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Emotions and self-efficacy toward simple machines learning through a STEM practice

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Introduction: This study explores the impact of an interactive physics class on the emotions and self-efficacy of elementary education students, specifically in their future roles as educators using STEM-based pedagogical methods. The research aims to understand how such an approach affects students' emotional responses and confidence in teaching STEM topics.

Methods: The sample included 97 fourth-year prospective elementary teachers. Participants completed pretests and posttests measuring emotions and self-efficacy related to both course content and the pedagogical approach.

Results: Findings indicated a significant increase in both positive emotions and self-efficacy following the interactive class. Male students reported higher levels of positive emotions and self-efficacy than their female peers. Furthermore, students with backgrounds in sciences and technology showed greater improvement compared to those from social science backgrounds. A positive correlation between emotions and self-efficacy was observed.

Discussion: The manipulative, collaborative, and interdisciplinary nature of the physics class likely contributed to the observed positive changes in emotions and self-efficacy. Network analysis suggested that reducing boredom could enhance emotional responses, given its role in affecting both positive and negative emotions. On the other hand, it has been observed that uncertainty could be beneficial in STEM activities due to their relationship with self-efficacy.

KEYWORDS

emotions, self-efficacy, science education, STEM approach, active learning, interdisciplinarity, simple machines, pre-service teachers

Introduction

Relevance of affective factors for learning: neuroscientific, psychological and educational perspectives

Education is inherently emotional: students and teachers experience a wide range of emotions, attitudes, and feelings throughout the teaching and learning processes, as well as when analyzing the outcomes (Pekrun, 2014). Current research across various fields, including neuroscience, psychology, and specific didactics, has demonstrated the significant impact of affective factors (such as academic emotions, subjective value, self-efficacy, self-regulation, motivation or attitudes) on learning in different subjects, including science.

Firstly, numerous neurophysiological studies have established the bidirectional relationship between affective factors and various cognitive processes (such as memory, attention, problem-solving, understanding, reflection, language) (Dunsmoor et al., 2015; Gkintoni et al., 2023; Gu et al., 2013; Kensinger and Corkin, 2004; Mega et al., 2014; Todd et al., 2020; Tyng et al., 2017).

Neuroscientific theories, such as the content valuation model (Dixon et al., 2017), support these findings, suggesting that eight brain subregions are involved in the subjective valuation of stimuli and the modulation of associated emotions. The integration of cognitive and affective processes, based on dynamic interactions within neural networks, is crucial for responding to stimuli. This integrated response is typical for complex behaviors like learning, which require the combined action of cognitive and emotional skills (Pessoa, 2008). As Mora (2008) argues, neuroscience indicates that emotions "activate" the connections needed for the brain to reach its maximum cognitive potential.

This interplay between learning and affective factors is also modeled in psychology through expectancy-value and control-value theories. These theories provide the primary frameworks for understanding the relationship between affective factors and academic achievement. According to expectancy-value theory (Eccles and Wigeld, 2002), academic achievement and students' decisions are influenced by their expectation of success (confidence in their ability to succeed) and the subjective value attributed to the achievement (its importance, usefulness, and personal enjoyment). Recently, this theory has been refined into the situated expectancy-value theory, which emphasizes the need for individualized analysis of affective factors in specific classroom activities (Eccles and Wigfield, 2023). The control-value theory (Pekrun, 2006) further specifies that emotions precede achievements and arise from subjective assessments of the control individuals believe they have over an activity and the value they attribute to it. Both psychological theories thus suggest that affective factors are immediate precursors to academic achievement.

The significance of affective factors in learning has been corroborated by several studies across various subjects, methodologies, and educational levels (Pekrun, 2014). Notably, science education and initial teacher training are among the most extensively studied areas (Mellado et al., 2014; Sinatra et al., 2014; Pozo-Rico et al., 2023).

Academic emotions, subjective value and self-efficacy in science education

In this contribution, we focus on three affective factors that teachers and students may experience during science lessons: academic emotions, subjective value, and self-efficacy. Academic emotions refer to the emotions that teachers and students feel in academic environments due to teaching and learning-related factors (Pekrun, 2014), distinct from emotions arising from other factors such as personal relationships with peers or personal matters. According to current research, academic emotions reflect the subjective value ascribed to teaching and learning tasks and can influence teachers' and students' behaviors (Pekrun, 2006). This task value can encompass positive aspects, such as the usefulness of content for learners or methodologies for teachers, and negative aspects, such as the cost of learning or implementing something.

The interaction between academic emotions and task values aligns with the contemporary understanding of emotions as evolutionary tools humans use to subjectively evaluate their environment (Damasio and Carvalho, 2013). This perspective, supported by the scientific community since Darwin's time, posits that emotions help humans evaluate stimuli and formulate appropriate responses (Ekman, 2009). In academic settings, students and teachers use their emotions to evaluate stimuli, influencing their decisions regarding science teaching and learning processes, such as time management or the choice of teaching and learning strategies (Mega et al., 2014). Factors such as age, academic year, gender, content mastery, and previous academic experiences and results can influence academic emotions in science (Marcos-Merino et al., 2022; Mellado et al., 2014; Pekrun, 2014; Raccanello et al., 2013; Vázquez and Manassero, 2007). Studies have shown that emotions toward science change as educational levels increase, with negative emotions like anxiety, frustration, and boredom becoming more frequent. These emotions also vary by gender and previous education, with negative emotions toward physics being more intense among women and students with less prior knowledge of the subject.

