ZDM – Mathematics Education (2025) 57:603–620
https://doi.org/10.1007/s11858-025-01651-w

ORIGINAL PAPER

Emotions in mathematics learning: a systematic review and meta-analysis

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Accepted: 31 December 2024 / Published online: 3 February 2025

Abstract
Academic emotions play a crucial role in mathematics learning, significantly influencing motivation, academic achievement, and career aspirations in mathematics. With the notable increase in research on emotions in recent years, our review uses Pekrun's control-value theory with two primary objectives: to systematically describe the characteristics of emotions in recent research through a systematic review, and to synthesize evidence on the relationships between specific emotions, control-value antecedents, and mathematics achievement via a meta-analysis. The systematic review of 112 studies revealed that more than 100 specific emotions have been addressed in recent research, which we analyzed based on key emotion characteristics: valence and activation, type of object, temporal stability, and social context. The findings from the systematic review provide an overview of mathematics-specific objects that emotions have referred to in the most recent research. The subsequent meta-analysis demonstrated that mathematics achievement (e.g., test scores and grades) was positively related to enjoyment, hope, and pride ($\bar{r}$ = .247, .224, and .344, respectively) but negatively related to anger, boredom, frustration, hopelessness, and shame ($\bar{r}$ = − .322, − .187, − .207, − .378, and − .291, respectively). Theoretical and practical implications of these results are discussed.

Keywords Emotion · Mathematics · Control · Value

1 Introduction

1.1 Objective and rationale

Imagine a mathematics classroom where the air is charged with a mixture of hopeful anticipation, excitement, and, occasionally, a hint of trepidation. In this setting, students undergo a spectrum of emotions that influence how they process information, where they direct their attention, and what they remember (Hannula, 2002; Pekrun et al., 2002). Emotions are relevant to mathematics learning at all levels of education as well as during transitions between educational levels (e.g., Di Martino et al., 2023; Middleton et al., 2023). Understanding the diversity of emotions in the classroom is thus an important goal of research in mathematics education (Schukajlow et al., 2023).

Whereas anxiety has historically dominated research on emotions in mathematics education (Di Martino & Zan, 2011; Loderer et al., 2020), there has recently been a substantial increase in the number of studies focusing on diverse emotions in mathematics and beyond [see meta-analyses by Camacho-Morles et al., (2021) and Loderer et al., (2020)]. The control-value theory (CVT; Pekrun, 2024) provides a prominent framework for characterizing emotions and their relationships with academic achievement and for explaining emotional arousal in learners by referring to specific combinations of perceived control and perceived value. Whereas the basic mechanisms linking emotions to antecedents and academic achievement are predicted to apply universally (Pekrun & Goetz, 2024), there are differences in students'

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emotional experiences between domains (Goetz et al., 2010). For example, the relationships between enjoyment and anger and academic achievement tended to be stronger in mathematics than in other subjects, such as literacy (Camacho-Morles et al., 2021), suggesting particular importance of emotions in teaching and learning mathematics. One possible explanation is that in mathematics classrooms, students receive frequent feedback on tasks that provide immediate correctness cues (e.g., solving problems with definitive answers), which may strengthen the relationship between mathematics achievement and emotions. Additionally, the object that a specific emotion refers to may depend on the topics in the domain itself, with mathematics offering unique topics (e.g., probability vs. algebra) and tasks (modelling vs. word problems) that emotions might reference.

To the best of our knowledge, research on emotions that are specific to mathematics learning, beyond mathematics anxiety (e.g., Barroso et al., 2021), has yet to be synthesized. We synthesize research on emotions in mathematics learning through a two-stage systematic review and meta-analysis. These approaches provide complementary perspectives by offering breadth and depth: The systematic review situates studies within the broader research context, while the meta-analysis synthesizes evidence about relationships between emotions, control-value antecedents, and mathematics achievement. In combination, the systematic review and the meta-analysis provide a comprehensive overview of research on emotions in mathematics education and establish a foundation for future research and evidence-based practices to enhance beneficial emotions and minimize detrimental ones in mathematics learning.

1.2 Characterizing emotions in mathematics learning

In line with contemporary definitions (e.g., Shuman & Scherer, 2014), emotions in the context of mathematics learning are viewed as multicomponent changes in an individual's psychophysical system in response to events or situations relevant to learning processes and learning achievement. These changes involve affective, cognitive, physiological, motivational, and expressive-behavioral components.

In the academic context, Pekrun's CVT (Pekrun, 2024) is a prominent psychological framework that explains emotions in academic settings (and beyond). The generalized CVT encompasses a broad spectrum of emotions, considering their individual and social antecedents, their influence on academic achievement and well-being, their origins, and strategies for regulation and associated interventions (Pekrun, 2024). The CVT helps understand distinct emotions based on key characteristics, including valence and activation, type of object, and control-value antecedents (Pekrun et al., 2023; Schukajlow et al., 2023). In addition to these core CVT constructs, temporal stability and social context are key dimensions of emotions in mathematics learning and beyond (Schukajlow et al., 2023). In this systematic review and meta-analysis, we integrate these additional dimensions to comprehensively characterize emotions in mathematics learning. In the second step, we accumulate evidence on the relations between specific emotions, their control-value antecedents, and mathematics achievement in a meta-analysis (Fig. 1).

1.2.1 Type of object and emotion groups

Emotions are directed toward specific objects, such as enjoyment of solving word problems (Pekrun et al., 2023; Schukajlow et al., 2023). Based on distinct types of objects, emotions can be categorized into groups, including achievement emotions, epistemic emotions, and social emotions (Table 1). A single emotion can belong to more than one emotion group, depending on its object (Pekrun, 2024). For example, experiencing enjoyment after achieving a good grade in mathematics is an achievement emotion, whereas enjoyment that results from resolving a cognitive conflict after confusion is considered an epistemic emotion. Considering an emotion's object is important, as it helps people understand what triggered an emotion and how it might influence academic achievement (Pekrun, 2024).

Achievement emotions are the emotions students experience in response to achievement activities or outcomes (Pekrun et al., 2023). Achievement activities include learning mathematics, attending mathematics classes, completing mathematics homework, or taking mathematics tests and exams. For example, enjoyment of the search for a mathematics proof or frustration during a mathematics exam when

Fig. 1 Overview of key emotion characteristics and relations with control-value antecedents and mathematics achievement

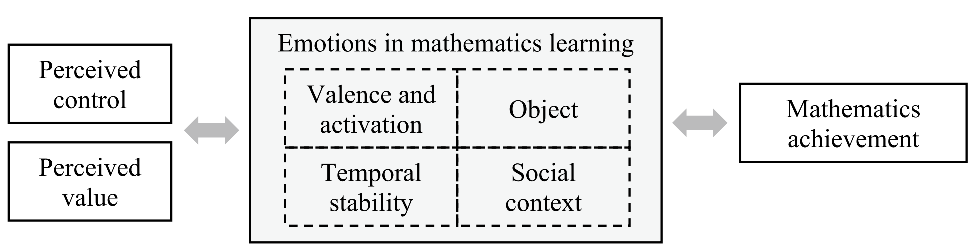

Table 1 Key characteristics of emotions and exemplary emotions based on the CVT (Pekrun, 2024)

Emotion group *Object*	Positive		Negative	
	Activating	Deactivating	Activating	Deactivating
Achievement emotions *activities and outcomes (e.g., problem solving, strategy use, algebra)*	Enjoyment	Relief	Frustration	Sadness
Epistemic emotions *knowledge incongruity (e.g., conceptual changes when moving from natural numbers to integers)*	Curiosity	Contentment	Confusion	Boredom
Social emotions *self and others (e.g., mathematics teacher)*	Pride	Sympathy	Shame	Antipathy

all attempts to solve a word problem fail are two examples of achievement emotions. The objects of achievement emotions related to mathematics learning encompass the broader category of mathematics as a domain, specific mathematics competencies (e.g., mathematical modelling), topics (e.g., algebra), and strategies (e.g., self-generated drawing), extending to individual mathematical tasks, problems, and activities (Fig. 2; Schukajlow et al., 2023).

