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Real-time fluctuations in student emotions and relations with day of the week, time of the day, and teaching methods

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Introduction: This study investigated the real-time variability of secondary school students' academic emotions (i.e., enjoyment, enthusiasm, boredom, and frustration) in mathematics classes, examining their relation to the day of the week, time of the day, and teaching methods. Utilizing experience sampling methodology, the research captures the dynamic nature of emotions as states, providing insights into their situational dynamics.

Methods: 440 students reported twice during their mathematics classes for a period of 10 school days on their real-time experiences of academic enjoyment, enthusiasm, boredom, and frustration. Additionally, their teachers indicated the teaching methods that were used on each measurement occasion.

Results: Results indicated students to have a more positive emotional pattern on Fridays (i.e., a "Thank God it's Friday" effect) and Wednesdays, likely due to the anticipation of leisure time. Additionally, a "Frustrating Tuesday" effect was observed, while no evidence was found for a "Blue Monday" effect. Time of the day effects were less consistent, with frustration increasing throughout the day and boredom being higher in the afternoon, possibly due to postprandial somnolence (i.e., post-meal dip). Teaching methods differently related to emotions; during individual and group work students experienced more enjoyment and enthusiasm but also more frustration compared to whole-class instruction. During classroom discussion more frustration was experienced relative to whole-class instruction. Female students experienced less enthusiasm than male students, and higher ability students experienced more enjoyment, enthusiasm and less boredom than lower ability students.

Discussion: This study underscores the importance of considering temporal factors and teaching methods in understanding students' emotional experiences in educational settings.

KEYWORDS

academic emotions, day of the week, time of the day, teaching methods, experience sampling method, mathematics

Introduction

Students' emotional experiences in school are highly important as they have been linked to various crucial student outcomes such as academic achievement, dropout, self-regulated learning, and social functioning (Camacho-Morles et al., 2021; Frenzel and Stephens, 2013; Pekrun and Linnenbrink-Garcia, 2012). Moreover, emotions serve as important outcomes in themselves as they constitute essential facets of students' psychological well-being (Frenzel and Stephens, 2013). The growing recognition of the importance of academic emotions has contributed to a recent increase of studies investigating why and when students experience certain emotions in school. As such, several predictors of academic emotions have been proposed and examined in the literature, such as teaching and task characteristics (e.g., Goetz et al., 2020; Krannich et al., 2022; Mainhard et al., 2018). One such teaching characteristic that may be particularly relevant for student emotions are the teaching methods used by the teacher (Bieg et al., 2017). However, studies on student emotions predominantly used retrospective student surveys that measure student emotions as traits. Yet, these methods are known to be affected by memory biases. Moreover, emotions are highly dynamic in nature, fluctuating across time as a function of external events and internal regulation efforts. In order to understand what drives emotions in the classroom, research should thus examine how they evolve over time as states, not as traits. Yet, such research is scarce. Consequently, little is known about the real life variability of students' academic emotions throughout and across school days, and how these emotions fluctuate in response to teaching methods. To fill this gap, the present study aims to describe the situational dynamics of students' emotions and to examine a number of possible determinants of these dynamics in terms of how they relate to the day of the week, time of the day and teaching methods. In doing so, experience sampling methodology will be used in actual mathematics classes.

Academic emotions

When emotions are related to learning and achievement contexts (e.g., while listening to a teacher at school, while doing homework), they are referred to as academic emotions (Pekrun, 2006). Academic emotions can be further subdivided into two types according to their object focus. Emotions can be categorized as activity-related when experienced in an ongoing academic activity (e.g., enjoyment, boredom), or as outcome-related when they are linked to the anticipatory or known outcome of that activity (e.g., anxiety, pride; Pekrun, 2006). Further, in line with circumplex models of emotions (e.g., Feldman Barrett and Russell, 1998), academic emotions can be described along two orthogonal dimensions of valence (i.e., positive versus negative states) and activation (i.e., activating versus deactivating states).

A prominent theory on the antecedents and effects of academic emotions is Pekrun's (2006) control-value theory. According to this theory, students' appraisals of control and value are the primary antecedents of their academic emotions (e.g., Goetz et al., 2020; Pekrun et al., 2010). Control appraisals refer to students' perceptions of the influence they have over their learning activities and outcomes, whereas value appraisals refer to students' perceptions of valence of their learning activities and outcomes. The theory further assumes that depending on the control and value appraisals and the object focus (i.e., whether the emotion is outcome- or activity-related), different academic emotions are experienced. As such, situational classroom factors and individual factors are assumed to influence the emotions experienced in school through their impact on students' control and value appraisals. Further, control-value theory highlights the importance of investigating academic emotions as separate constructs as each emotion is theorized to have different effects and antecedents.

Emotions are primarily defined as dynamic, short-lived states that alert the individual to important changes in the immediate environment and motivate the individual to respond to these changes (Pekrun, 2006; Rosenberg, 1998; Scherer and Moors, 2019). However, previous studies have predominantly approached student emotions as traits (e.g., Bieg, 2013; Ganotice et al., 2016; Raccanello et al., 2019), which reflect more enduring patterns of emotional tendencies or proneness to experience certain emotional states more frequently or intensely than others (Frenzel et al., 2021; Pekrun, 2006). Yet, examinations of state emotions are essential in understanding how students' emotional responses emerge and vary in function of individual, situational and temporal characteristics. While research investigating emotions as traits holds importance for examining and explaining stable between-person differences or long-term trends, it falls short in capturing the dynamic nature and real-time variability of students' emotions in its natural school setting and how emotional experiences are shaped by situational and short-term temporal factors. Due to limited research on state emotions in academic settings, little is known on the natural fluctuations and dynamics of students' real-time experiences of academic emotions in their classes. In the present study, we focused on two positive and two negative activity-related academic emotions that vary in their level of activation: enjoyment, enthusiasm, boredom and frustration.

Despite being few in number, some studies have examined the situational variability of students' enjoyment and boredom in their natural classroom environments. State levels of academic enjoyment and boredom have for instance been linked to teacher and teaching characteristics such as teacher emotions, teaching methods, supportive presentation style, and to task characteristics such as the difficulty level of a class (Becker et al., 2014; Bieg et al., 2017; Goetz et al., 2020; Krannich et al., 2022). Most studies, however, did not assess state emotions in real time during classes (e.g., instead used post-lesson questionnaires, which are also subject to retrospective biases; Donker et al., 2021; Mainhard et al., 2022), and research has mostly focused on a restricted set of emotional states, leaving the dynamics of enthusiasm and frustration largely unaddressed. Moreover, although research has paid some attention to situational predictors of academic emotions, temporal factors that may play a role in the emotional experiences of students in academic settings have been largely neglected. Existing evidence nevertheless points to daily and weekly patterns of individuals' general affect (i.e., a general construct compiling various positive or negative emotional states) in daily life (e.g., Miller et al., 2015; Stone et al., 2012). As such, the day of the week and time of the day may introduce systematic variability in students' academic emotions throughout and across schooldays. From an educational perspective, identifying time patterns in academic emotions may aid educators in optimally scheduling learning materials in order to foster positive learning and emotional experiences in students. From a scientific perspective, time effects may function as important control variables in future studies on student emotions in order to increase validity, reliability and replicability of results.

Day of the week

The day of the week is commonly believed to have an influence on our affect, with the most negative affect on Mondays and the most positive affect on Fridays and weekends. Empirical research generally supports this weekly cycle in affect as evidence has been found for a "Blue Monday" effect, a "Thank God it's Friday (TGIF)" effect, and a weekend vs. weekday effect. Concerning the "Blue Monday" effect, several investigations have shown that Mondays tend to be characterized by higher levels of negative affect and lower levels of positive affect as compared to the other weekdays (e.g., Suk et al., 2021; for a meta-analysis, see Areni et al., 2011). Additionally, studies have demonstrated individuals to experience more positive and less negative affect on Fridays as compared to the other weekdays likely due to the anticipation of leisure time available on the weekend, representing the "TGIF" effect (e.g., Reis et al., 2000; Stone et al., 2012; Suk et al., 2021). Yet, few studies have examined day of the week effects on emotions in student samples, with the available studies focusing largely on higher education. In Chow et al. (2005), college students reported at the end of each day during 53 days how often they felt the emotions of love, joy, sadness, fear, anger, and shame. The authors found that positive emotions increased from Mondays through Saturdays, whereas negative emotions peaked in the middle of the week. In a study by Csikszentmihalyi and Hunter (2003), elementary and secondary school students reported on their happiness levels throughout the day both during and after school hours for a period of 1 week. Descriptive results indicated that happiness levels increased from Mondays through Saturdays, although differences between weekdays were not statistically significant. These studies, however, did not specifically assess students' experiences in a school setting.