Various taxonomies of emotions exist, with one of the most widely used in educational research classifying emotions by their valence as positive or negative (Pekrun et al., 2023). Generally, positive emotions (such as joy or satisfaction) are positively associated with science learning, while negative emotions (such as boredom or nervousness) are negatively associated (Pekrun, 2014). However, this association is influenced by factors such as the intensity of the emotions—mild nervousness might enhance learning, whereas intense nervousness might inhibit it (Tyng et al., 2017)—and their effect on arousal (activating or depressing emotions). Activating emotions can increase attention, enhance memory encoding, and boost achievement motivation (e.g., for exams) (D'Mello et al., 2014; Todd et al., 2020). Consequently, some activating negative emotions, like nervousness, may benefit science learning (Marcos-Merino et al., 2022; Pekrun et al., 2017; Villavicencio and Bernardo, 2013). Conversely, even positive emotions can impair learning if they are depressing or experienced with high intensity and not directly related to learning (e.g., pride or fun) (Pekrun et al., 2002).

Self-efficacy refers to a person's belief in their own ability to organize and carry out tasks, significantly influencing their feelings, thoughts, and actions (Bandura, 1997). In an academic context, self-efficacy is the perception that students have of their ability to learn content or that teachers have of their ability to teach it. It measures their perceived ability to perform academically (for students) or professionally (for teachers) in science. Perceived self-efficacy allows individuals to exert control over situations and significantly impacts the decisions teachers and students make in the classroom, affecting academic performance (Eccles and Wigeld, 2002). As with emotions, students' self-efficacy is influenced by factors such as gender, with research indicating that women often have lower self-efficacy in science and mathematics than their male peers (Dávila-Acedo et al., 2021; Kyaruzi, 2023; Mellado et al., 2014).

Different affective variables are highly interrelated: students and teachers who experience more positive emotions and fewer negative emotions toward learning and teaching science tend to attribute higher subjective value to content and methodologies (Artino, 2010; Pekrun, 2014; Villavicencio and Bernardo, 2013) and have a higher perception of self-efficacy (Dávila-Acedo et al., 2021; Hernández-Barco et al., 2021; Muñoz-Expósito et al., 2023).

Affective factors in pre-service science teacher education

Given the influence of affective factors on learning, it is essential to consider them in teaching practices (Pekrun, 2014). Notably, research has shown that teachers' emotions toward their subject and its teaching can be transferred to their students (Frenzel et al., 2009; Frenzel et al., 2018; McLean et al., 2023). Because teachers can modulate emotions, it is fundamental to promote positive activating emotions and avoid intense negative and depressing emotions. However, primary teachers often display a lack of enthusiasm for teaching science, a tendency observed from their initial training (Brígido et al., 2013a; Brígido et al., 2013b; Mellado et al., 2014). Studies of future elementary teachers from various Spanish universities have found that these students typically experience numerous negative emotions toward science learning and future teaching, assign it low value for their daily lives, and report low levels of self-efficacy.

Affective factors toward science in pre-service primary teachers depend on various factors such as content, methodology, gender, and memories of past academic experiences in science. Biology is often associated with positive emotions and higher self-efficacy levels, whereas physics, chemistry, and geology are commonly linked to negative emotions and lower self-efficacy (Brígido et al., 2010; Hernández-Barco et al., 2021; Mellado et al., 2014). Physics is perceived as the most challenging science, eliciting higher levels of negative emotions (e.g., nervousness, frustration, worry, uncertainty) and lower self-efficacy. Affective factors also show gender biases and are related to previous training. Female pre-service teachers report fewer positive emotions, lower self-efficacy, and more anxiety than their male peers (Dávila-Acedo et al., 2021; Riegle-Crumb et al., 2015). Regarding background, future teachers who pursued a non-scientific track in upper-secondary education describe more negative emotions and lower self-efficacy toward science learning than those with prior science training (Brígido et al., 2013a; Marcos-Merino et al., 2022).

Future teachers' emotions toward science are also related to their retrospective emotions during their academic history and the emotions they expect to feel as teachers. Academic emotions they describe toward science learning as university students are related to those they felt as secondary school students (Brígido et al., 2013b). Likewise, academic emotions toward science learning influence the emotions they anticipate experiencing when teaching science content and those they actually feel during their practicum (Brígido et al., 2013a).

Considering the current affective factors toward physics learning among pre-service primary teachers, there is a strong need to enhance physics education in initial teacher education programs (Mallow and Kastrup, 2023). One way to achieve this is by including practical activities implemented through active and interdisciplinary approaches (Hernández-Barco et al., 2021; Marcos-Merino et al., 2019). One such approach is STEM (Science, Technology, Engineering, and Mathematics), recently included in the Spanish educational system as a mandatory component in elementary education (Spanish Government, 2022). Evidence supports the positive effect of the STEM approach on various affective factors, including emotions, interest, self-efficacy, and attitudes, from primary education to initial elementary teacher training (Garner et al., 2018; Dökme and Ünlü, 2023; Kim et al., 2015). According to Murphy et al. (2019), affective aspects toward the STEM approach are crucial as they can influence science performance, the choice of science subjects, and professional careers, thereby impacting students' scientific vocations. These authors also found that affective factors toward the STEM approach are influenced by gender, with females generally showing lower self-efficacy toward STEM than males. Negative emotional responses to STEM can develop early and persist throughout schooling. This highlights the need for effective STEM interventions to improve students' affective factors from primary education.