Epistemic emotions are prompted by cognitive incongruity, which is involved in knowledge acquisition and exploration (Muis et al., 2018; Pekrun, 2024). As examples of key epistemic emotions, curiosity arises when there is a perceived gap between the learner's current knowledge and their desired knowledge. Curiosity refers to a desire for information that can close that gap. For example, learning about growth models might make students curious about how these models can be applied in real-world scenarios, such as ecology or economics. Confusion arises when current information appears contradictory or is not easy to understand. The student may be confused about how to compare fractions and determine which one is larger, especially if the fractions have different denominators, since the rules for comparing natural numbers do not directly apply in this case. If the cognitive incongruity is resolved, epistemic enjoyment may be experienced; otherwise, epistemic frustration and boredom may result (D'Mello & Graesser, 2012).

Social emotions are a subset of academic emotions that specifically pertain to the social aspects of the learning environment, encompassing interpersonal interactions, relationships, and the social context in which learning occurs. Social emotions fall into two groups (Middleton et al., 2023; Pekrun, 2024): self-related social emotions, which are related to the learner's own attributes and actions (e.g., pride, shame, or guilt), and other-related social emotions, which involve feelings about other individuals (e.g., admiration, jealousy, or envy). For example, a student might feel pride in their problem-solving abilities and perseverance after successfully solving a challenging mathematics problem. Conversely, they might feel envious of a peer's better

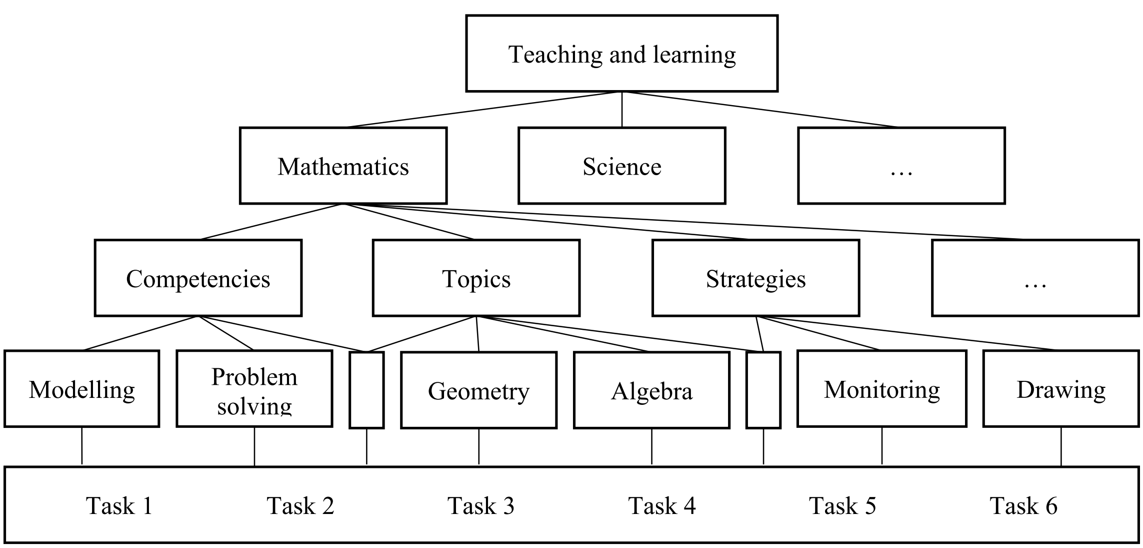

Fig. 2 Objects of achievement emotions in mathematics education (Schukajlow et al., 2023)

grade in mathematics, even if they have put in similar or more effort.

The extent to which recent mathematics education research addresses various groups of emotions and whether the objects referred to are specific to mathematics learning are open questions.

1.2.2 Valence and activation

Valence pertains to how individuals perceive emotions, ranging from positive (or pleasant) to negative (or unpleasant) experiences (Pekrun et al., 2023). Positive academic emotions include enjoyment while working on a specific mathematics problem or pride in contributing to group work in a mathematics class. On the other hand, negative academic emotions encompass frustration during mathematics lessons, confusion when learning a new strategy, or shame for not participating in mathematics discussions.

Activation describes the extent to which an emotion is accompanied by a physiological mobilization of resources to engage in a specific academic activity (Pekrun, 2024). Examples of activating emotions include excitement about a mathematical task and nervousness before an exam. Conversely, deactivating emotions include hopelessness about performing well in mathematics and relaxation after passing a mathematics exam.

The characteristics of valence and activation can be crossed to create four categories of emotions, which help explain the relations between specific emotions and academic achievement (Pekrun, 2024). According to CVT, task-related positive activating emotions, such as enjoyment of learning, usually exert positive effects, whereas negative deactivating emotions, including boredom and hopelessness, have negative effects. Explanations include an increase in effort and self-regulation when experiencing positive activating emotions (Camacho-Morles et al., 2019), whereas negative deactivating emotions undermine effort, motivation, self-regulation, and engagement during learning (Camacho-Morles et al., 2019; Muis et al., 2015; Tze et al., 2016). The effects of negative activating and deactivating emotions, such as shame, frustration, boredom, and anger, may be more variable but are expected to be often negative as well. The relationship between positive deactivating emotions and academic achievement remains an open question (Pekrun et al., 2023).

Prior meta-analyses have confirmed the predicted relations for anger, boredom, and enjoyment in educational contexts (Camacho-Morles et al., 2021; Loderer et al., 2020). However, evidence on other emotions and their relations to academic achievement is scarce. For instance, Pekrun et al. (2017) reported positive relations for enjoyment and pride and negative relations for anger, shame, boredom, and hopelessness with students' grades in mathematics.

1.2.3 Temporal stability

In addition to the CVT-based dimensions, constructs of emotions can be characterized by their temporal stability. The temporal stability of emotions in mathematics learning pertains to their consistency over time, distinguishing between trait-level and state-level emotions. Trait emotions are habitual emotions that are typically experienced, whereas state emotions are momentarily experienced emotions in specific situations (Bieg et al., 2013; Biese et al., 2024). For example, a student with high trait-level enjoyment in mathematics generally enjoys mathematics classes but may experience low state-level enjoyment working on an uninteresting mathematics task. Previously, achievement emotions in educational psychology have most often been conceptualized as trait emotions (Biese et al., 2024). In contrast, the state character of emotions, especially during non-routine problem-solving, was addressed early in mathematics education research (McLeod, 1989). Considering the difference between trait and state emotions is important because they might relate with different strength to mathematics achievement (Camacho-Morles et al., 2021). For example, state-level emotions may be strongly related to immediate academic achievement in specific situations, such as solving a particular mathematics problem, but less so to cumulative achievement outcomes, such as mathematics course grades. Thus, temporal stability is an important but understudied characteristic of emotions that can enhance our understanding of the role of emotions in learning.

1.2.4 Social context

Emotions relevant to mathematics learning are embedded in social contexts (Di Martino & Zan, 2011; Hannula, 2012). Social contexts comprise an important part of the situational specificity of emotions (Schukajlow et al., 2023). Individual emotions are learner-specific, whereas collective emotions are shared, creating a group-level emotional experience. For example, a learner's enjoyment of problem solving is individual, whereas ninth-grade students' collective enjoyment of a modelling problem is considered collective (Kanefke & Schukajlow, 2024). Individual and collective emotions interact, with collective emotions often being shaped by shared social and cultural influences. For instance, stereotypes affecting a minority group's perceived competence in mathematics may trigger negative collective and individual emotions (Raccanello et al., 2020). While collective emotions are not solely a function of the individual psychophysical system, they are intertwined with individual emotional experiences and can have a reciprocal relation with both those experiences and individual students' academic achievement (Hernández et al., 2023). Therefore, the social context in which an emotion is embedded contributes to its characterization and may shape its relations with achievement.