Despite these findings, results on day of the week effects have been equivocal, and previous studies have typically suffered from small sample sizes. For instance, in Stone et al. (2012), no evidence was found for a "Blue Monday" effect when controlling for affect on Fridays, implying that experiencing a negative affect on Mondays as compared to other days of the week could be attributed to the contrast with the generally positive affect people tend to have on Fridays. Most studies, however, do not take into account TGIF effects. Previous studies also suffer from several additional limitations. First, prior research has mainly examined affect as a general construct without differentiating between discrete academic emotions. Second, studies have only to a limited extent used real-time assessments of emotions or affect. Emotions were usually measured using daily diary methods in which individuals reported on their experienced emotions once at the end of each day. Consequently, no information was gathered on real-time emotional experiences in context, which raises concerns about ecological validity and potential recall biases. This is further indicated by the finding that studies that did use real-time assessments (e.g., Areni, 2008; Totterdell et al., 1997) found weaker or no day of the week effects on emotions as compared to studies that asked about past emotional experiences, suggesting that "Blue Monday" or "TGIF" effects may at least to some extent result from inaccurate memories of past experiences (Areni et al., 2011). As a consequence of these limitations, it is fairly unknown to what extent a "Blue Monday" and a "TGIF" effect are also found for secondary school students' discrete emotions experienced in academic contexts.

Time of the day

In addition to the day of the week, also time of the day may contribute to moment-to-moment variability in students' academic emotions. It is plausible to assume that students' emotional experiences in school may show natural fluctuations throughout the day due to physiological changes such as fatigue, hunger or biologically based circadian rhythms (Finn and Pannozzo, 2004; MacCormack and Lindquist, 2019). Fatigue, for instance, has been linked to the experience of emotions, also in academic settings (Palmer and Alfano, 2017). As such, there is mounting evidence that adolescents have higher academic performance, less negative mood and better socioemotional outcomes when having a longer sleep duration due to later starting times of schools (Yip et al., 2022). That is at least in part attributed to the fact that adolescents experience a shift in their biological clock, leading to a tendency to fall asleep later at night and sleep later in the morning (Crowley et al., 2018). These biological influences might also cause students to be less attentive and to show more negative and less positive emotions in the early morning hours, when students are not yet fully awake.

Prior empirical studies both inside and outside academic settings have consistently found evidence for diurnal patterns in positive affect, but less consistently so for negative affect. Positive affect has been shown to synchronize to internal circadian rhythms, and generally increases from the morning hours until the early afternoon, followed by a plateau phase and a subsequent decline in the evening (Barber et al., 1998; Miller et al., 2015; Murray et al., 2002). Negative affect has generally proven to be rather stable throughout the day (e.g., Itzek-Greulich et al., 2016; Murray, 2007), although some studies do find a small but progressive decline in negative affect (e.g., Kivelä et al., 2022), and others indicate an increase throughout the day (Murray et al., 2002). Despite these findings, previous studies rarely focused on diurnal variations of emotions within academic settings (for exceptions see, e.g., Díaz-Morales et al., 2015; Itzek-Greulich et al., 2016), resulting in a paucity of knowledge on the within-day experiences of students in secondary education. Further, as for day of the week effects on emotional experiences, studies on time of the day effects focused mainly on general affect measures rather than discrete emotions. Gaining insights into the variability of secondary school students' academic emotions throughout the school day may aid in optimal planning of learning materials.

Teaching methods

As indicated by the control-value theory and empirical evidence, teaching characteristics such as value induction, autonomy support, and structure may serve as important distal antecedents of students' academic emotions (Goetz et al., 2013; Goetz et al., 2020; Pekrun, 2006). Also the teaching methods used by the teacher may be crucial for students' emotional experiences in class. Following the definition of Bieg et al. (2017), we refer to teaching methods as "a group of specific teaching principles and activities used for classroom instruction" (p. 413). Specifically, the present study focused on whole-class instruction (i.e., the teacher gives instructions in front of all students in class), individual work (i.e., students work on individual tasks), group work (i.e., students work on tasks in smaller groups), and classroom discussion (i.e., dynamic verbal exchanges between the teacher and students). Previous studies have consistently found whole-class instruction to be the most frequently used teaching method in mathematics classes across grade levels and countries (Bieg et al., 2017; Hiebert et al., 2003).

Building on control-value theory (Pekrun, 2006) and Self-Determination Theory (Ryan and Deci, 2002), teaching methods may be argued to affect student emotions in different ways. In line with control-value theory, teaching methods may influence students' emotions via their control appraisals. During whole-class instruction, the teacher has control over the pace of instruction and the selection of learning materials, which may limit students' freedom of choice and customization of their learning experience (Bieg et al., 2017). Conversely, individual and group work allows students greater freedom to set their own pace and to select appropriate learning materials, thereby accommodating their individual needs more effectively. Also during classroom discussion, students are given the opportunity to express their own opinions and input. For these reasons, whole-class instruction may evoke less optimal levels of control relative to the other teaching methods and may therefore have a more negative effect on student emotions. From the perspective of Self-Determination Theory too (Ryan and Deci, 2002), individual work, group work, and classroom discussions may more than whole-class instruction fulfill students' need for autonomy, which is considered crucial for human motivation and may result in a more positive emotional experience. On the other hand, however, whole-class instruction may also provide students with more structural support, thereby fulfilling their need for competence. Moreover, the effect of teaching methods on students' emotions may depend on the type of learning materials or the learning goal that they aim to address.

Nevertheless, one experience sampling study has provided preliminary support for these assumptions by showing that teaching methods were associated with students' emotions in school, some of which were mediated by pace of instruction and perceived choice (Bieg et al., 2017). Specifically, students experienced higher levels of enjoyment and pride and lower levels of boredom during individual and small-group work relative to whole-class instruction. However, differences in student emotions across teaching methods found in Bieg et al. (2017) were mostly only marginally significant, possibly due to the small number of measurements resulting in limited observations for some of the teaching methods. With the exception of Bieg et al. (2017), there generally is little empirical research linking teaching methods to student emotions.

The present study

Given the connections of students' emotions with their academic performance and overall development, it is imperative to gain insights into the natural course of students' academic emotions and its predictors in order to foster emotional experiences that promote optimal learning experiences. Therefore, the present study relied on experience sampling methodology to examine the moment-to-moment variability of student enjoyment, enthusiasm, boredom and frustration in natural mathematics classes, and how different contextual factors (i.e., day of week, time of day, and teaching methods) may contribute to these fluctuations. Using experience sampling methodology allows the real-time assessment of emotional states in context, therefore taking into account the dynamic and context-dependent nature of academic emotions while minimizing potential recall bias and ensuring high ecological validity (Scollon et al., 2003).

The study focused on the subject of mathematics given its universality in schools across countries, its significance for students' further school trajectories (Lauermann et al., 2017), and its high number of classes taught per week in the general track in Flanders, ensuring sufficient measurements. The study sample consists of students from the academic track in Grade 11 and 12 in Flanders, Belgium. The end of secondary education is a crucial developmental period to focus on as students are preparing for their transition to higher education. The emotional experiences of students during this time may significantly impact their goal setting and career choice in higher education.

The following research objectives were addressed:

RO1: To examine whether students' real-time academic emotions are related to the day of the week. First, the overall pattern of emotional experiences was explored for each day of the week. Second, it was examined whether "Blue Monday" and "Thank God it's Friday" effects were found for students' experiences of enjoyment, enthusiasm, boredom and frustration in mathematics classes. Based on previous research outside the academic context, we tentatively expected students to experience less positive emotions (i.e., enjoyment and enthusiasm) and more negative emotions (i.e., boredom and frustration) on Mondays as compared to the other weekdays, and more positive emotions and less negative emotions on Fridays as compared to the other weekdays.

RO2: To examine whether students' real-time academic emotions are related to the time of the day. First, the overall pattern of emotional experiences throughout the school day was explored. Second, it was examined whether students' academic enjoyment, enthusiasm, boredom and frustration differ between mornings and afternoons. Based on the diurnal affect patterns found in previous studies, we tentatively expected enjoyment and enthusiasm to be higher in the afternoon as compared to before noon, whereas there were no expectations for frustration and boredom.

