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ORIGINAL PAPER

Confronted with mathematics: the impact of pre-service elementary school teachers' self-concept on emotional and physiological responses to mathematics exposure

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Abstract
This study employed a situated approach to evaluate how female pre-service elementary school teachers' mathematics self-concept impacts their emotional and physiological responses when confronted with mathematics tasks. We assessed participants' ($N = 70$, $M_{age} = 20.6$ years) self-concept before inviting them into the laboratory, where they solved arithmetic pattern tasks. We recorded their psychophysiological arousal via skin conductance response (SCR), heart rate (HR), and heart rate variability (HRV), and assessed their situated emotional experience using self-report during task performance. We hypothesized linear associations between self-concept and subjective emotional valence (more pleasant with higher self-concept), and curvilinear associations between self-concept and psychophysiological arousal (higher arousal with both low and high self-concept). As predicted, higher self-concept was associated with elevated pleasant and reduced unpleasant emotional experience, even when controlling for task performance. For SCR, we found evidence for the proposed curvilinear relationship between self-concept and physiological arousal, while HR was unrelated to self-concept, and HRV showed a predominantly negative linear relationship with self-concept. Our findings imply *pleasant engagement* (positive emotion, high arousal) when mathematics self-concept is high and *aversive disengagement* (negative emotion, dampened arousal) when mathematics self-concept is low during a relatively low-stakes mathematics task exposure. Our findings highlight the predictive role of self-concept for situated emotional experiences and imply that university teacher education should provide emotionally pleasant, success-promising situations for pre-service elementary school teachers to (re-)build a healthy mathematics self-concept to thrive as students, and later, become effective educators.

Keywords Self-concept · Situated emotion · Psychophysiology · Pre-service elementary school teachers · Control-value theory · Biopsychosocial perspectives

1 Introduction

Prior research shows (pre-service) elementary school teachers—most of them female—often hold negative attitudes toward mathematics, such as low self-concepts (Artemenko et al., 2021; Hembree, 1990; Lake & Kelly, 2014; Porsch, 2021). Low self-concepts can negatively impact emotional experiences (Frenzel et al., 2007; Respondek et al., 2017), likely leading to avoidance of mathematics classes (Ashcraft, 2002; Hembree, 1990), undermining study success (Pekrun et al., 2002), increasing the risk of dropout (Geisler et al., 2023), or bearing further potential adverse downstream effects on later in-service teaching quality and students' emotional and achievement outcomes (Beilock et al., 2010; Ramirez et al., 2018).

Understanding how pre-service teachers' mathematics self-concepts shape their emotional experiences in mathematics can inform interventions aimed at breaking such vicious cycles. However, despite increased research interest,

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literature on pre-service teachers' emotions remains dominated by trait-based, self-report methodologies. Recent calls emphasize considering emotions and self-concept in conjunction, including more objective measures, such as psychophysiological indicators, and examining both traits and states (Cipora et al., 2022; Pekrun, 2023; Schukajlow et al., 2023). This study explores how pre-service elementary school teachers' mathematics self-concept predicts their situated emotional and physiological responses to mathematics tasks. We confronted participants with arithmetic tasks involving "patterns and structures," a key content area in math education (Mulligan & Mitchelmore, 2009; Wijns et al., 2019), which is important for both pre-service elementary school teacher training and in-service teaching practice. Our findings aim to inform teacher training to foster future teachers' confidence and effectiveness in teaching mathematics.

1.1 Self-concept and situated achievement emotions

Pre-service teachers' mathematics self-concepts develop over many years of schooling (Ramirez et al., 2018), shaped by repeated successes or failures (Marsh et al., 2016). Thus, many enter university with deeply ingrained beliefs about mathematics (Lake & Kelly, 2014; Vacc & Bright, 1999), including their mathematics self-concept—that is, their conviction of how well they can do mathematics (Bong & Skaalvik, 2003).

The importance of self-concepts is emphasized in theories of motivation, such as Eccles' expectancy-value theory (EVT, Eccles & Wigfield, 2020), and in theories of emotions, such as the control-value-theory of achievement emotions (CVT, Pekrun, 2024). In EVT, expectancies of success—described as a person's belief in the degree to which they think they can do well on a task—are closely related to self-concept and self-efficacy, and are proposed to be key in predicting motivation (Eccles & Wigfield, 2020). Specifically, EVT proposes that high expectancies of success, in conjunction with high values attached to the task, predict task choice, effort, and persistence. CVT, in turn, focuses on emotions as outcomes. Similar to EVT, CVT proposes that a person's appraisals of the controllability of achievement outcomes, largely driven by their self-concepts and expectancies of success (which CVT subsumes by the umbrella term "control"), are key for predicting how they feel in achievement situations. The theory posits that higher control is typically associated with more pleasant, and lower control with more unpleasant emotional experiences (Pekrun et al., 2023). In addition, CVT proposes that for most emotions, these effects are stronger when the achievement outcome has high subjective value (Pekrun, 2024).