1.2.5 Control-value antecedents

The CVT posits that learners' emotions are shaped by perceived control and perceived value (Pekrun, 2024). Perceived control reflects learners' beliefs about their ability to perform activities and influence academic achievement in a given situation (e.g., confidence in answering a mathematics teacher's question). CVT predicts that higher perceived control is correlated with positive emotions, whereas lower perceived control is linked to negative emotions, but boredom is one important exception (Pekrun et al., 2023). Boredom may manifest when perceived control is either excessively low (leading to overchallenge) or excessively high (resulting in underchallenge). Perceived value pertains to the perceived importance of the activity or outcome (e.g., valuing proficiency in mathematics or the importance of obtaining a good grade). Perceived value is believed to contribute to both positive and negative emotions, with higher positive value (e.g., the importance of success) intensifying positive emotions, and negative value (e.g., the importance of avoiding failure) intensifying negative emotions. For example, curiosity is triggered when learners recognize a knowledge gap, attach value to closing that gap, and believe in their ability to achieve it (Pekrun, 2024). As another example, the combination of high control (feeling capable) and low positive value (finding the task unimportant and uninteresting) typically results in boredom.

Recent research provides support for the predicted links between control-value antecedents and some emotions, including anger, boredom, enjoyment, hope, hopelessness, pride, shame (Pekrun et al., 2023), curiosity, and confusion (Muis et al., 2015; Munzar et al., 2021).

Research on the relations between control-value antecedents and a broader range of emotions relevant to mathematics learning, and a synthesis of evidence using meta-analytic techniques, are still missing.

1.3 Research questions

For this systematic review and meta-analysis, we systematically reviewed recent empirical studies on emotions in mathematics education. Our aim was twofold: First, we sought to provide an overview of the most recent discourse on emotions in mathematics education research along key emotion dimensions. More specifically, the first research question guiding the systematic literature review was: To what extent are the key emotion dimensions (valence and activation, type of object, temporal stability, and social context) addressed in recent research on emotions in mathematics education? The second research question guiding the meta-analysis was: How are the investigated emotions related to perceived control, perceived value, and mathematics achievement? For value, we focused on positive value because studies considering negative value are largely lacking to date (see also Pekrun et al., 2023). Based on CVT (Pekrun, 2024), we tested the following hypotheses:

1. Positive emotions are positively related to perceived control, and negative emotions are negatively related to perceived control (except for boredom).
2. Positive emotions are positively related to perceived positive value, and negative emotions are negatively related to perceived positive value.
3. Positive activating emotions are positively related to mathematics achievement, whereas negative deactivating emotions and negative activating emotions are related negatively to mathematics achievement. Given the lack of research on positive deactivating emotions, no predictions were made regarding their relationship with mathematics achievement.

No predictions were made for aggregate constructs of positive and negative affect that summarize different positive and negative emotions without attending to their differences.

2 The present review

2.1 Inclusion criteria

We applied a two-step procedure to identify eligible studies for (a) the systematic review and (b) the meta-analysis. For inclusion in the systematic review, studies had to meet five criteria: (a) be an empirical study with a description of the sample and the qualitative or quantitative methods used, (b) focus on mathematics learners at any academic level regardless of age or prior knowledge, including primary (and earlier), secondary, and tertiary education, mathematics courses and specialist courses in other subjects (e.g., mathematics for engineers), and excluding studies on mathematics teachers' emotions, (c) explore emotions directly related to learning mathematics, excluding mathematics anxiety, as comprehensive reviews on this topic have already been conducted (e.g., Barroso et al., 2021), (d) be published in English, as English is widely accessible to most researchers, and (e) be published between 2020 and 2023 to ensure that the most recent research was included.

For the meta-analysis, studies had to meet three additional criteria: (a) provide a quantitative emotion measure, (b) offer at least one control-value or mathematics achievement correlate, and (c) report the necessary data for effect size estimation, such as correlation coefficients.

2.2 Literature search and eligibility screening

On October 23, 2023, our literature search included a primary search of interdisciplinary databases, namely, Web of Science, Education Resources Information Center, PsycInfo, and ProQuest Dissertations. These databases include literature from social sciences, education, and psychology. Additionally, we conducted an extended search in mathematics education journals within the Web of Science Core Collection to ensure the inclusion of relevant reports in mathematics education. Grey literature, such as dissertations, was incorporated to mitigate the potential for publication bias and to maximize the identification of relevant evidence.

We adapted the search term structure used in a previous systematic review by Loderer et al. (2020), as presented in Table 2. Search terms included a set of emotion terms, a set of education-related terms, and the term mathematics. Emotion terms encompassed both umbrella terms (e.g., emotion, mood, positive affect) and specific emotions (e.g., boredom and enjoyment) to identify reports on emotions as comprehensively as possible. All search terms were entered simultaneously by combining terms within the three sets through the Boolean "OR" and between the three sets through Boolean "AND." All databases were searched simultaneously. The search was restricted to Titles, Abstracts, and author-based Keywords and the publication years 2020 to 2023.

The search yielded 2776 reports, and the search in mathematics education journals yielded 94 reports. Before the screening, 671 duplicates were removed using the Citavi software. The flowchart in Fig. 3 outlines the process of eligibility screening, adhering to the PRISMA guidelines detailed by Page et al. (2021).

Titles and Abstracts of the remaining 2199 reports were screened manually by one trained student with a Bachelor's degree in mathematics education and removed if they did not meet the inclusion criteria. Exclusions were reviewed by the first author, and disagreements (which concerned less than 5% of identified reports) were resolved by consensus after consulting the co-authors. Then, the full texts of the accessible reports were independently assessed for eligibility and inclusion in the systematic review and in the meta-analysis by the first author and the trained student. Initial disagreements concerned again less than 5% of reports, and reports were removed after achieving consensus via discussion. We contacted the first authors of studies potentially eligible for inclusion in the meta-analysis to request correlation coefficients not provided in their reports. Studies for which the authors shared correlation coefficients or primary data were additionally included in the meta-analysis.

Table 2 Search terms adapted from Loderer et al. (2020)

Set 1: Emotion terms		Set 2: Educational focus	Set 3: Mathematics focus
General terms:	empathy	instruction	math*
emotion*	enjoy* (enjoyment)	learn*	
mood	envy	perform*	
positive affect	frustr* (frustration)	achieve*	
negative affect	gratitude		
Discrete emotions:	guilt		
admiration	hope		
ang* (angry)	hopelessness		
antipathy	joy* (joy)		
anx* (anxiety)	pity		
bored*, boring (boredom)	pride		
confus* (confusion)	relief		
curious*, curiosity	sad* (sadness)		
contempt	schadenfreude		
contentment	shame		
despair	surprise		
disappointment	sympathy		
relax* (relaxation)			

Asterisks indicate truncation

2.3 Coding strategy

2.3.1 Emotion characteristics

We applied qualitative content analysis to the full-text reports to extract information on the study characteristics, emotion characteristics, emotion antecedents, and mathematics achievement correlates examined by each study, as well as effect size information. All categories for which data were sought are presented in Table 3. Included studies, their coded characteristics, and reported statistics are provided in Tables S2 and S3 in the Supplementary Materials.

To systematically synthesize the studies and their findings, the first author and the trained student coded the included studies for key emotion dimensions, antecedents, and mathematics achievement with regular communication and validation. Initial double-coding of 25% of the included studies resulted in substantial agreement ranging from Cohen's $\kappa = .61$ (emotion's type of object) to $\kappa = .89$ (participants' level of education). The final coding results were achieved through consensus during discussion.