RO3: To examine whether students' real-time academic emotions are related to the teaching methods used in class. First, the overall pattern of emotional experiences were explored for each teaching method. Second, we examined differences in students' academic emotions between whole-class instruction on the one hand and individual work, group work and classroom discussion on the other hand. Building on control-value theory and Self-Determination Theory, we tentatively hypothesized students to experience lower levels of enjoyment and enthusiasm, and higher levels of boredom and frustration during whole-class instruction relative to individual work, group work and classroom discussion.

For all of the above research objectives, main effects and interactions with the student background characteristics sex and mathematics ability were additionally explored as they may play a role in students' emotional experiences. First, it is often observed that, in the domains of mathematics, girls indicate less positive emotions and more negative emotions and attitudes than boys, potentially influenced by the stereotyping of mathematics as a male domain (Frenzel et al., 2007; Hyde et al., 1990). Second, students' academic performance has been linked to a higher valuation of school and to more positive and less negative academic emotions (Pekrun et al., 2009; Vu et al., 2022). As such, varying levels of mathematics ability may result in varying emotional experiences in class. While we formulate no particular expectations of the effects of sex and mathematics ability for research objective 1 and 2, we tentatively predicted that individual work would evoke more positive emotions and less negative emotions for students with higher ability levels (RO3). This is because it has often been suggested that autonomy is particularly important for high-ability students (Figg et al., 2012) and because they have a greater need for individualization of the pace of instruction (Barbier et al., 2023; Eddles-Hirsch et al., 2010), both of which we expect to be met more during individual work.

Understanding the role of contextual factors in students' academic emotions has implications for theories on academic emotions and motivation, as well as for future research and teacher practice, which can be tailored accordingly. Additionally, findings will indicate the extent to which emotional experiences and their relations with teaching methods and temporal factors are generalizable across sex and ability levels, allowing the identification of individual-specific educational needs.

Methods

Participants

To determine the required sample size, the application of Lafit et al. (2021) was used to perform a simulation-based statistical power analysis for a two-level model with cross-level interactions ($\alpha = 0.05$, power = 0.80). Model parameters were based on a small subset of our data (i.e., data from the first four participating class groups). Based on the power analysis, we aimed to recruit a minimum of 300 students. The final study sample consists of 440 secondary school students (57% are females) from the 11th ($n = 337$) and 12th Grade ($n = 103$) from 25 class groups in 11 schools. Students had a mean age of 16.75 ($SD = 0.66$). Class groups of students and their mathematics teachers were recruited by advertisements in the newsletters of different educational networks and by email invitations that were sent to secondary schools participating in the TALENT study (PI: Karine Verschueren) and the project 'Voorbeeldscholen Cognitief Sterk Functioneren' (PI: Karine Verschueren). Class groups were recruited from the academic track (approximately 33% of 11th and 12th Grade students attend this track), and class groups with a high number of mathematics lessons per week were oversampled (79% of the sample), resulting in a sample selective on mathematics ability. In return for their participation, schools received aggregated feedback on the in-class experiences of the students in each participating class group, a practical book on guiding high-ability students, and free access to a study day. The total dataset consists of 6,497 non-missing ESM assessments for each academic emotion that was included in the study.

Procedure

This study used data from the MOMENT-study (MOmentary assessments of Motivation, ENgagement and emoTions in school). The study was approved by the Social and Societal Ethical Committee of KU Leuven (G-2021-4017). Data collection took place over a period of 4 weeks in each school. Three schools completed data collection in May 2022, whereas the other eight schools participated in October and November 2022. In week 1, students and mathematics teachers provided informed consent before study participation and subsequently filled out a student or teacher survey not relevant for the present study.

During weeks 2 and 3, experience sampling (ESM) took place. For a period of 10 consecutive school days, students reported twice during each mathematics class on their real-time emotions (i.e., enjoyment, enthusiasm, boredom, and frustration). During this 10-day ESM period, the total number of mathematics classes varied between the different class groups, as the number of weekly mathematics classes depends on the specific study program (the number ranges from 3 to 8 mathematics classes per week). Over the course of the 10-day ESM period, the average number of mathematics classes attended by a class group was 9.12. Using the m-Path app (Mestdagh et al., 2023), students reported on their momentary emotions, whereas mathematics teachers of participating class groups reported on the teaching methods used in class. The app was installed on their personal smartphone, or in case they did not have a smartphone themselves or its usage was not allowed by the school, a research dedicated smartphone.

To avoid predictability of assessments and to increase ecological validity, the app of the mathematics teacher beeped twice during each mathematics class using semi-random intervals to indicate when both students and teacher had to report on the items. Specifically, during each class, beeps were set to occur randomly between the first 10 and last 5 minutes of the class with a minimum interval of 5 minutes between both beeps. As such, all students and teacher from the same class group reported on the ESM questions at the exact same time (which was semi-randomly generated for each mathematics class), but measurement occasions varied between class groups. In total across all class groups, 456 beeps were sent to the teacher of which 14 were neglected by the teacher due to technical problems, planned exams or canceled classes, resulting in missingness for the whole class group (in total there were 222 missing assessments at the class level). No systematic registration was done for individual-level missingness, but oral debriefing with teachers revealed that individual missingness generally resulted from absence of the student or technical problems with the app (in total there were 1,259 (15.78%) missing assessments at the individual level).

Consistent with other experience sampling studies, all variables were assessed using single-item measures. The use of single items is a standard practice in experience sampling studies (Gogol et al., 2014). It is crucial for limiting participant burden (and hence jeopardizing data quality and compliance) due to the repeated nature of assessment (Myin-Germeys and Kuppens, 2022). All items were based on existing validated measures and were rated on a scale from 0 to 100. In the week after the experience sampling period (week 4), a standardized mathematics test was administered that lasted 2 hours.

Study measures

Academic emotions

Students' academic emotions were assessed during experience sampling using single-item measures for enjoyment, enthusiasm, boredom and frustration. Twice during each mathematics class students reported on the item "*During the preceding part of the class, how much [EMOTION] did you experience?*" on a continuous scale ranging from 0 (*very little*) to 100 (*very much*).

Day of the week

A Unix timestamp was automatically recorded by the m-Path app and indicates when students filled in the ESM items (in seconds since epoch). Based on this timestamp, a categorical variable was created indicating the day of the week.

Time of the day

Based on the Unix timestamp, a categorical variable was created indicating whether responses were given before (0) or after (1) noon (12:00 p.m.). Additionally, a variable was created representing continuous within-day time in hours passed since midnight (12:00 a.m.).

Teaching methods

Mathematics teachers reported on the teaching methods they used during their classes using a multiple choice question: "*During the preceding part of the class, which teaching methods did you use?*" Multiple response options could be selected per measurement occasion and options consisted of: "*whole-class instruction*," "*individual work*," "*group work*," "*classroom discussion*," and "*other, please describe*." All teaching methods indicated as "*other*" were not included in the analyses. For each teaching method a binary variable was created indicating whether the method was used (1) by the teacher during the preceding part of the class or not (0).

Mathematics ability

Mathematics ability of students was measured with a standardized mathematics test, which was developed in the context of the LiSO project in which students in Flanders were followed throughout secondary school (https://lisoproject.be; Van den Branden et al., 2019). The test consists of 42 questions covering different mathematical domains (e.g., Algebra, Geometry, and Statistics) and was carefully constructed based on the learning goals and curricula in secondary education in Flanders. Further, the test was found to have good reliability and validity, and a factor analysis revealed that the sum scores represented one underlying dimension of mathematics ability (Dockx and Denies, 2020). Sum scores were used as indicators of students' mathematics ability level.

Sex

The biological sex of students was provided by schools and added as a binary variable categorized as 0 for male students and 1 for female students.

Analysis plan

First, descriptive statistics are reported for all four academic emotions. This includes descriptive means, standard deviations, and bivariate between- and within-person correlations between all academic emotions. Additionally, for each academic emotion, an empty multilevel model was run to extract the intraclass correlation coefficient to determine how much of the variability in each academic emotion is situated at each level of analysis. Mean levels of each emotion (taken into account the data structure) are indicated by the intercepts of these models. Subsequently, students' sex was added to these empty models as a categorical predictor to explore whether mean levels of emotions differed between female and male students. Similarly, mathematics ability was added as a predictor to the empty models to explore whether mean levels of student emotions differed according to mathematics ability level.

To investigate our research objectives, three-level multilevel models with fixed effects were run with measurements nested in students nested in class groups. For each predictor variable (day of the week, time of the day, and teaching methods), we planned to first explore their overall effects on academic emotions, followed by a more specific examination of our proposed hypotheses.