Notably, most empirical findings in the traditions of both EVT and CVT rest on trait-trait variable covariation assessed via trait questionnaires such as the AEQ (Bieleke et al., 2023; Pekrun et al., 2011) or the Expectancy-Value Scale (Peixoto et al., 2023), asking people *what they generally* think and feel about a given domain. For example, there is ample evidence on the links between self-concept and trait achievement emotions in mathematics and other domains (Goetz et al., 2006, 2010; Pekrun et al., 2023; Schoenherr et al., 2025). However, both the EVT—specifically in its recent elaboration into the *situated expectancy-value theory* (Eccles & Wigfield, 2020)—and the CVT (Pekrun, 2024) emphasize that the mechanisms at work are rooted in contextualized, situated judgments, which fluctuate over time.

Only a few studies have examined how trait self-concept relates to situated or momentary emotional experiences. Previous research has, for example, explored its moderating role in the discrepancy between trait and state ratings of emotion (e.g. Goetz et al., 2013; Keller et al., 2025). While low self-concept has been suggested as a potential risk factor for in-situ anxiety (Ashcraft, 2002) in mathematics, direct links between self-concept and situated emotional responses have hardly been investigated. One exception is a study by Macher et al. (2013), who reported a significant negative bivariate correlation between self-concept in mathematics and state anxiety in statistics. Based on CVT, we propose that low self-concepts bias individuals toward appraisals of low control and should therefore predict less favorable emotional outcomes in achievement situations.

1.2 Considering psychophysiological measures

There is growing interest in and a call for the use of psychophysiological measures in educational psychology (Frenzel et al., 2018; Pekrun, 2023; Wigfield & Koenka, 2020) and mathematics education research (Cipora et al., 2022; Schukajlow et al., 2023). Psychophysiological measures are considered more objective measures of individuals' states than self-reports during test situations, as they reflect activity of the autonomic nervous system and are therefore difficult to mask or control (Pekrun, 2023; Wilhelm & Grossman, 2010).

The autonomic nervous system comprises two main branches, the sympathetic and parasympathetic systems. These regulate bodily functions, including heart rate, sweat production, and digestion. The sympathetic nervous system (SNS) is typically associated with activation (e.g., faster heartbeat and sweaty palms before an exam), and the parasympathetic nervous system (PNS) is linked to inhibition, relaxation, and recovery (e.g., calming down after stress; Weissman & Mendes, 2021). Parasympathetic signaling is primarily transmitted via the vagus nerve, a major cranial nerve that regulates heart activity and other bodily

functions. Importantly, the SNS and PNS are not simply opposites; instead, they represent two distinct dimensions that can act independently or together, a relationship conceptualized as an Autonomic Space (Berntson et al., 1994; Kreibig, 2010). While they often function in opposition (one increasing, the other one decreasing), coactivation and coinhibition (both systems increasing or decreasing simultaneously) can also occur (Berntson et al., 1994; Weissman & Mendes, 2021). In this study, we assessed SNS and PNS activity by measuring electrodermal activity—changes in skin conductance due to sweat gland activity—and cardiovascular activity—changes in heart rate and heart rate variability. This approach captures their complex interplay (Kreibig, 2010) and provides deeper insight into individuals' psychophysiological arousal during a mathematics situation.

1.2.1 Electrodermal activity

Electrodermal activity reflects variations in sweat production by eccrine sweat glands, which are particularly dense on the palms of the hands. Sweat production increases skin conductance, enhancing the transmission of electrical signals through the skin (Braithwaite et al., 2015; Christopoulos et al., 2019). Because the SNS solely regulates these glands, electrodermal activity provides a direct measure of sympathetic activity free from parasympathetic interference (Kreibig & Gendolla, 2013). Electrodermal activity can be separated into a tonic signal, which reflects slower baseline changes in skin conductance (skin conductance level), and a phasic signal, which responds rapidly to stimuli and appears as distinct peaks (skin conductance response). In this study, we focus on skin conductance response as a commonly used indicator of sympathetic arousal (Braithwaite et al., 2015; Christopoulos et al., 2019).

1.2.2 Cardiovascular activity

Cardiovascular activity is regulated by both the SNS and PNS, which interact in influencing the heart's function. Sympathetic activity has an arousing function on cardiac activity, and parasympathetic activity has an inhibitory effect (Wehrwein et al., 2016). At rest, these systems are balanced, producing an arousal equilibrium or homeostasis (Rozenman et al., 2017). In demanding situations, sympathetic activity typically rises, while the parasympathetic activity decreases. The parasympathetic system acts like a brake on the heart via the vagus nerve, and releasing this "brake" allows sympathetic influences to dominate (Porges, 2007). This process, known as vagal withdrawal, refers to a temporary reduction in parasympathetic activity, which enables faster and stronger cardiac responses. Vagal withdrawal thus reflects decreased parasympathetic activity alongside increased sympathetic activation, facilitating rapid, coordinated cardiovascular responses to meet situational demands (Laborde et al., 2018).

Common measures of cardiovascular activity are heart rate and heart rate variability. As both the sympathetic and parasympathetic nerves dually innervate the heart, increased heart rate may result from either heightened SNS or reduced PNS activity. Thus, the measure of beats per minute is not a distinct measure of either one (Berntson et al., 1994; Kreibig, 2010). In contrast, heart rate variability, which describes fluctuations in the timing between consecutive heartbeats—the interval between beats is not perfectly uniform—is primarily influenced by the PNS (Laborde et al., 2017). Larger HRV serves as a distinct positive marker of PNS activity (Chapleau & Sabharwal, 2011). In this study, we used both heart rate and heart rate variability to capture the full range of sympathetic and parasympathetic contributions to cardiovascular arousal.