However, it is necessary to train future teachers in implementing these activities, as issues with active interdisciplinary activities (such as STEM) can lead to negative emotions like anxiety or frustration (Cooper and Brownell, 2020). Implementing STEM activities in initial training programs could be key to ensuring their correct implementation in future professional practice. A recent meta-analysis highlighted the need to accurately detect emotions toward the STEM approach in activities designed to teach specific content of disciplines included in the acronym (Anwar et al., 2023). This paper presents the design of a STEM practice for teaching basic physics concepts (mainly simple machines) and analyses its effect on the affective factors of a sample of pre-service primary teachers.

Research objectives and hypotheses

The primary objective of this study is to analyze the effect of a STEM practice on the affective factors of a sample of pre-service primary teachers. This overarching goal is broken down into the following specific objectives and research questions:

- Diagnose and explore affective factors: To assess academic emotions, subjective value, and self-efficacy related to both scientific content (simple machines) and methodology (STEM approach), and to explore how these factors vary based on participants' gender and prior training (O1) To address this, the study poses the question: How do pre-service teachers' academic emotions, self-efficacy, and perceived value toward simple machines and the STEM approach vary by gender and academic background?
- Analyze changes in affective factors: To examine how these affective variables change with the implementation of the intervention (O2), leading to the question: What changes in academic emotions, self-efficacy, and perceived value occur among pre-service teachers after participating in a STEM-focused practical activity on simple machines?
- Examine interactions between affective variables: To analyze the interactions between these affective variables and how they vary with the implementation of the intervention (O3), which leads to the question: How do the interactions between affective factors (academic emotions, self-efficacy, and perceived value) evolve before and after a STEM intervention?
- Investigate causes of changes: To explore the possible causes of observed changes in these affective variables (O4), which raises the question: What are the perceived challenges and benefits reported by pre-service teachers regarding the implementation of STEM-based activities in primary education?

Based on these objectives and the studies discussed in the Introduction, the following hypotheses are proposed:

- Pre-Intervention gender differences: Before the intervention, there are significant differences in academic emotions, self-efficacy, and subjective value toward simple machines and the STEM approach based on the participants' gender (O1)

- Pre-Intervention background differences: Before the intervention, there are significant differences in academic emotions, self-efficacy, and subjective value toward simple machines and the STEM approach based on the participants' background (O1)
- Impact of the intervention: The implementation of the intervention improves participants' positive emotions, self-efficacy, and subjective value, while decreasing negative emotions toward both simple machines and the STEM approach (O2)
- Changes in affective interactions: A change in the interactions between affective factors (academic emotions, self-efficacy, and subjective value) is expected after the intervention (O3)
- Nature of the intervention: Participants' affective factors (academic emotions, self-efficacy, and subjective value) improve due to the manipulative and interdisciplinary nature of the intervention (O4)

Methodology

Sample and procedure

The study involved 97 pre-service elementary teachers who were in their fourth year of the primary education degree program at the University of Extremadura's Faculty of Education and Psychology. All participants were enrolled in a science education course. This non-probabilistic, convenience sample was selected from students pursuing this degree. Upon completion, these students are qualified to teach primary education, covering ages 6–12 across six grade levels (1st to 6th). Notably, this course represents the final science education class they take in their degree program, following two previous courses related to physics, chemistry, geology, and biology education, and three courses in mathematics education.

Regarding demographics, participants ranged in age from 22 to 27 years, with the majority being 22 years old and predominantly female (76.3%). Concerning their upper-secondary education background, only 33% of participants followed science and technology tracks, while the majority pursued non-science tracks: social science (58.8%), arts (3.1%), or humanities (1%). Additionally, 4.1% of participants entered university via vocational training. These demographics are consistent with previous studies on pre-service teachers in Spain (Marcos-Merino et al., 2022).

Participants attended practical sessions in groups of around 20 students, working in smaller groups of approximately four members. Each session lasted 3 h and involved a STEM practice focused on simple machines. The intervention phases, starting with the engineering problem "How did the Egyptians transport the stone blocks of the pyramids without modern machinery?," are detailed in a subsequent section.

Students were informed about the goals of the research, procedure, duration and anonymity of their data. The students were also informed that implemented research instruments would not be used in any case for the evaluation of the subject. Participation was voluntarily and it was possible to withdraw participation at any time.

Instrument

The research instrument was a questionnaire (Appendix 1) assessing affective factors (academic emotions, self-efficacy, and subjective value) toward simple machines and the STEM approach. A simple and fast quantitative self-report test was used, as this method is easy to implement, minimally disruptive to classroom activities, and effectively measures subjective and verbalized emotional experiences (Gogol et al., 2014). Single-item assessments were used for affective factors, offering sufficient validity, requiring less time, and being less intrusive compared to longer multi-item measures (Goetz et al., 2016). The use of simple self-report items for assessing emotions is supported by neurophysiological studies correlating brain activity with self-reported mood (Kragel et al., 2016). Scales for emotions, self-efficacy and subjective values were sourced from previously validated tests (Brígido et al., 2013a; Marcos-Merino et al., 2022), with validation processes encompassing internal validity (intercorrelations, exploratory and confirmatory factor analyses, measurement invariance) and external validity. The questionnaire demonstrated strong internal consistency, with McDonald's ω value of 0.895 and Cronbach's α value of 0.910.

Twelve simple items were assessed: 10 academic emotions (joyful, trusting, satisfied, enthusiastic, fun, worried, frustrated, uncertain, nervous, bored), self-efficacy, and subjective value. Emotions and self-efficacy were assessed for both scientific content (simple machines) and methodology (STEM approach). For task value, participants evaluated the importance of the STEM approach for their future professional performance. The selection of academic emotions was based on previous descriptions in pre-service teacher samples (Brígido et al., 2013a; Brígido et al., 2013b; Mellado et al., 2014) and their influence on learning (Pekrun, 2014). Emotions were rated on a Likert scale from 1 "not experienced" to 5 "intensely experienced," while self-efficacy and subjective value were rated on scales from 1 "little" to 10 "much." To avoid influencing affective responses, questions about academic emotions, self-efficacy, and subjective value were asked before knowledge questions.