To explore overall day of the week effects on students' emotional experiences (RO1), dummies for each day of the week were added to an empty multilevel model without intercept for each emotion. To address our research objectives, it was subsequently examined whether a "Blue Monday" and a "Thank God it's Friday (TGIF)" effect were present in students' academic emotions by comparing mean levels of each academic emotion as experienced on Mondays, respectively, Fridays (dummy coded as 1) to the levels of the same emotion experienced on either Tuesdays, Wednesdays, or Thursdays (dummy coded as 0). By not including emotions experienced on Fridays or Mondays as part of the rest of the week in the analyses, we disentangle "Blue Monday" from "TGIF" effects. Both dummies were separately included as a predictor to an empty multilevel model for each emotion. Finally, main effects and interactions between both dummies and sex or mathematics ability (grand-mean centered, M = 17) were added to the models to explore their effects.

To explore overall fluctuations of students' academic emotions throughout the school day (RO2), a multilevel model was run for each academic emotion with grand-mean centered time (operationalized as hours passed since midnight) and grand-mean centered time squared as predictor variables. Time was included as a squared predictor variable in addition to a linear predictor of time in order to allow the description of curvilinear patterns throughout the day as these have been repeatedly described for emotions and physiological responses in previous studies (e.g., MacCormack and Lindquist, 2019; Miller et al., 2015; Murray et al., 2002).

The modeled within-day trajectory of each emotion on the basis of these models was subsequently plotted. To examine our second research objective (i.e., whether students' emotions differ between mornings and afternoons), a dummy indicating whether responses were given before or after noon (operationalized as before and after lunch time) was added to the empty multilevel models. Finally, interactions between the dummies and sex or mathematics ability (grand-mean centered) together with their main effects were added to the model.

Finally, the overall effects of teaching methods used in class on academic emotions (RO3) was explored by calculating descriptive means for each emotion as experienced during each teaching method (either in combination with other methods or not). In addition, the frequency of each teaching method was reported in percentages. Further, to explore our third research objective, dummies indicating whether responses were given during whole-class instruction alone (0) or during either other teaching method (i.e., individual work, group work or classroom discussion; either in combination with other methods or not; 1) were separately added to the empty multilevel models. Finally, interactions between these dummies and sex or mathematics ability (grand-mean centered) together with their main effects were added to the model. We used conventional levels of statistical significance ($p = 0.05$), applied pairwise deletion at the measurement level for missing data, and all analyses were conducted in R/R Studio.

Results

Descriptive statistics

Average within-person means (i.e., mean of all student-specific means) and average within-student variability (i.e., mean of all student-specific standard deviations) over time of each academic emotion (on a scale from 0 to 100) and bivariate between-person (i.e., correlations between students' means across measurements) and within-person correlations (i.e., correlations between measurements centered around each students' mean) between all academic emotions are reported in Table 1. Enjoyment showed strong positive between- and within-person correlations with enthusiasm, medium to strong negative between- and within-person correlations with boredom, and medium negative between- and within-person correlations with frustration. Enthusiasm showed medium negative between- and within-person correlations with boredom, and weak to medium between- and within person correlations with frustration. Finally, boredom and frustration showed medium positive correlations. Correlations were generally weaker within students than between students.

For each emotion, the variability situated at each level of analysis is represented by the intraclass correlation coefficient (ICC) extracted from empty multilevel models (Table 2). For all emotions, most of the variability was explained by differences between measurements within students (level 1), followed by differences between students within a class (level 2), with relatively little of the variability explained by differences between class groups (level 3). Comparatively, negative academic emotions had slightly more variability situated at the within-student level (level 1) compared to positive emotions. These findings highlight the importance of using experience sampling to provide state-level assessments of students' academic emotions in addition to the trait-level assessments of emotions mainly used in previous studies to fully capture the natural variability of students' emotional experiences in class. Further, as presented in Table 2, the intercepts of the empty multilevel models showed that students experienced on average medium levels of enjoyment and enthusiasm during mathematics classes, and relatively low levels of boredom and frustration.

Finally, results revealed significant sex differences in mean levels of positive academic emotions, with female students experiencing on average significantly lower levels of enthusiasm, $\beta(SE) = -4.58(1.60)$, $p = 0.005$, during mathematics classes than male students. No differences between female and male students were found in the mean levels of enjoyment, $\beta(SE) = -3.20(1.65)$, $p = 0.053$, boredom, $\beta(SE) = -1.54(1.68)$, $p = 0.36$, and frustration, $\beta(SE) = 1.29(1.89)$, $p = 0.50$. Finally, students' average emotional experiences varied in function of their mathematics ability levels. Students with higher mathematics ability levels experienced on average significantly higher levels of enjoyment, $\beta(SE) = 0.50(0.16)$, $p = 0.002$, higher levels of enthusiasm, $\beta(SE) = 0.45(0.16)$, $p = 0.004$, and lower levels of boredom, $\beta(SE) = -0.35(0.16)$, $p = 0.033$. Mathematics ability was not related to the experience of frustration, $\beta(SE) = -0.33(0.18)$, $p = 0.071$.

TABLE 1 Average within-person means, average within-person variability over time (SD), and bivariate within- and between-person correlations between academic emotions.

Variable	*M*	*SD*	(1)	(2)	(3)	(4)
(1) Enjoyment	53.44	15.18	–	0.91***	−0.60***	−0.35***
(2) Enthusiasm	50.59	15.70	0.60***	–	−0.59***	−0.30***
(3) Boredom	38.60	18.07	−0.37***	−0.35***	–	0.50***
(4) Frustration	31.36	18.88	−0.35***	−0.29***	0.30***	–

Between-person correlations are presented above the diagonal, whereas within-person correlation are presented below the diagonal. M, Average within-person means, SD, Average within-person variability over time expressed in standard deviations.
*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.

Academic emotions and day of the week

Overall day of the week effects on academic emotions

Mean levels of each academic emotion on each weekday are plotted in Figure 1. Generally, the plots suggest that students tend to experience more positive and less negative emotions on Wednesdays and Fridays, with comparable mean levels on Mondays, Tuesdays, and Thursdays. Only for students' experience of frustration, there seemed to be a peak on Tuesdays.

"Blue Monday" and "Thank God it's Friday" effects on academic emotions

As presented in Table 3, our findings did not support a "Blue Monday" effect. Specifically, no significant differences were found

TABLE 2 Means and intraclass correlations extracted from empty multilevel models.

	Enjoyment	Enthusiasm	Boredom	Frustration
	β(*SE*)	β(*SE*)	β(*SE*)	β(*SE*)
Intercept	54.02 (1.63)	51.51 (1.46)	37.97 (1.44)	31.06 (1.48)
Intraclass correlations				
Level 1 (measurements)	0.49	0.52	0.58	0.57
Level 2 (students)	0.42	0.41	0.37	0.39
Level 3 (class groups)	0.09	0.07	0.05	0.04

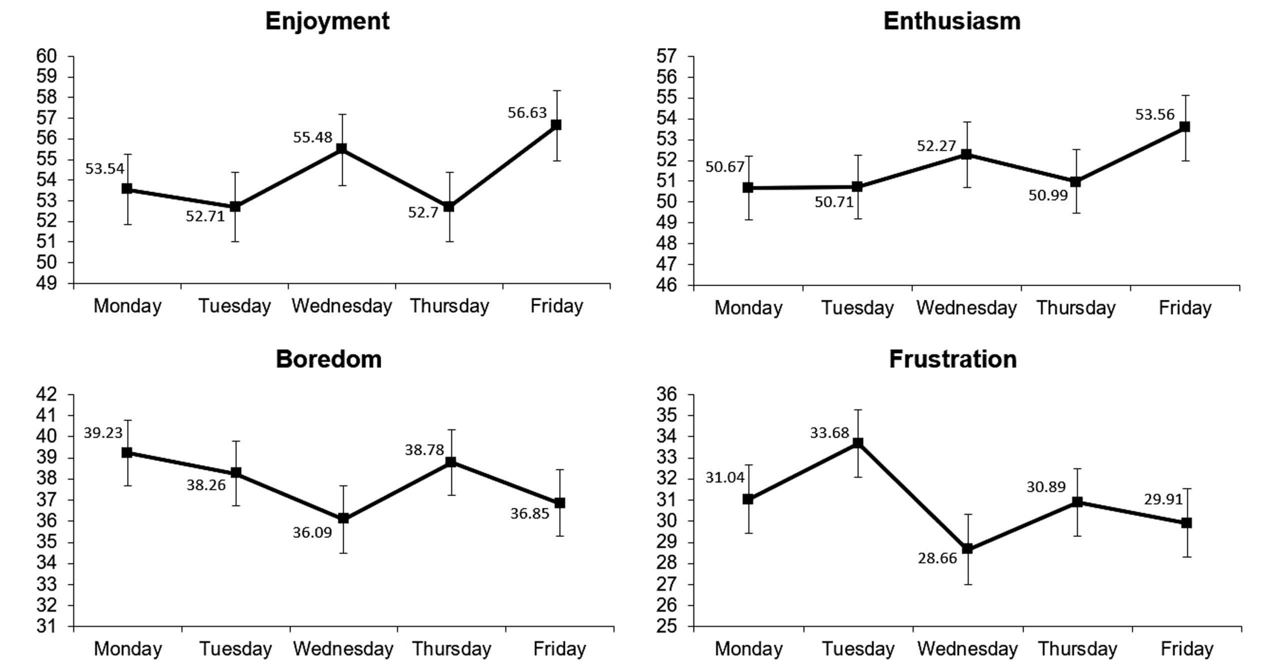

FIGURE 1
Mean levels of students' academic emotions in function of the day of the week. Error bars represent standard errors.