1.3 Appraisals of threat or challenge

Biopsychosocial perspectives explain how physiological responses depend on an individual's appraisals of situational demands relative to available resources (Blascovich & Mendes, 2000; Maloney et al., 2014; Vick et al., 2008), suggesting that physiological responses vary depending on whether a situation is perceived as a challenge or a threat. Challenge appraisals occur when individuals believe they have sufficient resources to meet the situational demands, whereas threat appraisals occur when they perceive them as insufficient. Importantly, both types of appraisals can increase physiological arousal through vagal withdrawal—the temporary reduction in parasympathetic activity that removes inhibitory control over the heart (Mammarella et al., 2023; Vick et al., 2008). As such, both (positive) challenge appraisals and (negative) threat appraisals can lead to heightened physiological arousal. This aligns with evidence showing that intense state emotions of both positive and negative valence can be linked to elevated psychophysiological arousal (Kreibig & Gendolla, 2013).

Based on CVT, we propose that individuals' self-concepts drive their situated appraisals of control: High self-concepts should bias individuals to view demanding situations as challenges, whereas low self-concepts should bias them to view them as a threat. Following biopsychosocial perspectives, we assume that both challenge and threat increase arousal. Based on this reasoning, we hypothesize a curvilinear, U-shaped relation between self-concept and arousal during demanding tasks, with both very low and very high self-concept levels associated with stronger arousal. In contrast, moderate self-concept should align with weaker arousal, as such situations are likely appraised as neither threatening nor challenging. Hence, sym-

pathetic arousal is expected to decrease from low to moderate self-concept levels, then increase from moderate to high self-concept levels. Conversely, parasympathetic activity—indexed by heart rate variability and inversely related to sympathetic arousal—should exhibit an inverted U-shaped pattern.

We apply this reasoning to the mathematical context, and propose that these dynamics should manifest similarly when individuals are confronted with a math task. Those with low mathematics self-concepts are likely to interpret the task as a threat and to display heightened physiological arousal—potentially intensified among females who may have internalized considering mathematics as male domain (Leslie et al., 2015; Nguyen & Ryan, 2008). Individuals with moderate self-concepts may appraise the situation as neither a threat nor a challenge, resulting in relatively lower arousal. Finally, those with high mathematics self-concepts, regardless of gender, should be inclined to perceive the task as a challenge, also accompanied by increased arousal.

1.4 Prior findings on psychophysiology and emotions in education

Physiological markers are increasingly used in educational psychology and mathematics education research; however, studies remain scarce, and findings are often inconclusive (Cipora et al., 2022; Roos et al., 2021). Consistent with the idea that physiological arousal is associated with appraisals of threat and low perceived control, a meta-analysis by Roos and colleagues (2021) reported a moderate positive correlation between test anxiety and sympathetic indicators, namely heart rate and skin conductance response. In the mathematics context, several studies show that exposure to mathematics tasks can increase sympathetic activity, reflected in elevated heart rate, skin conductance, blood pressure, or cortisol secretion (Buckley et al., 2016; Eidlin Levy & Rubinsten, 2021; Hunt et al., 2017; Qu et al., 2020; Rozenman et al., 2017; Strohmaier et al., 2020). This pattern is often interpreted as a "fight or flight" response, suggesting that math tasks are perceived as a *threat*. Importantly, such interpretations disregard the interplay between sympathetic and parasympathetic activity (Weissman & Mendes, 2021). Heart rate does not purely reflect sympathetic arousal (Berntson et al., 1994), and heightened arousal during task execution can result not only from appraisals of *threat* but also from appraisals of (manageable) *challenge* (Blascovich & Mendes, 2000; Vick et al., 2008). The latter has been considered in only very few studies so far (Jamieson et al., 2012; Mammarella et al., 2023; Mattarella-Micke et al., 2011).

Mammarella et al. (2023) explicitly manipulated testing conditions to evoke threat and challenge in fifth graders completing mental arithmetic tasks by providing bogus trial-by-trial feedback (fabricated positive or negative feedback not based on actual performance) or no feedback. They measured psychophysiological arousal, indicated by skin conductance level and heart rate variability, during task completion, and subjective emotional valence before and after. Children in the negative feedback condition reported considerably sharper declines in emotional valence than those in the positive and control conditions. The authors further reported heightened skin conductance levels and reduced heart rate variability—hence, vagal withdrawal—in both the positive and negative conditions relative to the neutral condition, indicating that psychophysiological indicators can imply arousal coupled with both positive and negative valence. Mathematics self-concept was not considered, which the authors identified as an important missing factor. The present study addresses this gap by examining the link between self-concept and physiological arousal in a demanding mathematics achievement situation.

