequent mathematics achievement (Lichtenfeld et al., 2022; Putwain, Becker, et al., 2018). However, changes in the emotions were largely unrelated either to the initial level of or changes in arithmetic fluency. As an exception, there was a minor positive connection between the initial level of arithmetic fluency and an increase in boredom, suggesting that students with good arithmetic skills in first grade may experience boredom, perhaps due to a lack of challenge (Pekrun et al., 2007).

Unsurprisingly, the initial levels and rate of change in arithmetic fluency were predictive of mathematics performance at the end of the third grade, in line with our assumption (H3.1). However, in spite of the links between achievement emotions and arithmetic fluency, and against our expectation, none of the emotions predicted third grade mathematics performance (H3.2), possibly due to the strength of arithmetic fluency as a predictor. Then again, with the exception of anxiety, emotions at each measurement point failed to correlate with curriculum-based mathematics performance, thus contributing to the given finding. Unfortunately, the data do not provide us with means to elaborate this lack of connection more thoroughly.

As expected (H4), there were no differences in girls' and boys' arithmetic skill development or mathematics performance. However, some gender effects in the achievement emotions were observed. Contrary to some previous findings (Lichtenfeld et al., 2012), girls reported higher initial enjoyment, and boys higher initial boredom. Previously, boys experiencing higher boredom than girls has been observed in native language studies (Raccanello et al., 2019), as well as regarding school lessons in general (Vierhaus et al., 2016). However, although enjoyment of school lessons has been noted to decrease more among boys compared with girls (Vierhaus et al., 2016), we found gender unrelated to changes in the emotions over time, possibly due to the younger age of our participants.

4.1. Limitations, future directions, and practical implications

Naturally, this study has some limitations. The sample size was relatively small, especially in relation to the complexity of the models, and socio-economically fairly homogenous, although this also enabled us to minimise the effect of other factors on the relationships under examination (see, Vierhaus et al., 2016). Although we were able to follow our participants over the first three school years, the Covid-19 pandemic forced us to change the way data were collected at t4, and the way of collecting data (i.e., in person vs. online) may have been reflected in students' responses. Finally, future studies should include measurements related to control (e.g., mathematics self-concept) and value (e.g., mathematics interest) that enable explaining individual differences in the levels of and changes in achievement emotions. However, as it stands, the present study offers new knowledge on the early development and parallel processes of various emotions central for learning, as well as some practical implications.

Teachers should be aware that the developmental trajectories of students' mathematics emotions and arithmetic skill vary significantly already in early grades. Intensified educational support should be provided especially for those struggling to learn basic arithmetic skills already from the early school years, as it was demonstrated here to be linked both with later, more general mathematics performance, and with learning-related emotions. Further, teachers should pay attention to creating a mathematics learning environment that promotes positive emotions in mathematics and alleviates negative emotions (e.g., giving suitably challenging mathematics tasks related to students' interests, providing positive feedback, showing interest in mathematics). This seems to be more critical when students get older, as positive emotions decrease and negative emotions, especially boredom, increase.

4.2. Conclusions

This study examined the development of and parallel processes between mathematics-related achievement emotions and arithmetic fluency over the course of the first three school years. The educationally maladaptive developmental patterns of decreasing mathematics-related enjoyment and increasing boredom were observed over time. Further, changes in emotions were connected to each other, meaning that a decrease in enjoyment was linked with an increase in boredom and anxiety. Still, the mean level of enjoyment remained fairly high, and of both boredom and anxiety quite low. Although the developmental trajectories of achievement emotions failed to predict later mathematics performance independently, the patterns of connections observed suggest them to be linked with students' mathematics skills, and thus, important to take into account in mathematics teaching.

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Code availability

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Consent for participation

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Consent for publication

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Declaration of competing interest

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.learninstruc.2023.101776.

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