TABLE 3 Multilevel models examining "Blue Monday" and "Thank God it's Friday" effects on academic emotions.

	Enjoyment		Enthusiasm		Boredom		Frustration	
	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*
Intercept	53.46 (1.67)	< 0.001	51.25 (1.43)	< 0.001	37.76 (1.45)	< 0.001	31.14 (1.61)	< 0.001
BM	0.23 (0.58)	0.69	−0.43 (0.59)	0.47	1.27 (0.68)	0.061	−0.23 (0.73)	0.75
Intercept	53.51 (0.59)	< 0.001	51.35 (1.56)	< 0.001	37.84 (1.84)	< 0.001	31.41 (1.41)	< 0.001
TGIF	3.51 (0.59)	< 0.001	2.48 (0.61)	< 0.001	−1.34 (0.69)	0.052	−1.68 (0.75)	0.025
Intercept	53.01 (1.69)	< 0.001	50.88 (1.44)	< 0.001	38.57 (1.46)	< 0.001	31.74 (1.63)	< 0.001
WED	2.55 (0.71)	< 0.001	1.32 (0.73)	0.070	−2.56 (0.83)	0.002	−3.36 (0.89)	< 0.001
Intercept	–	–	–	–	–	–	30.13 (1.65)	< 0.001
TUE	–	–	–	–	–	–	3.26 (0.71)	< 0.001

BM, Blue Monday (0 = Tuesday, Wednesday or Thursday; 1 = Monday); TGIF, Thank God it's Friday (0 = Tuesday, Wednesday or Thursday; 1 = Friday); WED, Wednesday effect (0 = Monday, Tuesday, Thursday; 1 = Wednesday); TUE, Frustrating Tuesday effect (0 = Monday, Wednesday, Thursday; 1 = Tuesday).

when comparing academic emotions experienced on Mondays to emotions experienced on Tuesdays, Wednesdays, and Thursdays combined. Further, findings largely provide support for a "Thank God it's Friday (TGIF)" effect, as students experienced significantly more enjoyment and enthusiasm, and significantly less frustration during mathematics classes on Fridays as compared to the other days of the week combined (Mondays excluded). For boredom the effect was only marginally significant.

Further, we also checked whether sex and mathematics ability moderated "Blue Monday" and "TGIF" effects. The "Blue Monday" indicator interacted with mathematics ability level but not with sex. Specifically, the "Blue Monday" effect, while remaining insignificant, becomes stronger with increasing mathematics ability levels for student enjoyment, $\beta(SE) = -0.39(0.10)$, $p < 0.001$, enthusiasm, $\beta(SE) = -0.45(0.10)$, $p < 0.001$, and frustration, $\beta(SE) = 0.29(0.13)$, $p = 0.023$, but not for boredom, $\beta(SE) = 0.16(0.12)$, $p = 0.17$. Interaction plots revealed that students with higher ability levels had a more positive emotional pattern during the rest of the week than on Mondays, whereas lower ability students had a more positive emotional pattern on Mondays than during the other weekdays. Additionally, no interaction effects were found between the TGIF effect and mathematics ability level, but the TGIF effect was partially moderated by sex. Particularly, the TGIF effect was more pronounced for female students' experience of enjoyment, $\beta(SE) = 2.74(1.18)$, $p = 0.020$, and frustration, $\beta(SE) = -3.58\ (1.51)$, $p = 0.018$, but not for enthusiasm, $\beta(SE) = 2.25(1.21)$, $p = 0.063$, or boredom, $\beta(SE) = -1.92(1.38)$, $p = 0.16$. Specifically, interaction plots revealed that female students experienced less positive and more negative emotions relative to male students particularly on the first 4 days of the school week, whereas these sex differences seemed to disappear on Fridays.

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Post-hoc analysis of Wednesday and frustrating Tuesday effects

Post-hoc analyses were performed based on the descriptive means plotted in Figure 1. First, the plots suggested a more positive emotional pattern not only on Fridays, but also on Wednesdays. Analyses confirmed this observation as students experienced significantly higher levels of enjoyment, $\beta(SE) = 2.55(0.71)$, $p < 0.001$, and lower levels of boredom, $\beta(SE) = 2.56(0.83)$, $p = 0.002$, and frustration, $\beta(SE) = -3.36(0.89)$, $p < 0.001$, on Wednesdays as compared to on Mondays, Tuesdays, and Thursdays combined. For enthusiasm the effect was only marginally significant, $\beta(SE) = 1.32(0.73)$, $p = 0.070$. Second, plots indicated a peak in students' experience of frustration on Tuesdays when compared to the other weekdays (i.e., Mondays, Wednesdays, and Thursdays), which was confirmed by the analysis, $\beta(SE) = 3.26(0.71)$, $p < 0.001$.

Academic emotions and time of the day

Overall time of the day effects on academic emotions

The natural variability of students' emotional experiences throughout the school day is visualized in Figure 2. As shown in Table 4, within-day time (represented by hours passed since midnight) significantly predicted the course of students' experiences of enthusiasm and frustration throughout the school day. Specifically, enthusiasm was significantly predicted by a parabolic function with a peak in the afternoon, whereas frustration was found to increase linearly throughout the school day.

Differences in academic emotions between mornings and afternoons

Of all unique measurement occasions, 68.79% took place in the morning hours, whereas 31.21% took place in the afternoon. Table 5 shows that students experienced significantly more boredom in the afternoon as compared to in the morning hours. For the other emotions, no significant differences were found in students' experience before and after noon. Differences in emotional experiences between mornings and afternoons did not depend on sex or mathematics ability. However, when controlling for interactions with sex, differences between mornings and afternoons in student boredom disappeared.

Academic emotions and teaching methods

Overall effect of teaching methods on academic emotions

The frequency of use of each teaching method (represented by percentages) during mathematics classes is displayed in Figure 3.