Participants completed the questionnaire:

- Before the intervention, to assess their prior affective factors: anticipatory emotions, self-efficacy, and subjective value.
- Two weeks after the intervention, to assess the affective factors experienced during implementation. The follow-up questionnaire included two open-ended questions (Appendix 1) about the perceived positive aspects of this type of intervention for primary education and the difficulties primary teachers might face in implementing it. These questions aimed to identify potential causes for changes in affective factors post-intervention.

Data analysis

A mixed-method approach, combining quantitative and qualitative analysis, was employed. Quantitative analysis was applied to Likert-scale data on academic emotions, self-efficacy, and subjective value. Due to the non-normal distribution of the data (p-value >0.05, Kolmogorov–Smirnov test) Spearman's correlations was employed to analyze interactions between affective factors. ANOVA f-test was used as a robust statistical method with unbalanced sample sizes (Mair and Wilcox, 2020). To gain a systemic perspective on variable interactions, a statistical network analysis was performed using the generalized method of moments, where variables are represented as nodes and their interactions as edges. This method identifies maximum unique shared covariance between variables (Hevey, 2018). Quantitative analyses were conducted using JASP v. 0.16.2.0 and Jamovi 2.3.28.

For the qualitative analysis, the first step was to establish analysis categories and create a system of emerging codes based on participants' responses to open-ended questions. This categorization followed content analysis procedures, systematically and objectively describing message content as outlined by Bardín (1991). Categories were non-exclusive, allowing multiple codes per participant response. The frequency of responses related to each code was quantified to determine the main advantages and difficulties noted by participants post-intervention (Table 1).

Description of the experience

Before starting the hands-on activity, students were introduced to fundamental theoretical concepts of the STEM approach as a pedagogical method in a comprehensive lecture lasting 1 h and 30 min. This session conceptualized the STEM approach as a type of project-based learning with a strong interdisciplinary focus, integrating science, technology, engineering, and mathematics skills to solve an initial engineering problem. To supplement their understanding, a detailed document outlining the experience was provided, offering a concise summary of scientific principles and a step-by-step guide for assembling and testing models of inclined planes, pulleys, and levers.

The educational materials used in the practical session were deliberately chosen to emphasize sustainability. Everyday reusable items like cardboard, wooden sticks, strings, yogurt pots, matchboxes, straws, toilet rolls, and expanded polystyrene were repurposed, reinforcing the concept of sustainability for future educators. Before the session began, students completed a brief knowledge questionnaire consisting of five questions probing basic concepts of simple machines. The intervention itself spanned approximately 3 h, encompassing the lecture, hands-on activities, and the initial knowledge test. Given this time constraint, the STEM activity was strongly guided by the teacher. As in all STEM projects, the starting point was an initial problem, but the teacher guided the students in designing the practical activities to solve it.

TABLE 1 Emerging categories and codes for positive and negative aspects of the STEM experience.

Categories	Codes
Positive aspects of the STEM experience	
Methodological aspects	Manipulative experience
	Collaborative work
	Interdisciplinary approach
	Useful for future career
	Based on everyday environment
	Innovative and creativity enhancing
	Miscellaneous
Motivation	Increase of motivation
Learning	Improve of learning
No positive aspects	
Negative aspects of the STEM experience	
Lack of training	In content
	In methodology
Methodological aspects	Difficulties in implementation
	Collaborative work
	Manipulative experience
Motivation	Decrease motivation
No difficult aspects	

The STEM experience began with a problem-solving approach, posing the question: "How did the Egyptians transport stone blocks for the pyramids without modern machinery?" This real-world problem linked directly to the participants' future professional roles, encouraging them to envision incorporating STEM experiences into their teaching practices.

The document included images depicting the assembly process (Figure 1) to aid participants, and two teachers were present in the laboratory to offer guidance and address any queries throughout the entire process. Working in groups of around four members, students followed a descriptive guide that outlined materials and steps for each model. They recorded the acquired data on a sheet and subsequently engaged in analyzing these findings. Following this analytical phase, students delved into a series of activities detailed below.

The STEM experience started with creating pulley models, encompassing both simple and compound pulley systems. For the simple pulley system, participants used a yogurt pot connected to the matchbox and weight system via a string, suspended from a stick supporting the pulley. Students introduced a weight into the matchbox and raised it by adding various weights to the yogurt pot. They then weighed all components and engaged in activities, illustrating that simple pulleys alter the direction of force without reducing the necessary force to lift an object. Moving on to the compound pulley system, participants constructed the model using a yogurt pot, two pulleys, string, a clip, and a stick. They attached a weight to the mobile pulley and added weights to the yogurt pot, demonstrating how compound pulleys effectively reduce the necessary force to lift an object.

Next, participants created a simple lever model using cardboard, toilet rolls, expanded polystyrene, and glue. They investigated the relationship between the fulcrum-to-load distance, introducing 15 coins into the R pot (load) and determining the effort (number of coins) needed in the P pot to lift the R pot. This exercise was conducted at various fulcrum positions, revealing that the number of coins (force) needed varied with the distance from the load to the fulcrum. Applying the law of the lever, participants calculated the required effort for any fulcrum position, providing valuable insights into lever mechanics and force distribution.