1.5 The present study

As outlined, most existing findings on self-concept—emotion links are based on correlations among self-reported trait constructs (Goetz et al., 2006, 2010). The present study extends this literature by adopting a situated approach: pre-service elementary school teachers were explicitly exposed to algebraic pattern tasks, while both their self-reported emotions and psychophysiological arousal were measured in situ. Based on CVT (Pekrun, 2024), biopsychosocial reasoning (Blascovich & Mendes, 2000; Vick et al., 2008), and prior evidence showing heightened physiological arousal in response to both threat and challenge appraisals (Mammarella et al., 2023; Mattarella-Micke et al., 2011; Vick et al., 2008), we proposed the following hypotheses:

Hypothesis 1 (H1) Mathematics self-concept is negatively associated with self-reported unpleasant emotional experiences and positively associated with pleasant emotional experiences during task execution, even when controlling for task performance.

Hypothesis 2 (H2) Self-concept exhibits a curvilinear association with psychophysiological arousal: vagal withdrawal—reflected in increased sympathetic activity (higher skin conductance response and heart rate) and reduced parasympathetic activity (lower heart rate variability)—is most pronounced at the lower and upper ends of the self-concept distribution.

2 Method

2.1 Procedure and sample

The study employed a two-step assessment design (Fig. 1). Participants were recruited during a mandatory mathemat-

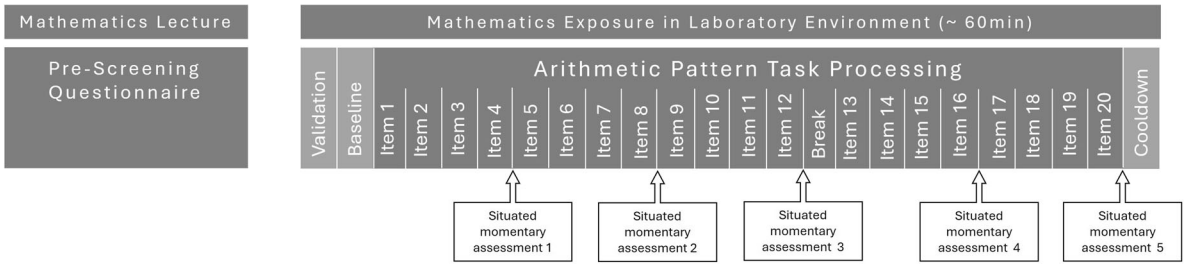

Fig. 1 Two-Step Assessment Study Design

ics didactics lecture at a large German university. In the first step, they completed a digital pre-screening questionnaire via the SoSciSurvey platform on mobile phones, tablets, or laptops. Participation was voluntary, required explicit informed consent, and could be withdrawn at any time.

A total of 409 students provided answers to the pre-study questionnaire ($N_{\text{females}} = 360$; $N_{\text{males}} = 49$), most of them in their first or third semester (93.8%); 6.5% of them majoring in mathematics.[1] The questionnaire assessed mathematics self-concept and additional constructs not reported here. Ultimately, students could opt to consent to future contact. To ensure confidentiality, responses were anonymized, stored separately from contact details, and linked only via a randomly assigned ID.

In the second step, students who had provided follow-up consent were contacted by e-mail and invited to a lab-based study, for which a small monetary compensation was offered. Only female students were invited,[2] of whom 241 were contacted and 74 participated.

In the lab, all participants underwent a validation protocol to identify and exclude skin conductance non-responders (see Supplementary Information 1). After excluding four participants due to low-quality signals or missing self-report data, the final sample included 70 participants ($M_{\text{age}} = 20.7$, $SD = 4.6$). After sensor attachment and verification of their proper functioning, the participants followed on-screen instructions, starting with deep breathing exercises (vagal maneuvers; Gerritsen & Band, 2018) to lower initial arousal triggered by the novelty of the lab environment. A three-minute resting phase served to record a physiological baseline. Participants then completed the algebraic pattern task on screen, preceded by examples and instructions indicating that it would measure numerical intelligence and that feedback would be provided afterwards; this served to induce ego threat and enhance task value. The task consisted of 20 items in total. After every four items—so in total five times across the duration of the mathematics task exposure—participants reported their situated emotional experience using a paper-and-pencil self-report booklet. Skin conductance response, heart rate, and heart rate variability were continuously recorded throughout the session; sequences of filling in the self-report booklets were excluded during post-processing. An untimed break was allowed after they completed 12 items. Upon finishing the task, participants received feedback, a debrief, and compensation.

2.2 Measures

2.2.1 Mathematics self-concept

Mathematics self-concept was measured on a 5-point Likert scale, ranging from 1 (*strongly disagree*) to 5 (*strongly agree*), with three items (e.g., "I learn quickly in mathematics") based on the Self-Description Questionnaire (SDQ II; Marsh, 1990). We used the mean score across the three items as a measure of self-concept. Internal consistency was excellent ($\omega = .95$).

2.2.2 Situated emotional experience

We recorded participants' overall pleasant and unpleasant task experiences by repeated assessments of their current state. After every four items, participants were asked to indicate how much the following statements applied to them "right now" on a 5-point Likert scale ranging from 1 (*not true at all*) to 5 (*completely true*). Overall pleasant task experience was operationalized via the aggregated ratings across

[1] In the Bavarian elementary school teacher education program, students must select one major subject for in-depth study. Even if mathematics is not chosen as a major, taking "teaching mathematics" courses is still obligatory; these courses focus on methods for teaching elementary school mathematics rather than on studying the subject in depth. The proportion of mathematics majors in our sample (6.5%) was very similar to the ~6% of individuals in elementary school teacher education who chose mathematics as a major in 2023/24 in Bavaria (Bayerisches Landesamt für Statistik, 2024).