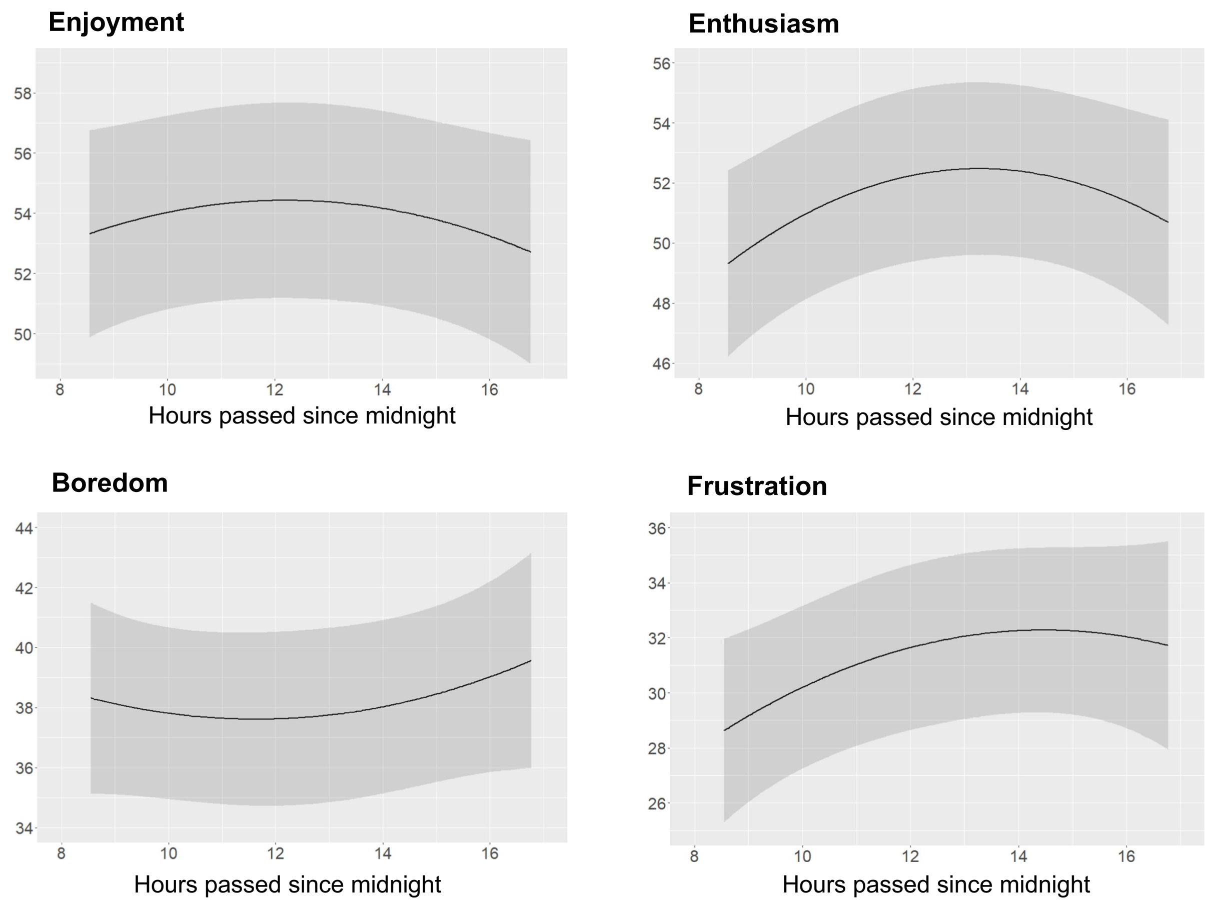

FIGURE 2
Visual representation of the natural fluctuations of academic emotions throughout the school day.

TABLE 4 Multilevel models examining time of the day effects on academic emotions.

	Enjoyment		Enthusiasm		Boredom		Frustration	
	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*
Intercept	54.42 (1.65)	< 0.001	52.20 (1.46)	< 0.001	37.61 (1.48)	< 0.001	31.57 (1.53)	< 0.001
Time	0.06 (0.12)	0.63	0.39 (0.12)	0.001	0.03 (0.14)	0.81	0.54 (0.15)	< 0.001
Time^2	−0.08 (0.06)	0.15	−0.14 (0.06)	0.015	0.07 (0.07)	0.27	−0.10 (0.07)	0.15

Time represents hours passed since midnight and was grand-mean centered (M = 11.87).

TABLE 5 Multilevel models examining differences between mornings and afternoons in academic emotions.

	Enjoyment		Enthusiasm		Boredom		Frustration	
	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*
Intercept	54.20 (1.65)	< 0.001	51.34 (1.46)	< 0.001	37.60 (1.46)	< 0.001	30.75 (1.49)	< 0.001
Afternoon	−0.60 (0.52)	0.25	0.56 (0.53)	0.29	1.21 (0.60)	0.045	1.01 (0.66)	0.13

Afternoon represents whether the measurement took place before (0) or after (1) noon.

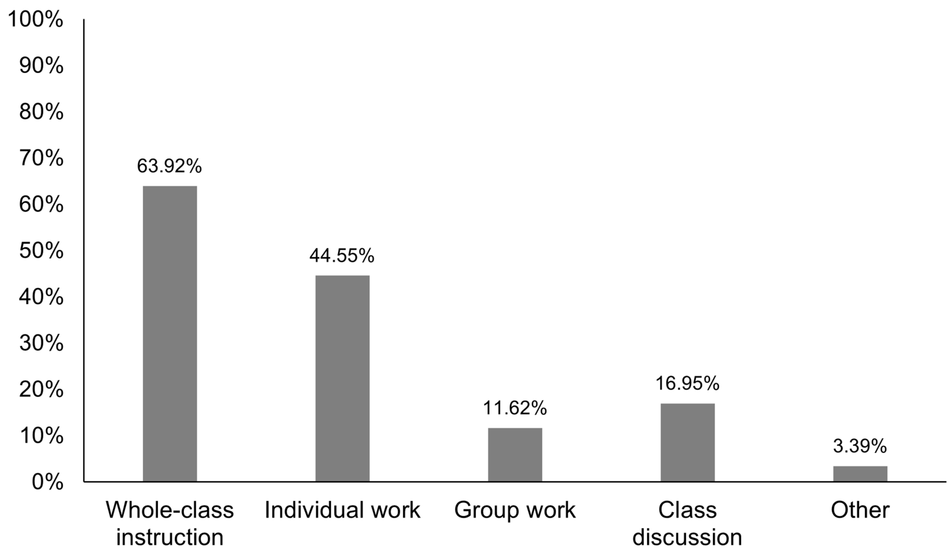

FIGURE 3
Frequencies of teaching methods used during mathematics classes as reported by teachers. Percentages represent the percentage of unique measurement occasions ($n = 413$) during which the teacher reported to have used a certain teaching method. Percentages do not add up to 100% as more than one teaching method could be selected per measurement occasion.

Descriptive means and standard deviations of students' experiences of their academic emotions for each teaching method are presented in Table 6.

Academic emotions during whole-class instruction vs. other teaching methods

Students' emotional experiences during whole class instruction were subsequently compared to their experiences during either individual work, group work or classroom discussion (Table 7). Individual work was found to provoke significantly higher levels of enjoyment, enthusiasm and frustration and significantly lower levels of boredom in students as compared to whole-class instruction. Similarly, during group work, students experienced significantly higher levels of enjoyment, enthusiasm, and frustration and lower levels of boredom. When teachers employed classroom discussion, students experienced significantly higher levels of frustration compared to during whole-class instruction. For individual work and group work, differences in students' academic emotions when compared to whole-class instruction were not moderated by sex and mathematics ability level. When comparing classroom discussion with whole-class instruction, sex moderated students' experiences of boredom, with female students experiencing significantly lower levels of boredom during classroom discussion compared to male students, $\beta(SE) = 5.83(1.79)$, $p < 0.001$. Additionally, although students with higher mathematics ability were expected to emotionally benefit from individual work, mathematics ability did not interact with individual work or group work. However, mathematics ability did moderate students' experiences of frustration, with students with higher mathematics ability levels experiencing significantly higher levels of frustration during classroom discussion, $\beta(SE) = 0.42(0.16)$, $p = 0.010$.

TABLE 6 Means and standard deviations of academic emotions experienced during each teaching method.

	Enjoyment	Enthusiasm	Boredom	Frustration
	M(*SD*)	M(*SD*)	M(*SD*)	M(*SD*)
Whole-class instruction	52.45 (23.91)	50.21 (23.53)	39.48 (25.65)	30.76 (28.02)
Individual work	56.03 (23.30)	54.07 (23.30)	34.54 (24.58)	32.17 (28.26)
Group work	59.08 (23.09)	57.93 (22.98)	31.59 (23.11)	32.30 (27.89)
Classroom discussion	53.37 (25.35)	51.98 (24.24)	38.01 (26.88)	32.03 (29.78)

TABLE 7 Multilevel models examining differences between whole-class instruction and individual work, group work, and classroom discussion in academic emotions.

	Enjoyment		Enthusiasm		Boredom		Frustration	
	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*	β(*SE*)	*p*
Intercept	52.53 (1.62)	< 0.001	49.56 (1.40)	< 0.001	40.24 (1.42)	< 0.001	30.12 (1.54)	< 0.001
IW	3.15 (0.50)	< 0.001	3.85 (0.52)	< 0.001	−4.50 (0.58)	< 0.001	1.73 (0.64)	0.007
Intercept	52.85 (1.74)	< 0.001	49.71 (1.45)	< 0.001	40.00 (1.44)	< 0.001	29.59 (1.43)	< 0.001
GW	5.18 (0.86)	< 0.001	6.71 (0.90)	< 0.001	−6.92 (1.01)	< 0.001	3.61 (1.09)	0.001
Intercept	52.55 (1.81)	< 0.001	49.34 (1.53)	< 0.001	40.10 (1.49)	< 0.001	29.80 (1.48)	< 0.001
CD	0.44 (0.77)	0.56	1.46 (0.78)	0.062	−1.31 (0.91)	0.15	3.71 (0.98)	< 0.001

IW, Individual work; GW, Group work; CD, Classroom discussion. Individual work, group work, and classroom discussion represent whether the measurement took place during whole-class instruction alone (0) or during individual work, group work or classroom discussion, respectively, (either in combination with other teaching methods or not; 1).