The exploration concluded with an inclined plane equipped with a pulley, utilizing household materials such as cardboard, wooden sticks, strings, yogurt pots, matchboxes, straws, adhesive tape, and glue. Plastic pulleys were provided to simplify the process, recognizing the complexity for elementary education in constructing one from common materials. They placed a weight in a matchbox and elevated it using the inclined plane, introducing various weights into the yogurt pot. After achieving this objective, students used a balance to weigh all components—weights, matchbox, yogurt pot, and clip—forming the basis for subsequent activities analyzing the forces at play. These

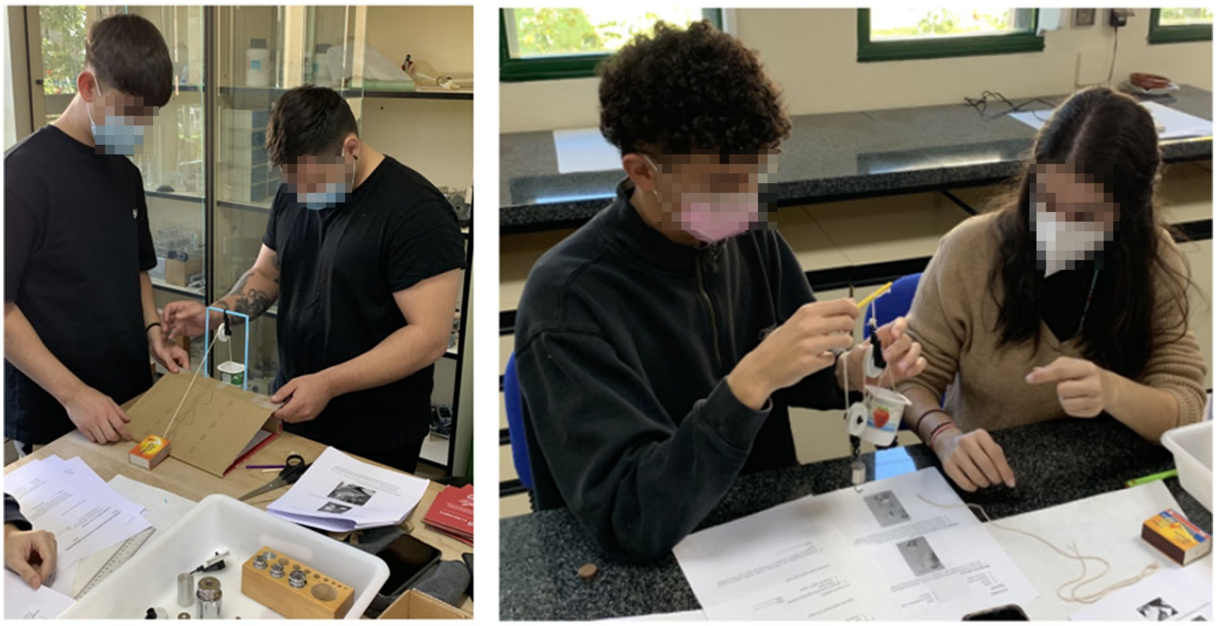

FIGURE 1
Future elementary teachers working with models of simple machines.

activities demonstrated how inclined planes effectively reduce the force required to lift an object, highlighting the impact of the inclined plane's angle on the lifting force.

This experience on simple machines effectively integrated the four disciplines of the STEM approach, as shown in Table 2. This approach aims to highlight the interdisciplinary nature of STEM projects to future teachers.

Unlike many STEM activities that focus purely on cognitive learning outcomes, this intervention also investigates the affective factors, such as emotions and self-efficacy. By addressing how emotions like confidence, frustration, or boredom play a role in learning, this activity acknowledges and seeks to improve the emotional engagement of pre-service teachers, which is crucial for their future teaching. This approach highlights the importance of not only what students learn but how they feel during the learning process, enhancing their overall motivation and self-efficacy in teaching STEM subjects effectively.

TABLE 2 Aspects of science, technology, engineering and mathematics (STEM) disciplines worked on during the experience.

Science	Technology	Engineering	Mathematics
Concept of mass Concept of force Types of forces: weight, friction, tension Difference between mass and weight Simple machines Scientific method	Election and manipulation of materials Model making Use of tools and instruments (balance, dynamometer…) Use and interpretation of scales Use and interpretation of plans and sketches	Engineering problem as context Teamwork Problem solving during design, construction and testing	Measuring process (angles, distances, …) Units Performing calculations (formulas, conversion factors…) Problem solving Organization of information in tables Graphical representation Trigonometry Geometry, shapes, and geometric relationships

Results

Diagnosis of affective factors: academic emotions, self-efficacy and subjective value before the experience

Before starting the experience, students uniformly assigned equal value to both positive and negative emotions concerning both content and methodology (results gathered in Table 3). The initial emotional assessments, although apparently balanced, set the stage for understanding subsequent shifts in students' emotional responses. Within the initial emotional ratings, certain trends stand out. Positive emotions toward both content and methodology received relatively modest ratings, ranging between 2.45–2.73 and 2.50–2.80 out of five, respectively. Conversely, negative emotions, including uncertainty, boredom, nervousness, and frustration, garnered slightly higher scores. Notably, there was an increase in worry regarding the methodology, particularly since it was the students' first encounter with it. It is noteworthy that the negative emotion with the lowest value was boredom, since *a priori* they consider that working manipulatively with simple machines through a STEM approach, although not to their liking, is not boring.