[2] According to statistics from the Bavarian State Ministry of Education for 2023/24, 90.9% of in-service elementary-school teachers are female, supporting the appropriateness of a female-only sample (Bayerisches Staatsministerium für Unterricht und Kultus, 2024). Our sample represents this predominance (Artemenko et al., 2021; Bayerisches Landesamt für Statistik, 2024). Moreover, including males in proportion to their population share would have resulted in only about seven male participants in a sample of 70, rendering any gender-based analyses severely underpowered and uninformative. For these reasons, recruitment focused on the predominant group in the target population.

each of the five ratings of "I am enjoying the task" and "I feel proud"; overall unpleasant task experience was operationalized via aggregated ratings of the items "I feel stressed/frustrated/angry/tense and nervous" across the five measurement instances over the task phase. Both composite scores had excellent internal consistency ($\omega = .97$ for both the pleasant and unpleasant aggregate scores).

2.2.3 Psychophysiological measures

Psychophysiological data were continuously recorded at 200 Hz using a BioNomadix wristband (MP200), and synchronized via the iMotions software (iMotions, 2022). Data segments during baseline and task were selected for analysis, with artifact-related segments removed. Cardiovascular raw data were exported to Kubios HRV software for automated beat correction and data cleaning (Kubios Oy, 2024; Tarvainen et al., 2014). Detailed settings for the extraction of the psychophysiological parameters are reported in Supplementary Information 2, Tables S1 and S2.

Skin conductance response We assessed skin conductance response by measuring the electrical current between two electrodes attached to the palm of the participant's non-dominant hand. We utilized the iMotions peak detection algorithm (iMotions, 2022), which distinguishes between the phasic (skin conductance response) and tonic (skin conductance level) signals and detects peaks at a 0.01 microSiemens threshold, resulting in a measure of skin conductance response in peaks per minute (PPM). PPM baseline and task-specific indices were obtained by dividing the total number of peaks by the duration (in minutes) of the baseline and task execution periods, respectively.

Heart rate The participants' heart rate, indicated in beats per minute (BPM), was measured using a photoplethysmography (PPG) finger-clip sensor, which detects changes in blood volume pressure (Park et al., 2022). The finger-clip sensor was attached to the index or ring finger of the participant's non-dominant hand. Heart rate baseline and the task-specific BPM index were obtained by dividing the total number of beats by the duration (in minutes) of the baseline and task execution periods, respectively.

Heart rate variability Kubios HRV Scientific software (Kubios Oy, 2024; Tarvainen et al., 2014) was used to extract heart rate variability. The software calculates heart rate variability indices after applying correction mechanisms. For short-term analyses like ours, time-domain analyses are typically used, with the root mean square of successive differences (RMSSD) being the most common (Laborde et al., 2017). RMSSD baseline and the task-specific RMSSD index were obtained by aggregating over the baseline and task execution periods, respectively.

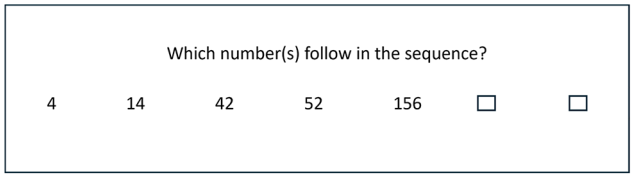

Fig. 2 Hypothetical Sample Item of the Algebraic Pattern Finding Task. *Note*. This item serves as an illustrative example and was not used in the study

2.2.4 Performance in algebraic pattern finding task

Participants completed 20 Rasch-scaled items from Loe et al. (2018),[3] which involved identifying a pattern in a number series; a type of mathematical task from the content area "patterns and structures"—which serves as the basis for developing young children's algebraic competencies (Mulligan & Mitchelmore, 2009; Wijns et al., 2019)—and is therefore highly relevant to elementary school education and teaching. Participants were instructed to fill in one or two numbers continuing the provided sequence, with no time limit and the option to skip an item by entering "X". Overall performance was assessed by total correct answers ($M = 9.74$, $SD = 3.55$; range = 2–17). An example task is shown in Fig. 2.

2.3 Data analysis

All analyses were conducted in R (R Core Team, 2024). To test Hypothesis 1, we used the R package lmtest (Zeileis & Hothorn, 2022) for multiple linear regression predicting pleasant and unpleasant emotional experience by self-concept while controlling for task performance to ensure that the effects reported reflect the impact of self-concept as competence appraisal above and beyond actual performance. For Hypothesis 2, we applied polynomial regression with the R package nlstools (Baty et al., 2015) to predict baseline-corrected psychophysiological measures from self-concept, including linear and quadratic terms, while controlling for task performance. See Supplementary Information 4 for a description of baseline correction. The data and analysis code are available on OSF (https://osf.io/mqnsz/overview).

3 Results

3.1 Descriptive results

Descriptives and intercorrelations are reported in the Supplementary Information 5, Table S4, and Table S5. Average mathematics self-concept and emotion composite scores

[3]For further details on the item selection, please see Supplementary Information 3.