Regarding the coding of investigated emotions, we assessed the specific emotion and the corresponding emotion group based on the authors' wordings. The coding

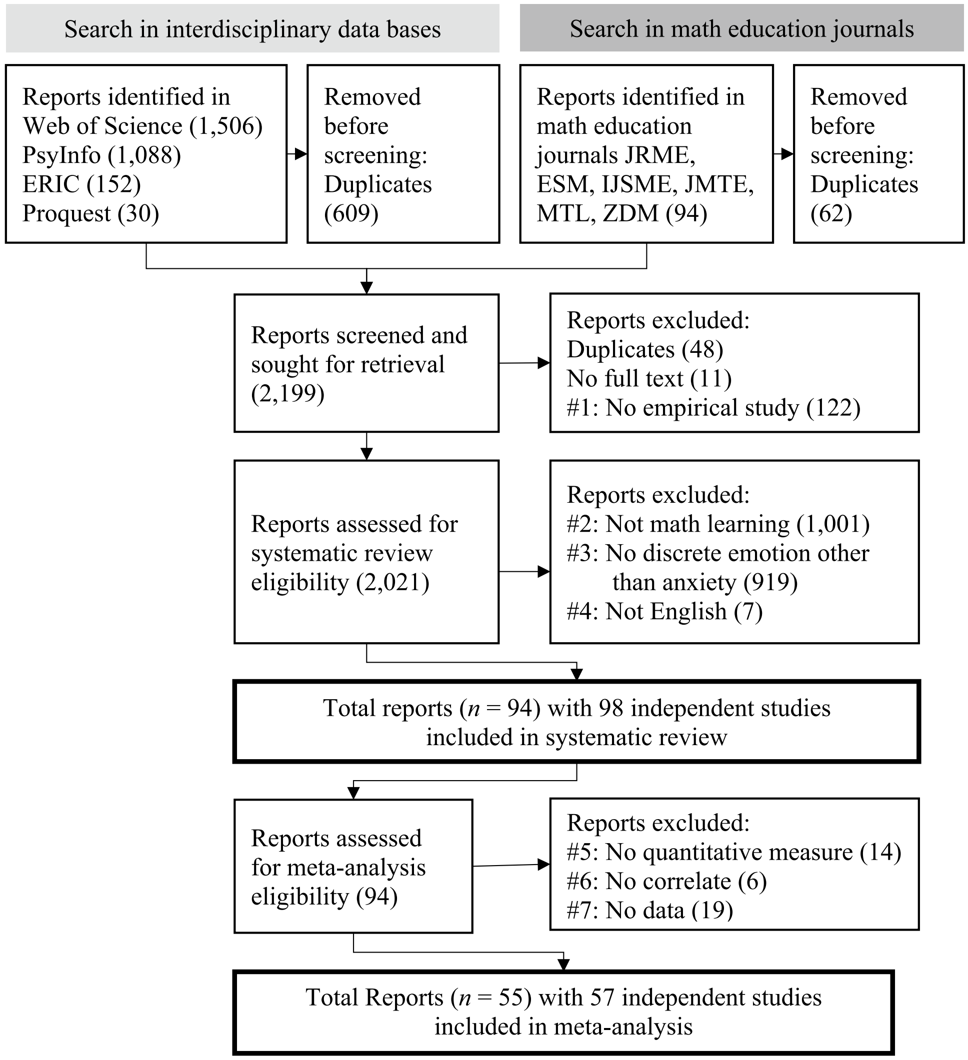

Fig. 3 Eligibility screening process. *JRME* Journal for Research in Mathematics Education, *ESM* Educational Studies in Mathematics, *IJSME* International Journal of Science and Mathematics Education, *JMTE* Journal of Mathematics Teacher Education, *MTL* Mathematical Thinking and Learning, *ZDM* ZDM – Mathematics Education

of valence and activation was based on CVT (Pekrun, 2024), based on the emotion's primary characteristic. Curiosity was categorized as a primarily positive, activating emotion (Pekrun, 2024; Schubert et al., 2023). However, curiosity can also be described as negative, as the lack of information that prompts curiosity might lead to a feeling of discomfort (Shin & Kim, 2019). Also, surprise was categorized as a predominantly positive, activating emotion (Pekrun, 2024). Depending on the context and the learner's interpretation of the unexpected information or event, surprise might alternatively manifest as neutral or even negative (Di Leo & Muis, 2020). We did not characterize the valence and activation of empathy because empathy refers to the ability to understand and share the feelings of others. Whether the empathetic response is perceived as pleasant, unpleasant, activating, or deactivating is likely to depend on the nature of the shared emotions.

For the 57 independent studies included in the meta-analysis, we assessed whether the study reported a measure of perceived control, including measures of self-concept, self-efficacy, and perceived problem-solving competence, or a measure of perceived positive value, such as intrinsic value, attainment value, utility value, or perceived usefulness related to mathematics. In addition, we assessed whether the study assessed mathematics achievement. Mathematics achievement measures ranged from specific tests addressing particular mathematics topics or competencies, such as an arithmetic fluency test, word problem-solving test, or proof construction test, to self-reports of prior mathematics grades and standardized mathematics achievement tests that covered multiple mathematics topics and competencies.

2.3.2 Extraction of effect sizes and statistical analysis

As a measure of effect size, we extracted Pearson product-moment correlations r as described by Harrer et al. (2021)

Table 3 Categories, descriptions, and examples

Category	Description	Examples
Study characteristics		
Publication year	Year of publication	2020, 2021, 2022, 2023
Publication type	Type of publication	Journal article, conference proceedings, dissertation, book chapter
Methodological characteristics		
Research methods	Research methods employed	Qualitative methods, quantitative methods, mixed methods
Level of education	Participants' level of education	Preschool and elementary, secondary, tertiary
Total sample size	*N* as reported in Method section	
Emotion(s) and their characteristics		
Emotion(s)	Specific emotion according to authors' wording	Enjoyment, tranquility
Emotion group	Emotion group according to the emotion's object	Achievement, epistemic, social
Valence	Emotion's valence	Positive, neutral, negative
Activation	Emotion's degree of activation	Activating, deactivating
Temporal stability	Emotion's state or trait level	State, trait
Social context	Individual or collective emotions	Individual, class, ethnic group
Object	Object the emotion is referencing	Mathematics competencies, mathematics topics, knowledge incongruity, self, others
Correlates		
Perceived control	Measure of perceived control	Self-concept, self-efficacy
Perceived value	Measure of perceived value	Intrinsic value, perceived usefulness
Mathematics achievement	Measure of mathematics achievement	Word problem solving test, arithmetic fluency test, mathematics grade

to capture the amount of covariation between an emotion and control, value, or an achievement variable. Using the sample size, we calculated the standard error of r according to Harrer et al. (2021). To avoid bias due to the restricted range of correlations and make sure that the sampling distribution is approximately normal centered, correlations were transformed into Fisher's z-values before pooling the effect sizes (Harrer et al., 2021).

We employed a three-level model to account for the hierarchical structure of our data (Harrer et al., 2021). Participants were nested within effect sizes, which, in turn, were nested within studies. This approach was essential, considering that multiple effect sizes were extracted from single studies (e.g., correlations between an emotion and multiple mathematics achievement scores; e.g., grades and test scores). To estimate our three-level models, we used the metaphor package in R (Viechtbauer, 2010). We computed mean weighted effect sizes for emotions and correlates with at least five effect sizes in the reviewed studies. Mean weighted effect sizes ($\bar{r}$) of .15, .25, and .35 can be interpreted as small, moderate, and large effect sizes, respectively (Gignac & Szodorai, 2016).