The examination of gender and background differences in emotional responses and self-efficacy provides valuable insights into the varied experiences of students before engaging in STEM activities. Figure 2 illustrates significant trends in emotional responses based on students' backgrounds. Those with a scientific and technological background (ST) exhibit notably higher positive emotions for both content and methodology compared to their social sciences background (SS) counterparts. The emotion of enthusiasm, specifically, shows statistically significant differences. Conversely, ST students attribute less importance to negative emotions, such as worry, boredom and frustration toward content, and nervousness, worry and frustration toward methodology. Regarding academic emotions, there are no significative differences according to the gender in previous emotions.

Participants exhibited low self-efficacy in either the delivery of the content or the application of the STEM approach before the experience, as reflected in their ratings of 4.32 and 4.19 out of 10, respectively (results gathered in Table 4). Individuals with a scientific background generally view themselves as more self-effective in terms of content and its subjective value is higher, compared to their counterparts with a social science background, revealing significant differences. These differences are determinant for considering greater self-efficacy in the teaching of this content if the student had taken a higher level ST training itinerary. In examining gender differences, a significant contrast is evident. Specifically, male participants demonstrate notably higher self-efficacy levels for both items compared to their female counterparts.

Regarding interactions between affective factors, students with the highest ratings in positive emotions showed a significant positive correlation (Spearman's p-value <0.001) with self-efficacy in both content and methodology. Conversely, emotions such as boredom, worry, and frustration correlate negatively (Spearman's p-value <0.01).

TABLE 3 Mean values and standard deviation (SD) for academic emotion valuations both content and methodology before the STEM experience.

	Content		Methodology	
	Mean	SD	Mean	SD
Joy	2.63	0.96	2.79	1.08
Satisfaction	2.73	0.92	2.80	1.04
Fun	2.73	1.00	2.59	0.96
Enthusiasm	2.74	1.03	2.76	1.04
Confidence	2.45	0.95	2.50	0.97
Boredom	2.72	1.15	2.63	1.04
Nervousness	3.16	1.27	3.21	1.22
Frustration	3.00	1.34	2.85	1.33
Uncertainty	3.43	1.11	3.33	1.17
Worry	2.96	1.27	3.20	1.20

Impact of the STEM experience in affective factors

Participants experienced a substantial increase in all analyzed positive emotions (both toward scientific content and methodology) following the STEM activity (Figure 3). Regarding negative emotions some decreases were detected toward scientific content (reduction of boredom) and methodology (reduction of boredom and worry). It should be noted that boredom decreased both content and methodology in a statistically significant way. However, it highlights that frustration toward scientific content increases significantly after the intervention.

When students are asked about their self-efficacy after the experience, the values improve statistically significantly both in terms of scientific content and methodology (Figure 4). As shown in this figure, this positive shift extends not only to the objective evaluation of self-efficacy but also encompasses the subjective value that students attribute to this methodology.

Interactions between affective factors before and after the STEM experience

The application of correlation and network analysis offers a comprehensive understanding of how emotions and variables interplay both before and after the STEM intervention. Correlation and network analysis are carried out, revealing that emotions are

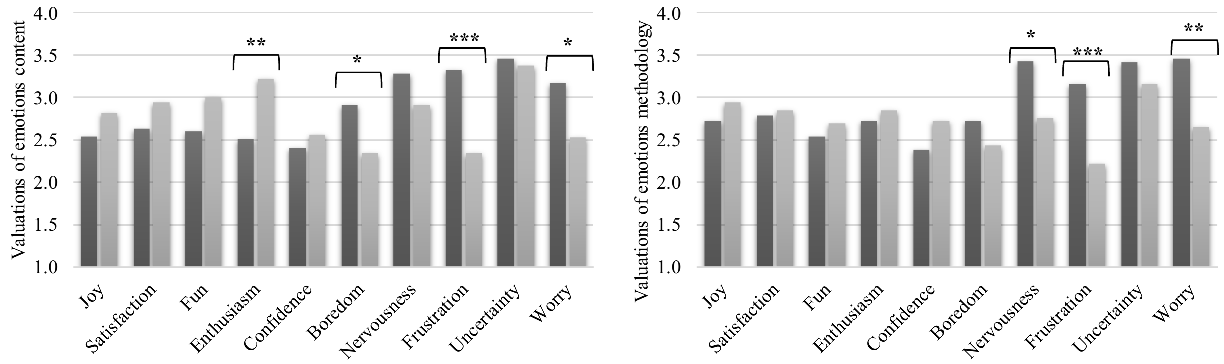

FIGURE 2
Valuation of academic emotions for content (left) and methodology (right) by background studies (dark and light gray for SS and ST background, respectively) and significant ANOVA p-values (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

TABLE 4 Self-efficacy values regarding content, methodology and subjective value of the STEM approach for all students, and by background and gender.

		Background studies			Gender		
	All	SS	ST	*p*-value	Female	Male	*p*-value
Content self-efficacy	4.32	4.02	4.94	0.043*	3.99	5.57	0.004**
Methodology self-efficacy	4.19	3.95	4.66	0.087	3.93	5.05	0.019*
Subjective value	5.47	5.12	6.19	0.039*	5.24	6.14	0.091

Significant ANOVA *p*-values (*$p < 0.05$; **$p < 0.01$).