Table 1 Self-Concept as a Predictor of Emotion (Hypothesis 1)

Predictor	Pleasant emotion composite score				Unpleasant emotion composite score			
	β	95% CI lower	95% CI upper	p-value	β	95% CI lower	95% CI upper	p-value
Intercept	.00	−.19	.22	1.00	.00	−.21	.21	.100
Self-concept	.34	.06	.54	.004	−.33	−.57	−.04	.008
Task performance	.34	.14	.61	.004	−.25	−.50	−.02	.045

Note: All values are standardized.

Table 2 Self-Concept as a Predictor of Psychophysiological Parameters (Hypothesis 2)

Predictor	Skin conductance response (PPM)			Heart rate (BPM)			Heart rate variability (RMSSD)		
	β	SE	p-value	β	SE	p-value	β	SE	p-value
Intercept	−.28	.18	.138	−.17	.18	.365	.23	.18	.220
Self-concept linear	.18	.14	.196	.19	.14	.182	−.32	.14	.021
Self-concept quadratic	.28	.14	.049	.17	.14	.234	−.26	.14	.070
Task performance	−.11	.14	.431	−.09	.14	.479	.07	.13	.629

Note: The table shows the baseline-corrected psychophysiological indicators.

were near the scale midpoint. As expected, self-concept correlated strongly with situated emotional experiences. Task performance correlated positively with self-concept and pleasant emotion, and negatively with unpleasant emotion, but showed no association with psychophysiological measures. Psychophysiological markers exhibited large intercorrelations: skin conductance response correlated positively with heart rate and negatively with heart rate variability; heart rate and heart rate variability correlated negatively. Overall, correlations between self-concept and emotion composite scores with psychophysiological indicators were small and mostly non-significant, except for a negative correlation of self-concept and pleasant emotion with heart rate variability, and a positive correlation of unpleasant emotion with heart rate variability.

3.2 Main analyses

3.2.1 Self-concept predicting state emotions (H1)

Table 1 presents the regression results predicting the pleasant and unpleasant emotion composite scores from mathematics self-concept and task performance, with significance tested using bootstrapped confidence intervals.

Results showed that mathematics self-concept significantly predicted situated emotional experience. Higher self-concept was associated with elevated pleasant emotion and reduced unpleasant emotion (controlling for task performance; see Table 1).

3.2.2 Self-concept predicting psychophysiological indices (H2)

Table 2 presents the polynomial regression results for each psychophysiological measure. Figure 3 illustrates these results by approximating the quadratic functions relating self-concept and the three baseline-corrected psychophysiological markers, while controlling for task performance.

In line with our hypothesized curvilinear relationship, self-concept showed a significant positive quadratic effect on baseline-corrected skin conductance response. Linear effects of self-concept and task performance on skin conductance response were not significant. As illustrated in Fig. 3a, this relationship followed a U-shaped pattern: participants with low or high self-concepts exhibited elevated skin conductance responses, whereas those with medium self-concepts showed relatively weaker skin conductance responses.

No significant linear or quadratic effects of self-concept on heart rate were observed, although Fig. 3b suggests a curvilinear pattern. In contrast, heart rate variability showed a significant negative linear relationship with self-concept. The quadratic effect, although negative and of considerable size, did not reach significance. Figure 3c illustrates the data pattern that drove this set of parameters: At the highest end of the self-concept spectrum, participants showed the lowest heart rate variability; with lower self-concepts, heart rate variability was relatively higher, but then leveled off without surpassing the predicted turning point of the hypothesized inverted U-shaped curve.

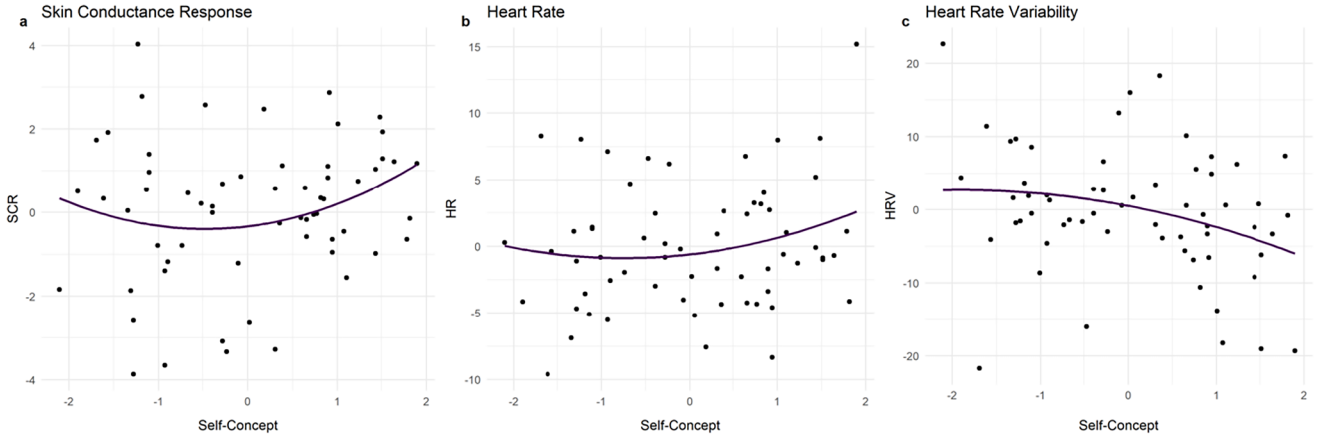

Fig. 3 Approximation of the Quadratic Function Relating Self-Concept to the Psychophysiological Markers. *Note*. Plots show the curvilinear associations between *z*-standardized self-concept scores corrected for task performance via residualization, and *z*-scored baseline-corrected psychophysiological markers

4 Discussion

This study extended research on self-concept—emotion links by examining how pre-service elementary school teachers' mathematics self-concepts relate to both situated emotional experiences and psychophysiological arousal during an arithmetic pattern recognition task.