Between-study heterogeneity refers to the variability or differences observed among the effect sizes of studies included in the meta-analysis. We report the commonly used Q-statistic and I^2-statistic to quantify the proportion of total variability in effect size estimates due to between-study heterogeneity (Harrer et al., 2021). If the Q-statistic is significantly greater than the value expected under the assumption of homogeneity, with a significant p-value, it suggests the presence of heterogeneity. The I^2-statistic complements the Q-statistic and provides additional information about the proportion of total variability that is attributed to heterogeneity rather than sampling error. I^2 values below 25%, 50%, and 75% indicate low, moderate, and substantial heterogeneity, respectively (Harrer et al., 2021). To assess potential publication bias and detect outliers or asymmetry in the distribution of study results, we visually inspected funnel plots (Harrer et al., 2021).

3 Results

3.1 Systematic review results

The 98 independent studies included in this systematic review were published as 93 journal articles, four conference proceedings, and one book chapter. Results on study and methodological characteristics are included in Sect. 1 of the Supplementary Materials.

Specific emotions. We identified a total of 101 different emotions, which were found across various studies. We conducted an in-depth analysis of 34 emotions that appeared in at least two studies. These 34 emotions and the number of independent studies in which they were addressed are presented in Fig. 4.

Valence and activation. Regarding the investigated emotions' valence and activation, the positive emotions were predominantly positive activating emotions, $n = 122$ (35%) of a total of 353 investigated emotions. Examples are enjoyment, pride, and hope (Fig. 4). Only a few positive deactivating emotions were addressed, including relief and satisfaction, $n = 13$ (4%). Regarding negative emotions, both activating and deactivating emotions were addressed to similar extents, $n = 92$ and 84 (26% and 24%), respectively. Negative activating emotions included anger, shame, and confusion, and negative deactivating emotions included boredom, hopelessness, and embarrassment (Fig. 4). Forty-two emotions (12%) could not be categorized based on valence or activation (e.g., aggregated positive and negative emotions or empathy). These measures of emotions assessed distinct emotions (e.g., by coding facial expressions, verbal statements, and tone of voice, Merrick & Fyfe, 2023) or aggregated scores across different emotions (e.g., Goetz et al., 2021).

Emotion groups. The majority of emotions investigated in the reviewed studies were achievement emotions, $n = 279$ (79%) of a total of 353 investigated emotions, such as enjoyment, boredom, pride, and anger in response to mathematical learning activities or outcomes (e.g., Sainio et al., 2021). In addition, 39 emotions (11%) were classified as epistemic emotions, which are prompted by cognitive incongruity involved in mathematical knowledge acquisition and exploration. Epistemic emotions included curiosity and surprise, leading to epistemic enjoyment and pride, and confusion, which can facilitate epistemic frustration and boredom (e.g., Di Leo & Muis, 2020; Munzar et al., 2021). A total of 19 emotions (5%) were social emotions, referencing the learner, their peers, or the teacher in the learning context, such as pride and embarrassment, empathy, and envy (e.g., Singh & Muis, 2021). Sixteen emotions (5%) could not be assigned to one emotion group. These emotions encompassed aggregate measures of distinct emotions, or their descriptions did not allow for a distinction between

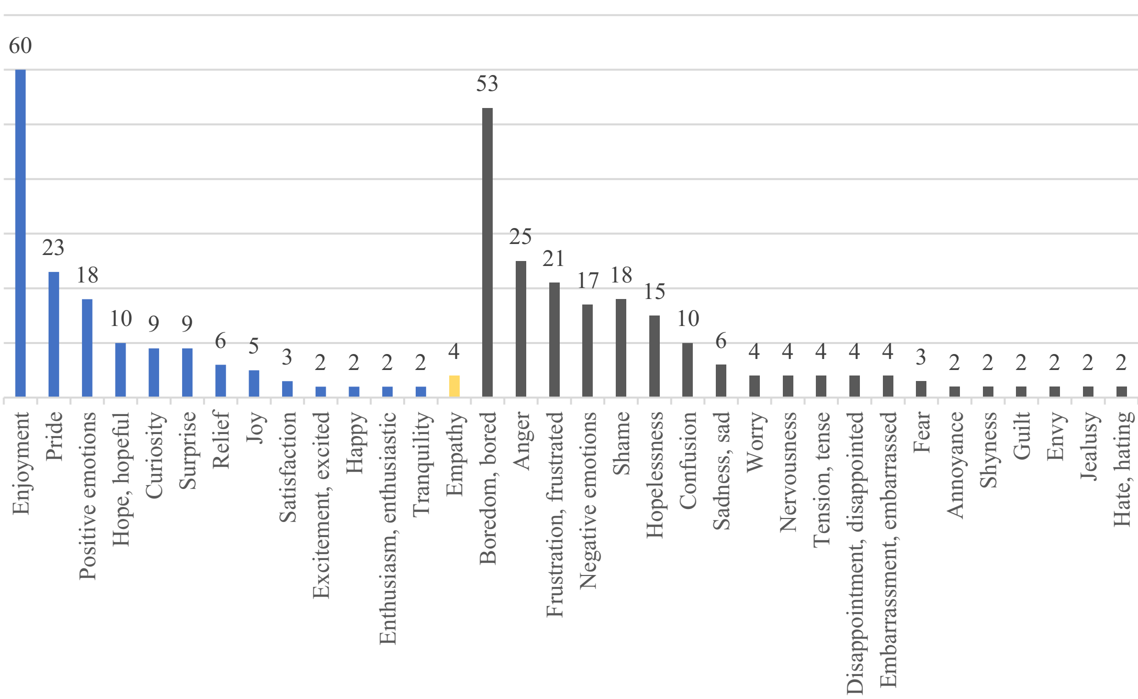

Fig. 4 Emotions identified in the reviewed studies with positive (Blue), neutral (Yellow), and negative (Grey) valence. Emotions that were identified once in the reviewed studies and excluded from the in-depth analysis: abandonment, accompaniment, affection/caring, agitation, anguish, apathy, apprehensive, approbation, attraction, blockage, brilliant, competitive, complainer, concentrated, confidence, contempt, culpability, delight/pleasure, depression, desirability, despair, despondency, determined, disgust, dismay, disorientation, distrust, engaged concentration, euphoria, Eureka, exasperation, exhausted, frightened, furious, gratitude, harmonious, humor, hypnotized, impotence, insecurity, interest, loneliness, love, mixed emotions, normal, nuisance, optimism, orientation, overwhelming, perseverance, pleased, power, puzzlement, rage, recognition, repentance, restlessness, rivalry, riveted, security, serenity, skeptical, stimulus, stress, suspicious, uncertainty

achievement emotions and epistemic emotions, as in the case of boredom (Pekrun, 2024).

Type of objects. In the category of achievement emotions, most emotions referred to *general mathematics learning* in school settings, $n=149$ (53%) of a total of 279 achievement emotions, including attending mathematics classes, doing mathematics homework, and taking mathematics tests (e.g., Clem et al., 2021). Similarly often, achievement emotions referred to *specific mathematics activities*, $n=119$ (34%), such as applying functional relations to real-life situations (e.g., Ayalon et al., 2022), solving word problems (van de Weijer-Bergsma & van der Ven, 2021), constructing geometric proofs (e.g., Schubert et al., 2023), problem posing (e.g., Yazgan & Ülger, 2023), the drawing strategy for solving modelling problems (e.g., Schukajlow et al., 2021), learning about functions with specific software (e.g., Augmented Reality, Tlalpan, 2021), or participating in collaboration tasks to deepen understanding of arithmetic algorithms, fractions counting, and spatial thinking (e.g., Näykki et al., 2021). In addition, emotions referred to specific *mathematical assessments*, $n=27$ (10%), including oral examinations in mathematics courses (e.g., Johnson et al., 2021), mathematics quizzes or tests in specialist courses in other subjects (e.g., Riegel & Evans, 2021), and mathematics competitions for girls only (e.g., Greensfeld & Deutsch, 2022).