Discussion

Theoretical and empirical work highlight the importance of students' emotions for a wide range of developmental and academic outcomes (e.g., Camacho-Morles et al., 2021; Pekrun and Linnenbrink-Garcia, 2012). The present study aimed to explore natural fluctuations of student emotions (i.e., enjoyment, enthusiasm, boredom, and frustration) as experienced in mathematics classes in function of the day of the week or time of the day, and to explore how teaching methods (i.e., whole-class instruction, group work, individual work, or classroom discussion) relate to these emotions.

Specifically, in the present study we addressed three research objectives. First, we planned to explore the overall effect of the day of the week on each academic emotion, and further examined whether a "Blue Monday" or "Thank God it's Friday (TGIF)" effect were apparent in the emotions (RO1). Second, the overall pattern of each academic emotion as experienced throughout an average school day was explored, and it was subsequently tested whether students experienced more positive academic emotions in the afternoon as compared to in the morning (RO2). Third, the overall effect of teaching methods (i.e., whole-class instruction, group work, individual work or classroom discussion) on students' emotional experiences was examined, testing if whole-class instruction would evoke lower levels of positive emotions and higher levels of negative emotions in students as compared to the other teaching methods (RO3).

RO1: day of the week effects on academic emotions

In the present study, it was found that students experienced higher levels of enjoyment and enthusiasm and lower levels of frustration during mathematics classes on Fridays as compared to the other days of the week combined. The more positive emotional pattern on Fridays is in line with the expected "Thank God it's Friday (TGIF)" effect, as previously found outside the academic context (e.g., Reis et al., 2000; Stone et al., 2012). As such, current findings extend previous research to the academic context by showing that "TGIF" effects are also apparent in the emotions that students experience in school.

Furthermore, our findings showed that the positive emotional pattern was not limited to Fridays alone, but also characterized Wednesdays. Specifically, students also experienced higher levels of enjoyment and lower levels of boredom and frustration on Wednesday as compared to the other weekdays combined. While differences in students' academic emotions between Wednesdays and other school days was not previously reported in the literature, it likely resulted from the Flemish school system as students only have a half-day of classes on Wednesdays. Similar to explanations given in previous studies on "TGIF" effects outside the academic context (e.g., Stone et al., 2012), the heightened positive emotional pattern on Fridays and Wednesdays may be due to the leisure time available on Wednesday afternoons and weekends. This free time may give freedom to students to schedule activities or social contacts they can look forward to, resulting in more positive emotional experiences on Fridays and Wednesdays during school hours. This subsequently implies that emotions, although measured in context, are not only influenced by the situational or contextual factors at a given moment, but also by the anticipation of future activities or events (Castelfranchi and Miceli, 2011; Frijda, 1993). Of course, our results do not allow us to draw definite conclusions about the possible explanation of these day-of-the-week effects.

In the present study, no evidence was found for a "Blue Monday" effect in students' academic emotions experienced during their mathematics classes, as students showed no differences in their experiences of their academic emotions between Mondays and the other weekdays. This contradicts previous studies in non-academic contexts that found individuals to have a worse mood on Mondays as compared to the rest of the week (Areni et al., 2011). Nevertheless, findings have been mixed and more recent studies with sufficient sample size also found no evidence for "Blue Monday" effects on mood when controlling for "TGIF" effects (e.g., Stone et al., 2012). It might also be, however, that "Blue Monday" effects characterize non-academic but not academic contexts, as students are reunited with their classmates and friends on Mondays with whom they can share their experiences of the past weekend, which may counter the "Blue Monday" effect that would otherwise be present.

Additionally, descriptive means unexpectedly suggested a peak in students' experiences of frustration on Tuesdays, which was subsequently confirmed in a *post-hoc* analysis. Following our prior argumentation, perhaps the positive effects of the leisure time in students' weekend and the reunion with their friends that were still present on Mondays may have worn off on Tuesdays. This, along with the prospect of another long week of school, may enhance feelings of frustration on Tuesdays. Follow up qualitative research may be necessary to gain insights into students' interpretations and experiences that may explain this "Frustrating Tuesday" effect. The above day of the week effects highlight the importance for future studies to take into account differences among these weekdays when examining affective experiences of students in school in order to ensure valid and reliable results.

When exploring sex and mathematics ability as potential moderators of the "Blue Monday" and "TGIF" effects, an interaction effect was found between the "Blue Monday" effect and mathematics ability for all emotions except boredom. Specifically, higher ability students were found to have more positive emotional experiences (i.e., more enjoyment and enthusiasm and less boredom) during the rest of the week than on Mondays, whereas lower ability students had more positive emotional experiences on Mondays than during the rest of the week. Possibly, the suggested greater need for autonomy of higher ability students (Figg et al., 2012) may lead to a more negative experience of the transition from weekend to school on Mondays, resulting in less positive and more negative emotions on Mondays as compared to the rest of the week. However, in view of the novelty of these findings, replication is necessary before any firm conclusions can be drawn. Further, female students showed stronger TGIF effects than males in their experiences of enjoyment and frustration. Specifically, female students experienced less enjoyment and more frustration relative to male students particularly on the first 4 days of the school week, whereas these sex differences seemed to disappear on Fridays. Perhaps looking forward to the weekend ahead dampens the sex differences in emotional experiences during mathematics classes that are otherwise present.

RO2: time of the day effects on academic emotions

In contrast to the day of the week effects, findings on time of the day effects were less consistent. When visualizing the overarching patterns of students' academic emotions throughout a typical school day, these emotions appeared to adhere to a parabolic function. Enjoyment, enthusiasm and frustration seemed to increase until late afternoon, followed by a decrease toward the evening, whereas boredom seemed to decrease until late afternoon, followed by an increase toward the evening. However, when statistically modeling these emotional patterns in function of the time of the day, the parabolic function held significant only in the case of enthusiasm. The emotion of frustration exhibited a statistically significant linear increase throughout the day. Interestingly, the observed parabolic pattern for enthusiasm aligns with prior research conducted outside of academic contexts, which indicated that positive mood tends to align with individuals' internal biological clock as it increases until the late afternoon, before experiencing a subsequent decline as the evening progresses (Murray et al., 2002; Murray et al., 2009). These findings underscore the potential influence of daily rhythms on emotional responses within an educational setting.

In our comparative analysis of students' emotional experiences during morning and afternoon classes, we observed significant differences specifically in the experience of boredom with students reporting higher boredom levels in the afternoons, while no differences were found in the experience of the other emotions. The observed elevation of boredom during the afternoon classes may be attributed to postprandial somnolence (i.e., post-meal dip), which is a general state of sleepiness and low energy levels following a meal that may relate to feelings of boredom (Reyner et al., 2012; Smith et al., 1988). Where previous research on diurnal emotional patterns outside the academic context presents a mixed picture for negative emotions (Itzek-Greulich et al., 2016; Kivelä et al., 2022), within an educational setting there appears to be a tendency for negative emotions to intensify as the school day advances (i.e., significant increase in frustration throughout the day and higher boredom levels in the afternoon). These observations suggest that the temporal structure of the school day may play a role in shaping the emotional experiences of students, and warrants further investigation into the mechanisms underlying these patterns. Time of the day effects were not moderated by students' sex or mathematics ability, suggesting that the diurnal patterns of emotions generalize across sexes and ability levels.

More generally, it was found that discrete academic emotions—even emotions of similar valence – exhibit unique diurnal patterns, thereby necessitating a differentiated approach to their examination. Consequently, it would be an oversimplification to categorize and analyze them as a general affect measure such as 'positive or negative affect'. Therefore, in line with control-value theory of Pekrun's (2006), our research advocates for a more nuanced understanding of emotional experiences, one that acknowledges the distinctiveness of individual emotions as they can have different precursors and functions in academic contexts.

RO3: effects of teaching methods on academic emotions

In line with previous studies, whole-class instruction was found to be the teaching method most often used in mathematics classes (Bieg et al., 2017; Hiebert et al., 2003), followed by individual work, classroom discussion and group work, respectively. When comparing the emotional experiences of students during whole-class instruction to the other teaching methods, it was observed that students experienced more enjoyment and enthusiasm, and less boredom during individual work and group work as compared to whole-class instruction.