As expected, self-concept systematically predicted participants' situated emotional experiences. Higher mathematics self-concept was associated with more pleasant and fewer unpleasant emotions. Thus, the present study provides evidence that the actual engagement with mathematics—which is common during university teacher training and in-service practice—is experienced as less pleasant and more unpleasant by those pre-service elementary school teachers with low mathematics self-concepts. Notably, these results were evident even when controlling for task performance, demonstrating the powerful influence of self-concepts on emotional experiences while working on mathematics tasks beyond mere performance. In line with theory (Eccles & Wigfield, 2020; Pekrun, 2024), our findings thus highlight that trait mathematics self-concept impacts not only trait emotions as shown in prior research (Frenzel et al., 2007; Goetz et al., 2010; Pekrun et al., 2023; Schoenherr et al., 2025), but also situated emotional experiences.

Furthermore, we examined the effects of self-concept on psychophysiological arousal to gain a holistic insight into pre-service elementary school teachers' situated responses, triangulating parameters of both sympathetic and parasympathetic activity. This has been considered in only a few prior studies in mathematics (see e.g. Mammarella et al., 2023). Building on CVT (Pekrun, 2024), we hypothesized that individuals' self-concepts would bias them to conceive the situation either as a challenge (with high self-concept) or as a threat (with low self-concept), and that both appraisal patterns would be associated with vagal withdrawal—elevated sympathetic activity, and lowered parasympathetic activity (Blascovich & Mendes, 2000; Vick et al., 2008). For participants with medium self-concepts, the situation was expected to be neither threatening nor challenging. Accordingly, we expected a curvilinear association between self-concept and physiological arousal, with both sympathetic activation (increased skin conductance and heart rate) and parasympathetic deactivation (reduced heart rate variability) being more pronounced at particularly low and high levels of self-concept compared to average levels.

The results supported our prediction for skin conductance response, showing a U-shaped association with self-concept. This implies that pre-service elementary school teachers with low and high self-concepts—linked to more intense unpleasant and pleasant emotions—exhibited elevated sympathetic arousal during testing. This finding aligns with prior research demonstrating elevated sympathetic arousal for both positive and negative emotions (Kreibig & Gendolla, 2013; Roos et al., 2023). However, these results were not significant for heart rate as a physiological marker. The absence of any significant link between self-concept and heart rate could be due to either the unreliability of this measure—photoplethysmography recordings can be affected by movement or imperfect sensor attachment (Park et al., 2022)—or because heart rate is influenced by both the sympathetic and parasympathetic nervous systems, and therefore does not distinctly indicate either system (Berntson et al., 1994; Kreibig, 2010).

Heart rate variability – a distinct marker of parasympathetic activity – showed a linear negative relationship with self-concept, implying that parasympathetic activation was systematically weaker as self-concept increased. As such, at high levels of self-concept, we found evidence for a full vagal withdrawal, characterized by elevated sympathetic activation coupled with reduced parasympathetic activation

(Laborde et al., 2018). However, for low levels of self-concept, we did not find evidence for full vagal withdrawal. Instead, low self-concept was associated with a pattern of sympathetic and parasympathetic co-activation (Weissman & Mendes, 2021), implying a stress reaction, yet not a full-blown "fight or flight" response.

When jointly interpreting our findings on subjective emotional experience and physiological arousal, we find evidence that pre-service elementary school teachers at the high end of the mathematics self-concept spectrum respond with both subjectively pleasant emotional experiences and full-blown vagal withdrawal, characterized by elevated sympathetic and reduced parasympathetic activity. Interpreting this from a biopsychosocial perspective (Blascovich & Mendes, 2000; Maloney et al., 2014; Vick et al., 2008), these students' high self-concepts may bias them to interpret the situation as challenging but manageable, leading them to be willing to invest available cognitive resources while feeling emotionally positively aroused – a pattern of *pleasant engagement*.

In contrast, we found that pre-service teachers at the lower end of the mathematics self-concept spectrum exhibited unpleasant emotional experiences when confronted with arithmetic tasks and tended to show a stress reaction as indicated by an elevated skin conductance response. However, they also remained parasympathetically activated, as indicated by high levels of heart rate variability. We speculate that these individuals did not appraise the task as a full-blown "threat," and therefore did not "fight" it by fully investing available resources. Instead, their low mathematics self-concepts contributed to experiencing the situation as emotionally aversive and stress-inducing. This may have dampened their willingness to engage with the task (see also Beauchaine et al., 2007; Laborde et al., 2018; Porges, 2007; on the interpretation of physiological arousal in terms of task engagement). Therefore, we propose referring to this as a pattern of *aversive disengagement*. We found this pattern in place of the initially expected pattern of *aversive engagement*, characterized by an unpleasant subjective emotional experience coupled with full-blown vagal withdrawal, when participants try hard to solve the tasks.