Epistemic emotions refer to *incongruity in knowledge* by definition, $n=39$ (100%) of 39 cases of epistemic emotions, such as surprise, confusion, and curiosity arising from cognitive incongruity, novelty, and impasses during problem solving (e.g., Di Leo & Muis, 2020).

Social emotions referred to either the *mathematics learner* themselves, $n=7$ (32%) of 22 cases of social emotions, or *others involved in mathematics learning*, $n=15$ (68%), such as the mathematics teacher or classmates (e.g., Headrick et al., 2020; Ronen, 2020).

Temporal stability. Emotions in the reviewed studies were conceptualized as *trait-level* emotions, $n=179$ (51%) of 353 investigated emotions, or *state-level* emotions, $n=174$ (49%). For instance, Middleton et al. (2023) assessed students' state emotions during specific algebra class activities, whereas Bieleke et al. (2023) assessed trait-level emotions by asking students to indicate how they typically feel before attending a mathematics class.

Social context. Most emotions in the reviewed studies can be characterized as *individual* emotions, $n=349$ (99%) of 353 investigated emotions. For example, a student's emotions referring to mathematics lessons are associated with the individual level. Few of the reviewed studies conceptualized emotions as *student group* emotions, $n=4$ (1%), by either using direct ratings of the collective emotion or by aggregating individual emotion ratings. For example, Kanefke and Schukajlow (2024) asked preservice mathematics teachers to rate ninth graders' enjoyment and boredom with respect to mathematical problems, assigning these emotions not to individual students but to a group of ninth-grade students. Hernández et al. (2023) asked teachers to rate students' individual positive and negative emotions and aggregated their ratings into a measure of peer emotions. A small proportion of emotions explored in the reviewed studies were investigated within their cultural context, $n=20$ (6%), focusing on studies examining emotional differences among countries and ethnic groups. For example, Raccanello et al. (2020) measured individual students' anger, embarrassment, boredom, and hopelessness, and aggregated the scores to investigate differences between groups of ethnic minority and majority students.

3.2 Meta-analytic results

3.2.1 Publication bias and outlier analysis

Funnel plots (see Table S4 in the Supplementary Materials) do not indicate a substantial publication bias, as points were mostly symmetrically distributed around the overall effect size. Outliers that deviated from the expected funnel shape were found for enjoyment and boredom. Explanations of outliers included differences in nationalities and educational levels (Camacho-Morles et al., 2021), as some of the included effect sizes for enjoyment and boredom came from international large-scale assessments, such as TIMSS and PISA (Borgonovi et al., 2023; Tze et al., 2023).

3.2.2 Relations between emotions, control-value antecedents, and mathematics achievement

Meta-analytic findings on the relations between emotions, control-value antecedents, and mathematics achievement are presented in Table 4.

In line with our first hypothesis, positive emotions, such as enjoyment and curiosity, were positively associated with perceived control, showing medium to large effect sizes. However, the relation was not statistically significant for curiosity. On the other hand, negative emotions like anger, frustration, hopelessness, and shame were negatively associated with perceived control, also with medium to large effect sizes.

In line with our second hypothesis, positive emotions such as enjoyment, curiosity, and pride were positively associated with perceived positive value, with large effect sizes. Negative emotions were negatively associated with perceived positive value, with large effect sizes for anger and boredom, and smaller effect sizes for frustration and

Table 4 Mean weighted effect sizes ($\bar{r}$) for relations between emotions, control-value antecedents, and mathematics achievement

Emotion	Correlate	*k*	*n*	$\bar{r}$	95% CI		*Q*	Total I^2
					LL	UL		
Enjoyment	Control	100	346,217	.550***	.478	.615	198.9978*** (df=99)	65.48
	Positive value	90	348,508	.563***	.441	.665	380.3134*** (df=89)	85.03
	Achievement	120	524,818	.247***	.195	.297	75.2543 (df=119)	26.84
Curiosity	Control	6	2,990	.218	−.015	.429	0.1905 (df=5)	0
	Positive value	5	2,923	.353*	.060	.589	3.0323 (df=4)	16.02
	Achievement	6	2,990	.157	−.079	.375	0.0754 (df=5)	0
Pride	Positive value	12	24,004	.542**	.293	.722	20.1283* (df=11)	63.1
	Achievement	14	20,035	.344***	.256	.426	6.4009 (df=13)	0
Hope	Achievement	7	15,945	.224**	.041	.444	5.9076 (df=6)	34.69
Anger	Control	19	21,204	−.424***	−.553	−.276	14.5841 (df=18)	40.41
	Positive value	24	32,248	−.380***	−.504	−.241	31.4208 (df=23)	37.93
	Achievement	21	25,585	−.322***	−.392	−.249	10.5491 (df=20)	1.15
Boredom	Control	90	331,927	−.324***	−.385	−.260	51.3778 (df=89)	30.49
	Positive value	96	339,519	−.395***	−.472	−.316	238.0090*** (df=95)	54.91
	Achievement	112	340,548	−.187***	−.212	−.161	26.1211 (df=111)	0
Frustration	Control	7	12,078	−.285**	−.428	−.127	4.5793 (df=6)	0
	Positive value	6	12,011	−.224*	−.384	−.052	2.1568 (df=5)	0
	Achievement	5	11,797	−.207*	−.387	−.012	0.8145 (df=4)	0
Hopelessness	Control	8	13,017	−.570***	−.655	−.472	4.8953 (df=7)	0
	Positive value	12	23,995	−.173**	−.273	−.069	13.1595 (df=11)	17.54
	Achievement	14	20,038	−.378***	−.457	−.292	5.6485 (df=13)	0
Shame	Control	7	12,949	−.371***	−.487	−.242	0.1866 (df=6)	0
	Positive value	12	24,008	−.034	−.129	.061	4.4347 (df=11)	0
	Achievement	13	20,036	−.291***	−.378	−.200	4.6046 (df=12)	0
Positive emotions	Achievement	10	11,021	.198	−.059	.431	10.2526 (df=9)	39.22
Negative emotions	Positive value	5	3,537	−.344	−.738	.225	6.87472 (df=4)	68.39
	Achievement	7	2,247	−.169	−.398	.080	4.4125 (df=6)	0

Larger Q and I^2 statistics indicate greater heterogeneity and the potential presence of moderator variables

k = number of effect sizes, n = total sample size, LL = lower limit, UL = upper limit of 95% confidence interval (CI)

*$p<.05$. **$p<.01$. ***$p<.001$

hopelessness. An exception to this pattern was the negative emotion of shame, which was not related to perceived positive value.

In line with our third hypothesis, positive activating emotions, including enjoyment, curiosity, pride, and hope, were positively related to mathematics achievement, with small to medium effect sizes. Again, the effect for curiosity was not statistically significant. Negative deactivating emotions were negatively linked to achievement, with a large effect size for hopelessness and a small effect size for boredom. Negative activating emotions were also negatively related to achievement, with medium effect sizes for anger and shame and a small effect size for frustration.

The relations between aggregate negative and positive emotions and perceived positive value and mathematics achievement were not significant. Due to fewer than five effect sizes for perceived control and aggregated emotions, we do not report an overall effect for these relations.

Table 4 shows moderate to substantial heterogeneity in the strength of the observed correlations, as evidenced by the extent of variance in effects not accounted for by sampling and measurement error (as denoted by I^2). The Q and I^2 statistics had low statistical power, as they were computed on only a small number of studies ($k<20$), and should be interpreted with caution (Huedo-Medina et al., 2006).