It is crucial to note that these findings do not necessarily imply that teachers should increase the use of individual or group work relative to whole-class instruction. That is because the effect that teaching methods have on emotions may differ from their effects on students' academic outcomes such as their concentration levels, learning rate, and academic achievement. Teaching methods that evoke positive emotions in students do not necessarily lead to better learning outcomes. Furthermore, depending on the content of the learning materials, different teaching methods may be most appropriate for delivering the materials (Evans and Martin, 2023; Evans et al., 2024), and teachers may use these methods accordingly. As such, the differential effects of teaching methods on student emotions may also result from the different contents of learning materials that are addressed with each teaching method. Additionally, while teachers reported on the types of teaching methods they employed, no data was collected on how these methods were implemented. However, the quality of implementation of teaching methods may significantly affect the experiences of students in the classroom (Seidel and Shavelson, 2007). Research on effective teaching highlights for instance the importance of need-supportive practices, such as attuning and guiding approaches, to achieve the most adaptive student outcomes (Aelterman et al., 2019; Lavrijsen et al., 2024).

In contrast with experiences of enjoyment, enthusiasm and boredom, it was found that students also experienced higher levels of frustration during individual work, group work, and classroom discussion when compared to whole-class instruction. It is plausible that frustration is more ambiguous in its function than boredom. For instance, frustration may also occur when classes are challenging and serve as catalysts for greater effort and engagement, and thus, it can be conducive to the learning process. Boredom on the other hand might be more unambiguously associated with negative academic outcomes. This suggests a complex interplay between emotional states and learning, where not all seemingly negative emotions are detrimental to the learning process. Future research is warranted to determine the potential effects of different teaching methods and the quality of their implementation not only on students' emotions, but also on their learning outcomes such as their learning rate and academic achievement. This will provide a more comprehensive understanding of the interplay between teaching and students' emotional and academic experiences.

Further, we tentatively anticipated that individual work would elicit a more positive and less negative emotional response in students with higher mathematical abilities when compared to whole-class instruction due to the suggested importance of autonomy and customization of pace for high-ability students (Barbier et al., 2023; Figg et al., 2012). However, our results provided little evidence of significant interaction effects between mathematics ability and teaching methods. The sole effect we found was that higher ability students experienced significantly lower levels of frustration levels during whole-class instruction than lower ability students.

This finding could be attributed to several factors. First, in a classroom discussion, the pace is typically set to accommodate all students, which might be slower than the preferred learning pace of high ability students. Second, classroom discussions might not provide the level of cognitive challenge that high ability students seek. Third, these students may experience frustration if they perceive a lack of comprehension or appreciation of their complex ideas by their peers. Observational or qualitative research could further elucidate the experiences and cognitions of high-ability students during classroom discussions. While this finding contributes to our understanding of the dynamics between academic emotions, teaching methods, and mathematics ability, no overly strong conclusions should be drawn as this interaction effect represents merely one significant finding out of 12 potential interaction effects examined.

Main effects of sex and ability level

Finally, differences in students' emotional experiences in class were found based on their sex and ability level. Concerning sex differences, female students were found to experience less enthusiasm during mathematics classes as compared to male students, whereas no differences were found between males and females in their experience of enjoyment, boredom, and frustration. Although previous studies examining sex differences in academic emotions using a trait-based approach to emotions have generally found females to experience more positive and less negative emotions in school relative to males (Lam et al., 2012), research focusing specifically on the subject of mathematics mostly showed females to experience a less positive emotional pattern relative to males (Frenzel et al., 2007; Murphy et al., 2019). Applying the control-value theory, as mathematics is often stereotyped as a male domain, females may have lower competence-related beliefs and lower value beliefs in mathematics as compared to males, explaining the lower enthusiasm in mathematics for females (Frenzel et al., 2007). Moreover, finding such differential effects of sex for different emotions supports the idea that academic emotions should be approached as separate constructs (Pekrun, 2006).

Concerning mathematics ability, students with higher mathematics ability levels were found to experience more enjoyment and enthusiasm, and less boredom during mathematics classes. Students with higher mathematics ability levels may also have more confidence in their mathematics abilities (Bergold et al., 2020; Košir et al., 2016) and additionally a higher valuation of school and mathematics (Frenzel et al., 2007) which, following propositions of the control-value theory, may have resulted in more positive and less negative emotional experiences in class. As such, these findings contribute to the validation of the control-value theory. Alternatively, it could also be the case that, as our sample is selective on mathematics ability, the provided learning materials are better tailored to the needs of high mathematics ability students in our sample. Nevertheless, findings from this study add to the literature by providing first insights into the emotions of students across ability levels as experienced in real-time during actual mathematics classes.

Strengths and limitations

The present study was the first to explore the role of temporal factors and teaching methods in students' emotions using experience sampling methodology. As such, in contrast to previous studies employing a trait-based approach to emotions, it allowed us to capture the real-time experiences of students' emotional states in their natural learning environments, thereby reducing recall bias and enhancing ecological validity. The significance of using a state-based approach to emotions was further supported by the large amount of variability in students' emotions that was due to differences over time within an individual student.

Despite these strengths, the present study also has some limitations. First, recruitment was limited to class groups from Grade

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11 and 12 in the academic track in Flanders, and class groups with a high number of mathematics lessons per week were oversampled. Hence, it remains unknown whether students' emotional experiences and their relations with temporal factors and teaching methods as reported in this study generalize to other age groups, academic tracks, and educational settings in other countries. Furthermore, as the sample was selective on mathematics ability, students in our sample may have valued mathematics more as compared to the general student population. Nevertheless, mean levels of emotions were found to be only medium with substantial variability both within and between students. Future research could also investigate the emotional experience of average to lower ability students.

Second, the study focused on mathematics classes only. Notably, according to the control-value theory, academic emotions are organized in domain-specific ways (Pekrun, 2006). Therefore, emotional experiences found in mathematics classes do not necessarily generalize to other school subjects. Nevertheless, according to the relative universality assumption of the control-value theory, there may be mean level differences in students' experience of academic emotions across school subjects, yet the structural relations between academic emotions, on the one hand, and temporal factors and teaching methods, on the other hand, can be assumed to be similar (Goetz et al., 2013). Nevertheless, future research should investigate whether similar relations are found for other school subjects (e.g., whether whole-class instruction is associated with less positive emotions for all subjects, as the appropriateness of teaching methods may relate to the subject contents). However, focusing on the domain of mathematics in particular is advantageous as it allows for more focused insights into the domain-specific relations with students' emotions, as the simultaneous study of multiple subjects may obscure the results. Finally, although the present study provides valuable insights into the emotional experiences of students in context, future research should further investigate to what extent these emotional experiences translate into students' academic outcomes such as their level of academic engagement, concentration or achievement.

Conclusion

In sum, this study examined students' academic emotions in mathematics classes and how they related to the day of the week, time of the day and teaching methods. By using experience sampling methodology, we were able to capture real-time emotional states, thereby extending previous studies that have mainly employed a trait-based approach to student emotions. The results underscore the significance of temporal factors in shaping students' emotional experiences, as evidence was found for a more positive emotional pattern on Fridays (TGIF effect) and Wednesdays, and a trend toward a negative post-meal effect on students' emotions. Additionally, the study highlights the differential relations of teaching methods with students' emotions, with individual work and group work relating to more positive emotional responses compared to whole-class instruction, but also to more frustration. Students experienced also higher levels of frustration during classroom discussion relative to whole-class instruction. These insights have implications for educational practice and research. First, they point to potentially influential factors (e.g., day of the week) on emotions that researchers should consider controlling for in future studies as they could confound results. Second, they highlight the fact that students' emotional experiences go beyond controllable attributes of students, classes or teachers themselves, as temporal factors also contribute to the emotional landscape of students. Weekly school schedules or time tables may be adjusted accordingly to optimize students' affective experiences. Yet, future research should continue to explore the interplay between students' academic emotions, other learning outcomes, and contextual variables to further elucidate the situational and contextual dynamics of students' experiences and learning in school.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors upon request, without undue reservation.

Ethics statement

The studies involving humans were approved by Social and Societal Ethics Committee (SMEC) KU Leuven. The studies were conducted in accordance with the local legislation and institutional requirements. Active written informed consent was required by the participants themselves and passive consent by the participants' legal guardians/next of kin. No active written informed consent was required from participants' legal guardians/next of kin because students from 11th and 12th Grade can be expected to be able to properly assess for themselves the advantages and disadvantages of their participation.

Author contributions

EC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – original draft. PK: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. JL: Conceptualization, Methodology, Resources, Supervision, Writing – review & editing. KV: Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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