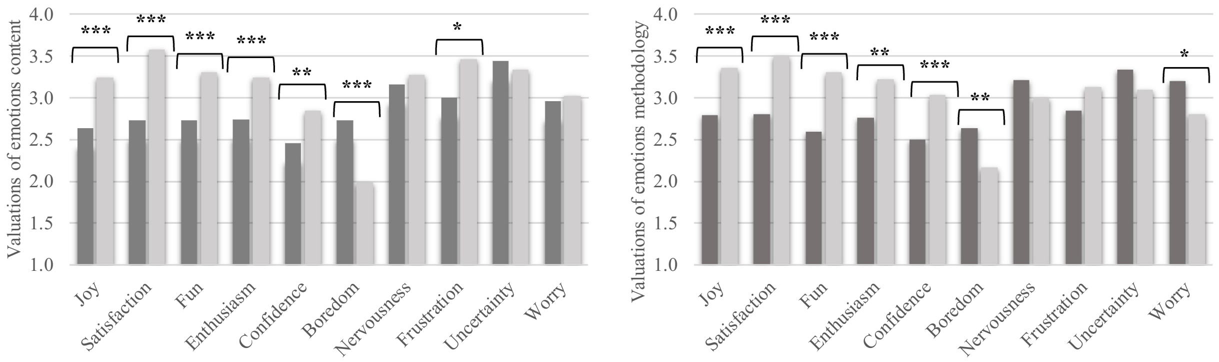

FIGURE 3
Valuation of emotions for content (left) and methodology (right) before (dark gray) and after (light gray) completing the experience. Significant ANOVA *p*-values (*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$).

grouped according to their valence both before and after the intervention (Figure 5). Before the intervention, negative emotions were grouped one by one, linking specific negative emotions toward scientific content with their counterparts related to methodology (e.g., frustration toward simple machines is related to frustration toward the STEM approach). Meanwhile, positive emotions cluster around scientific content (all positive emotions toward simple machines are related to each other) and methodology (all positive emotions toward the STEM approach are related to each other). After the intervention, a change on interactions of negative emotions is observed: some negative emotions (worry, frustration and nervousness) cluster around scientific content and methodology, whereas boredom and uncertainty are grouped one by one (boredom and uncertainty toward simple machines corresponds to its equivalent toward STEM approach). These results about interactions between negative emotions suggest that STEM experience change not only the intensity of negative emotions but also how they interact. Considering these results, it could be established that after the STEM activity negative emotions toward scientific content have less influence on negative emotions toward the STEM approach than before the intervention. Additionally, both self-efficacies (toward scientific content and methodology) are closely interrelated and connected to the subjective value of the STEM approach. This pattern is consistently observed both before and after the intervention.

Also noteworthy are the interactions established after the intervention by two negative emotions (boredom and uncertainty). Regarding boredom, this academic emotion positively interacts with other negative emotions and negatively affects self-efficacies and certain positive emotions such as fun or satisfaction, which could support that modulation of this emotion could contribute to improve not only negative emotions but also positive emotions and self-efficacy. Also, positive correlations of uncertainty (both regarding simple machines and STEM approach) with subjective value and self-efficacy are found. These interactions indicate that students experiencing more uncertainty during the intervention tend to report higher subjective value and self-efficacy toward the STEM approach post-experience.

Potentials and difficulties reported about the STEM experience

Once the experience was over, the students answered two open-ended questions: "What positive aspects could you highlight from this type of practice for a Primary School classroom?" and "What difficulties would you have as a teacher to implement this type of practice in a Primary School classroom?." The answers were categorized into four categories: methodological aspects, influence on motivation, influence on learning, and no positive aspects found. From these 4 main categories further, codes were developed.

Figure 6 illustrates the distribution of responses, indicating positive aspects of the STEM experience across various subcategories. Notably, the most highly valued aspect is related to the manipulative nature of the STEM approach (41%). Participants also express a strong belief in the utility of the experience for enhancing both content learning (39%) and motivation (26%). Additional noteworthy aspects within the methodology include the collaborative nature of the work involved (18%), the interdisciplinary approach (13%), and the incorporation of real-world problems into the learning environment (8%).

These results on the benefits of the intervention could explain the changes observed in the affective factors analyzed in this contribution. However, only 13% of participants believe that this approach will be beneficial for their future careers. It is worth noting that a small percentage (4%) of participants did not perceive any positive impact on teaching through this experience. The responses of these participants justified this lack of benefits with the frustration they experienced during the STEM activities, which could indicate that the frustration felt by the participants could limit the benefits they perceived on the STEM approach.

On the other hand, when asked about the difficulties of the experience (Figure 7), 44% cited a lack of knowledge about the contents, while 37% expressed a deficiency in training for this methodology. Notably, 31% of participants highlighted the perceived difficulty in implementing the STEM approach, attributing it to the extensive time commitment required and the necessity for less common resources. Moreover, 11% of students explicitly stated that they anticipated encountering significant difficulties in applying this approach in their future work.

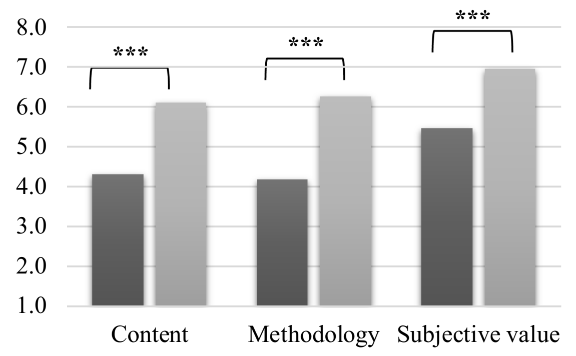

FIGURE 4
Self-efficacy values respect to the content, methodology and subjective value before (dark gray) and after (light gray) completing the experience. Significant ANOVA p-values (***$p < 0.001$).