4 Discussion

Research on academic emotions has substantially increased in recent years, with the largest number of studies addressing emotions in the domain of mathematics (e.g., Camacho-Morles et al., 2021). Therefore, the two-fold objective of this systematic review and meta-analysis was to characterize how emotions, beyond mathematics anxiety, have been addressed in the most recent mathematics education research and to meta-analytically synthesize existing evidence of relations between emotions, control-value antecedents, and mathematics achievement.

4.1 Empirical contributions

4.1.1 Emotion characteristics

The systematic review of 98 studies revealed that more than 100 different positive and negative emotions relevant to mathematics learning have been addressed in recent research. This finding underlines the diversity of emotions experienced in mathematics learning and shows the liveliness of the research field.

As in previous decades and across domains (Pekrun et al., 2002), most of the emotions we found in the reviewed studies were characterized as achievement emotions, of which enjoyment, boredom, anger, pride, frustration, hope, and hopelessness were the most commonly studied. A notable proportion of emotions referred to epistemic emotions, with curiosity, confusion, and surprise being the most studied. Although the social embedding of emotions relevant to mathematics learning is undisputed (Di Martino & Zan, 2011; Hannula, 2012), only a few were characterized as social emotions, such as pride, embarrassment, empathy, and envy.

Across different learning domains, a general lack of research on positive deactivating emotions, such as relief and satisfaction, has been noted (Camacho-Morles et al., 2021; Pekrun et al., 2023), and this issue is also evident in current research on emotions in mathematics learning. One explanation is that much research in mathematics education has been oriented toward understanding and mitigating challenges and difficulties in the learning process, including negative emotions, such as anxiety or frustration. Another explanation involves measurement challenges, as positive deactivating emotions can be subtle and nuanced, making them difficult to identify. Recent studies suggest that positive deactivating emotions, such as relief, can be measured through self-reports (Hanin et al., 2021; Pekrun et al., 2023) or inferred from think-aloud protocols (Di Leo & Muis, 2020). Thus, more research is needed on positive deactivating emotions and on emotions apart from achievement emotions to draw a more compelling picture of students' emotional experiences and how these experiences affect their learning of mathematics.

Regarding the type of object the emotions were connected to, most emotions referred to mathematics learning in general, such as mathematics classes, homework, and tests, as implemented, for example, in the Achievement Emotion Questionnaire–Mathematics (Bieleke et al., 2023). The important novel contribution of our study is the analysis of objects of emotions specific to mathematics. We identified emotions that referred to specific mathematics activities, such as emotions encountered while solving word problems, posing one's own problems, applying the drawing strategy, constructing a proof, or using specific software for mathematics learning. For example, a case study by Guzmán et al. (2023) linked control-value antecedents and emotions to covariational reasoning, showing that the level of ability to coordinate variables triggered high or low control appraisals. These appraisals, combined with the student's value appraisals of the task, helped relate appraisals to emotions that the student experienced when solving covariational reasoning tasks. Thus, beginning with the initial research on the role of emotions in problem-solving by McLeod (1989), contemporary research on emotions now encompasses a broader scope of activities and topics in mathematics learning. By investigating emotions that refer to specific mathematical topics, such as fractions and calculus, or mathematical processes and competencies, such as modelling and argumentation, future research might further expand on emotions specific to mathematics. This is important because the findings of our meta-analysis suggest that while predictions of CVT (Pekrun, 2024) generally apply across different types of objects, the specific object of emotions may help us understand their effects on learning behavior and motivation in mathematics in more depth. For example, a recent study by Middleton et al. (2023) found that negative emotions related to mathematics activities were negatively linked to social engagement, task efficacy, and interest. In contrast, negative emotions directed at oneself were only related to perceived task efficacy.

Whereas previous research has indicated a focus on trait emotions across various domains (Biese et al., 2024), our findings reveal that recent research has addressed state and trait emotions to a similar extent. On a continuum of temporal stability, state-level and trait-level emotions are situated at opposite ends, with intermediate levels of temporal stability in between. Given that state and trait emotions may differentially relate to in-the-moment and cumulative behaviors and academic achievement (Camacho-Morles et al., 2019), an important direction for future research will be to consider more nuanced distinctions regarding the temporal stability of emotions and their impact on mathematics achievement. This will contribute to a better understanding of how emotions specific to mathematics emerge and affect short- to long-term academic achievement.

Regarding individual versus collective emotions, results point to a massive focus on individually experienced emotions. One explanation for the lack of collective emotions is that research on collective emotions might rely on terms that go beyond specific emotions, such as classroom climate or school culture, and were therefore not identified by our search strategy. Few studies addressed the cultural context of emotions by investigating differences in emotional experiences between minority and majority student groups (Raccanello et al., 2020) and different countries (Greensfeld & Deutsch, 2022). Given the social and cultural embeddedness of emotions in mathematics learning contexts (Hannula, 2012; Schukajlow et al., 2023), there is a need for more research on emotions that are shared between individuals in different social groups and how these relate to individual emotions. Because individuals belong to diverse social groups nested in a hierarchical set of social systems, more research is needed on resulting top-down and bottom-up influences to better understand the social context of emotions in mathematics learning and their relations with mathematics achievement (Hannula, 2012). For example, Hernández et al. (2023) found a weak correlation between the positive emotions of peers at the classroom level and individual mathematics achievement. They concluded that the social context of collective emotions may influence this relation, with a potentially stronger relationship between collective emotions of students who frequently interact with the person—such as close friends or group members—and individual emotions and mathematics achievement.

Considering both individual and collective emotions relevant to mathematics learning can aid in developing effective educational interventions. By leveraging beneficial collective emotions and their dynamics, while also providing targeted support for individual emotion regulation, educators may create more impactful and supportive mathematics learning environments.

4.1.2 Relations between emotions, control-value antecedents, and mathematics achievement

The meta-analysis, in which we extracted effect sizes from 57 independent studies, is aligned with CVT and adds to the findings of previous studies that analyzed emotions across domains (Camacho-Morles et al., 2021; Loderer et al., 2020; Pekrun et al., 2017; Stumm & Ackerman, 2013).

Our findings suggest that feeling in control in mathematics learning is linked to positive emotions, whereas a lack of control is connected to negative emotions, including anger and hopelessness. In addition, valuing mathematics learning is linked to positive emotions, such as enjoyment, curiosity, and pride, whereas a lack of positive value is related to negative emotions, such as anger, boredom, frustration, and hopelessness. Regarding relations with mathematics achievement, positive relations of positive activating emotions, including enjoyment, curiosity, pride, and hope, indicate that these emotions benefit learning. In contrast, negative activating (anger, shame, frustration) and deactivating (hopelessness and boredom) emotions negatively correlated with mathematics achievement, suggesting that these emotions undermined learning. As academic achievements contribute to the learner's subsequent perceived control, the CVT assumes reciprocal relations between emotions, control-value antecedents, and achievement (Pekrun et al., 2017). Although previous meta-analyses conducted across various domains (Camacho-Morles et al., 2021; Loderer et al., 2020) reported near-zero relations between frustration and academic achievement, our findings show moderate negative correlations between frustration and mathematics achievement. Despite this difference, the results are consistent because the effects reported in previous studies fall within the confidence interval of our current meta-analysis. The large confidence interval in our analysis may be due to several factors, such as the heterogeneity of the studies included and the variability in effect sizes across different mathematics subjects and populations. Whether our findings indicate that students in the domain of mathematics struggle to regulate frustration effectively, which could negatively impact their learning, requires further investigation. Narrowing the confidence interval will help provide more definitive conclusions about the role of frustration in mathematics learning compared to other school subjects.