Finding that quite some learners responded with aversive disengagement is alarming: On the one hand, these individuals seem to maintain their bodily health by not succumbing to overly high physiological arousal when (potentially unsuccessfully) attempting to tackle a task in a domain where their self-concept is low. On the other hand, however, by disengaging from the task, they might deprive themselves of important learning experiences in the corresponding domain. Future research will be necessary to substantiate these speculations and replicate the existence and discernibility of the proposed three patterns of pleasant engagement, unpleasant disengagement, and unpleasant engagement.

5 Limitations and implications for future research

The present study had several limitations that provide directions for future research. First, our sample size was modest ($N = 70$), which limited our power to detect effects, specifically curvilinear effects (Button et al., 2013). The effects were small, with p-values just below the .05 threshold. Replication is warranted to confirm the robustness of our interpretation.

Second, our female-only sample, although representative of elementary school teacher demographics, limits the generalizability of our findings across genders, given known differences in self-reported emotions in mathematics, with females typically exhibiting a greater willingness or capability to report emotions (Bryant et al., 1996). Future studies should therefore include male samples.

Third, average self-concept levels in our sample were higher than expected, likely due to self-selection bias: participants with low mathematics self-concepts may have avoided participation, given that the trait screening emphasized mathematics. Because mathematics is a strongly stereotyped domain disadvantaging women (Leslie et al., 2015; Nguyen & Ryan, 2008), it is plausible that individuals with lower self-concepts opted out of the laboratory study.

Further, our task setting was not particularly high-stakes: Although we introduced feedback to encourage ego-involvement and a desire to succeed, the setting lacked substantial consequences, which may have influenced participants' emotional and physiological responses. Combined with the fact that our sample included relatively few participants with decidedly low self-concept levels, the power to detect vagal withdrawal at the lower end of the self-concept spectrum was likely reduced.

While our laboratory study provides valuable insights into potential mechanisms underlying pre-service elementary school teachers' engagement with mathematics, its ecological validity and generalizability are limited. The study focused on the content area of "patterns and structures." According to Schukajlow et al. (2023), findings may differ across other content areas (e.g., Geometry vs. Algebra) or competencies (e.g., modeling vs. problem-solving). Future research should replicate these findings across different mathematical topics and employ experience sampling or wearable devices during pre-service teachers' practicum to capture responses in authentic educational settings.

Lastly, we employed a between-person analysis approach in the present study by creating person-level aggregates of self-reported positive and negative emotions and physiological markers across the mathematics task exposure in our lab, and relating them to the corresponding individuals' mathematics self-concept (which is typically considered a rather

stable trait). Future research could also investigate within-person covariations across measures of state competence appraisals (which may also vary within individuals, see Niepel et al., 2022), self-reported state emotions, and physiological states.

In this context, it is worth noting that CVT (Pekrun, 2024) makes nuanced predictions about the links between different achievement emotions and emotion-related arousal from a within-person perspective. Specifically, CVT suggests that in situations of very low control, an individual may experience hopelessness or boredom due to overchallenge, both of which are characterized by low arousal. Conversely, in moments of very high control, boredom may also occur—this time due to underchallenge (Pekrun & Götz, 2024). In contrast, moderate levels of challenge may generate levels of perceived control that are sufficient to foster excitement and reduce boredom, accompanied by relatively higher arousal. Thus, on the within-person level, self-concept and arousal may follow an inverted U-shaped relation, mediated by boredom. Distinguishing between- and within-person covariations across control-value appraisals, arousal, and achievement emotions of different qualities remains a promising avenue for future research, yet goes beyond the scope of the present study.

6 Implications for pre-service mathematics education

Our findings have practical implications for teacher education. Many pre-service elementary school teachers hold low mathematics self-concepts, yet must engage with mathematics to achieve their vocational goals. Those prone to aversive disengagement may experience stress and unpleasant emotions without fully engaging, which can hinder the development of both content knowledge and pedagogical competencies. We conclude that teacher education programs should create emotionally supportive and engaging learning environments that foster control by promoting success, experiences of mastery (Street et al., 2024), and self-concept: Promoting students to reappraise math tasks as challenging can foster pleasant and engaged responses (Denny & Ochsner, 2014). Further, higher education instructors could implement interventions that strengthen self-concept and efficacy in this population (Granello et al., 2025; Hörsch et al., 2025; Täschner et al., 2025) and adopt teaching methods that benefit students with low self-beliefs (Schukajlow et al., 2019), such as demanding but success-promising homework sheets (Geisler et al., 2023). Pre-service teachers deserve support to (re)build healthy mathematics self-concepts, which can increase engagement, improve learning, and prepare them to become confident educators.

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Author Contribution FE, MW, and ACF contributed to the study conception and design. Data collection and coding were performed by FE and MW. Analysis was performed by FE. The original draft of the manuscript was written by FE. AF, RP, MW, LB, and MK contributed to manuscript review and editing. All authors read and approved the final manuscript.

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Data Availability The data and analysis code are available on OSF (https://osf.io/mqnsz/overview).

Declarations

Informed Consent Participation in the study required informed consent.

Competing Interests The authors have no conflicts of interest to declare.

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