The relations between aggregated positive and negative emotions and mathematics achievement were not statistically significant. One critical factor may be the broad categorization of emotions into the "positive" and "negative" valence categories. While valence captures the general experiential aspect of emotions, it may not be sufficient to predict how emotions influence learning processes and academic achievement. As the CVT suggests, different emotions, particularly activating versus deactivating emotions, have distinct effects on academic achievement (Pekrun, 2024). For example, negative emotions can sometimes motivate students to adopt new self-regulation strategies or increase their effort, leading to effective learning behaviors. For example, anxiety related to the drawing strategy was found to be negatively related to the use of drawings in low-achieving students but positively related in high-achieving students (Schukajlow et al., 2021). This result suggests that the effects of emotions can be variable and that they can depend on students' characteristics. Future research should consider the complex interplay between emotional appraisals, tasks, and students' characteristics to better understand the impact of emotions on mathematics learning.

Findings suggest moderate to substantial between-study heterogeneity. Possible explanations include different age groups and nationalities (Camacho-Morles et al., 2021), diverse emotion measures, state and trait emotions, different types of objects, and variations in the control, value, and achievement constructs measured (e.g., test scores or grades). Thus, future research might aim to address the between-study heterogeneity by conducting moderator analyses using these variables. This would provide a better understanding of the emotional experiences of mathematics learners, the origins of their emotions, and their impact on mathematics learning processes and academic achievement, ultimately guiding evidence-based practices to enhance beneficial emotions and minimize detrimental ones in mathematics learning.

4.2 Theoretical contributions

Our CVT-based systematic review of 98 studies on emotions in mathematics learning and teaching offers a contribution to the understanding of how emotions are addressed and characterized in recent research. The review's findings contribute to the theory by clarifying how the objects to which emotions are attached can manifest in the context of mathematics. While the synthesized empirical evidence on relations between emotions, control-value antecedents, and mathematics achievement supports central predictions of the CVT (Pekrun, 2024), it also demonstrates the robustness of CVT as a synthetic framework for integrating diverse empirical and theoretical perspectives on emotions. Furthermore, the findings underscore the robustness of the results themselves, which is particularly important in the context of replication, highlighting their reliability and consistency across studies (Star, 2021). Our findings show that perceived control and perceived positive value were related to most emotions included in the meta-analysis. In particular, our results may help characterize the antecedents of frustration, which remained unclear in previous meta-analyses (Camacho-Morles et al., 2021). Negative correlations between frustration and control, positive value, and mathematics achievement indicate that frustration is more likely to emerge if the learner perceives a lack of control and their values are compromised, hindering mathematics learning. More research is needed on the antecedents of shame in academic settings. The findings from the current meta-analysis support the prediction that shame is perceived when the individual does not feel in control of the situation. The relationship to value was near zero in the current meta-analysis, where value was operationalized as positive task value (e.g., Munzar et al., 2021; Schubert et al., 2023) or the positive value of achievement (e.g., Bieleke et al., 2023) in the original studies. Instead of the positive value of mathematics learning and achievement, perceived negative value, as the expected disapproval from others in response to violating social expectations, might contribute to the intensity of shame.

Generalized CVT (Pekrun, 2024) suggests that curiosity is triggered by a perceived gap in knowledge, along with a sense of control over closing that gap and the perception that closing the gap is valuable. Our meta-analytic findings support the predicted positive links of control and value with curiosity. The positive relation between control and curiosity was relatively weak and not significant, but this may be due to the general nature of measures of control used in the studies—these measures did not assess perceived control over closing information gaps specifically. The findings have important implications for educational practices, suggesting that cultivating an appreciation for the value of learning, even in areas where students may initially struggle, sustains curiosity and motivation.

4.3 Practical implications

The findings of this systematic review and meta-analysis have practical implications for the teaching and learning of mathematics. First, mathematics teachers should acknowledge and address the diverse emotions experienced in the mathematics classroom to support student learning. To address emotions appropriately, teachers need to be sensitive to the objects of students' emotions, which can vary widely—from mathematics in general or specific mathematical activities to those directed toward the learners themselves or their peers. For instance, if a student experiences anger when working on a mathematics problem in collaborative work, it could be because the problem surpasses the student's current skill level, because the student has trouble applying a strategy (e.g., making a drawing), because the problem context appears artificial and meaningless, or because the student feels that other group members are not contributing. Depending on the object of the student's emotion, the teacher might decide to provide scaffolding, prompt the use of another strategy, offer to let the student solve another problem, or assign specific responsibilities to the group members. Given previous research highlighting difficulties that preservice mathematics teachers encounter when evaluating student task-specific emotions (Rellensmann & Schukajlow, 2018), diagnosing emotions regarding mathematics tasks and addressing these emotions appropriately in the classroom should be included in teacher education.

Second, in alignment with the CVT, teachers should integrate strategies to enhance students' perceived control and emphasize the positive value of mathematics activities. This approach aims to promote positive activating emotions (e.g., enjoyment) and reduce negative emotions (e.g., boredom and anger). Cultivating an appreciation for the value of mathematics learning, even in areas where students may struggle, seems particularly promising for sustaining their curiosity and motivation in mathematics.

4.4 Strengths and limitations

The current systematic review and meta-analysis have some limitations that warrant consideration. First, the inclusion criteria may have overlooked important studies that indirectly addressed emotions relevant to mathematics learning, for example, by investigating related constructs such as classroom climate. Additionally, it is possible that the individual emotions included in our search terms (Table 2) were overrepresented, whereas emotions not covered in the search terms might have gone undetected. Although the list of emotions included in the search terms was comprehensive and mostly balanced with respect to the examined dimensions (e.g., a similar number of positive and negative emotions), adding further emotions could change findings on relative frequencies. In addition, we coded the emotion characteristics valence and activation based on the CVT to ensure a systematic and replicable approach. Future research could explore how study context affects emotion classification, such as valence of surprise, to further refine our understanding of how emotions are experienced in different settings.

Second, when coding the emotions addressed in the identified studies, we relied on the authors' terminology. Variability in our findings may arise from differences in how emotions were defined and measured across the studies. Standardizing these aspects by directly classifying measures (rather than relying on authors) might help reduce this variability and lead to more consistent results.

Third, in our systematic review and meta-analysis, we chose not to account for the quality of the included studies. This approach allowed us to provide a broad and inclusive perspective on how emotions are addressed within mathematics education, capturing a wide range of studies and methodologies. By weighting studies according to their quality and methodological rigor, future meta-analyses can provide more accurate and reliable estimates of the relations between emotions and mathematics achievement.

Fourth, the cross-sectional, correlational nature of effect sizes included in our meta-analysis limited our capacity to make inferences about causal relations between emotions, control-value antecedents, and academic achievement. Subsequent research would benefit from manipulating control or value appraisals and synthesizing the resulting empirical evidence to facilitate stronger causal inferences (Schubert et al., 2023).

Finally, we used the CVT (Pekrun, 2024), which offers a cross-domain theory to explain emotions in academic situations, to characterize emotions specific to mathematics learning. Future research should analyze whether the patterns we found in mathematics (e.g., valence, temporal stability, and social context of investigated emotions) are similar to or different from those in other domains. In addition, the studies in this review span the time of the COVID-19 pandemic, likely influencing students' emotions and learning experiences. Changes such as online learning, altered feedback mechanisms, and heightened uncertainty may have shaped students’ emotions, possibly limiting the generalizability to pre- and post-pandemic contexts.

5 Conclusion

Our systematic review of 112 recent studies identified over 100 distinct emotions relevant to mathematics learning, analyzing them across dimensions such as valence, activation, type of object, temporal stability, and social context. The meta-analysis supports CVT (Pekrun, 2024), revealing significant relations between perceived control, perceived positive value, and mathematics achievement for key emotions. In sum, this CVT-based review and meta-analysis enhances our understanding of emotions in mathematics learning and offers practical implications for educators to enhance beneficial emotions and minimize detrimental ones in mathematics learning.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11858-025-01651-w.

Funding Open Access funding enabled and organized by Projekt DEAL.

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