Discussion and hypothesis testing

Previous research consistently highlights the significance of self-efficacy as a strong predictor of academic achievement, reflecting students' confidence in their ability to tackle academic tasks effectively (Putwain et al., 2013). In this study, participants initially demonstrated low self-efficacy ratings of 4.32 and 4.19 out of 10 for delivering the scientific content of simple machines and applying STEM approaches, respectively. This aligns with existing literature indicating prevalent low self-efficacy among prospective teachers in science education, often accompanied by heightened negative emotions (Brígido et al., 2010; Hernández-Barco et al., 2021; Mellado et al., 2014).

The relationship between self-efficacy and emotions is notable, with higher ratings in positive emotions correlating positively with self-efficacy in both scientific content and methodological application. Conversely, negative emotions such as boredom, worry, and frustration correlate negatively with self-efficacy, consistent

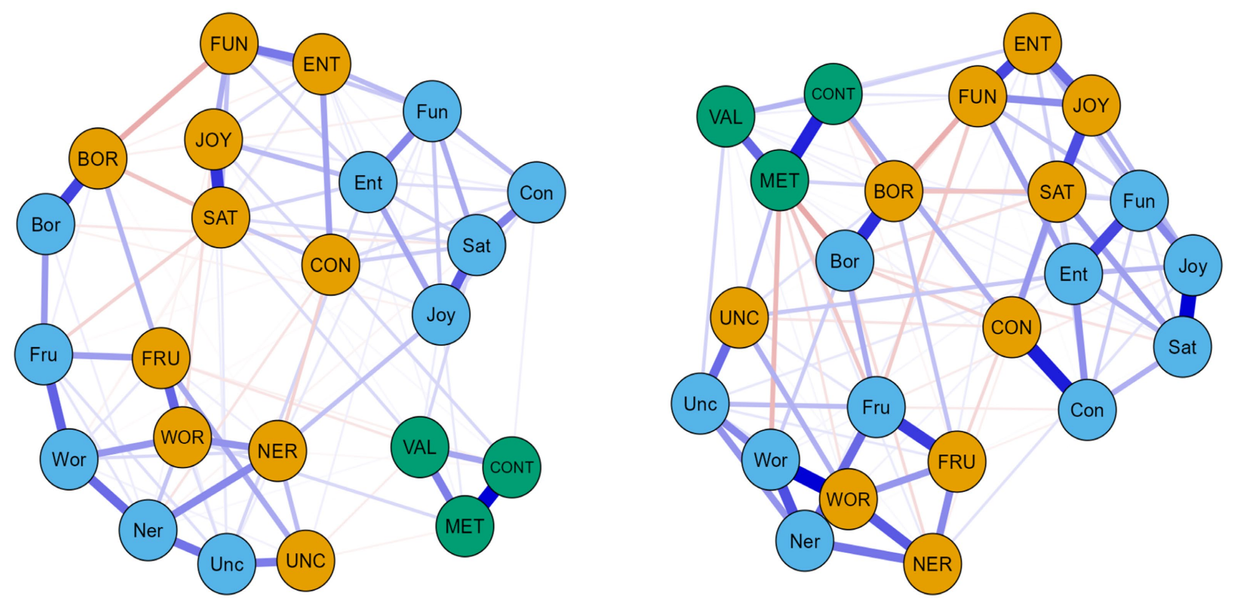

FIGURE 5
Network analysis between academic emotions, self-efficacy and subjective for both content and methodology, before (left) and after (right) completing the experience. Yellow circles indicate emotions towards content, blue circles emotions towards methodology and green circles indicate self-efficacies and subjective value. Abbreviations indicate joy (JOY), satisfaction (SAT), fun (FUN), enthusiasm (ENT), confidence (CON), boredom (BOR), nervousness (NER), frustration (FRU), uncertainty (UNC), worry (WOR), self-efficacy towards content (CONT), self-efficacy towards methodology (MET) and subjective value (VAL). The blue lines reflect positive interactions and the red lines negative interactions. The thickness of the line is proportional to the strength of the interaction.

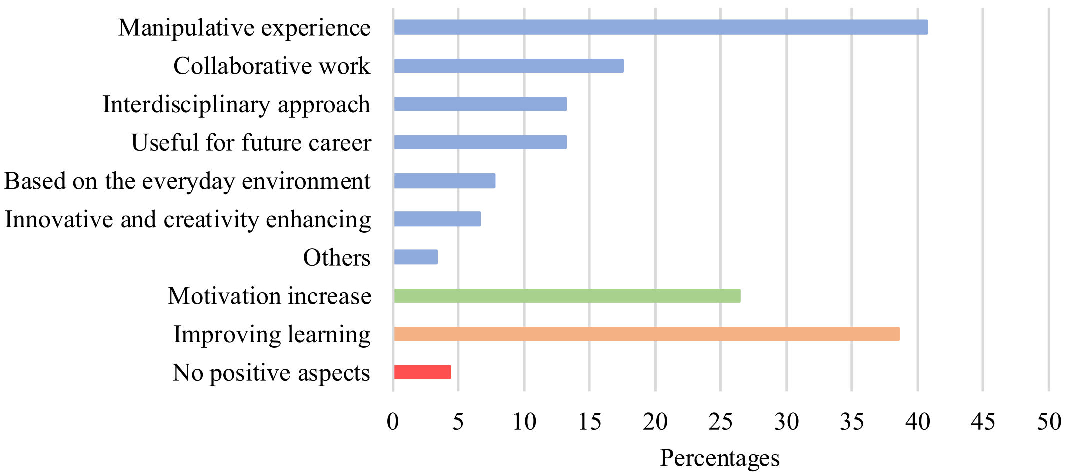

FIGURE 6
Percentages of positive responses relating to methodological aspects (blue), influence on motivation (green), influence on learning (orange), and no positive aspects (red).

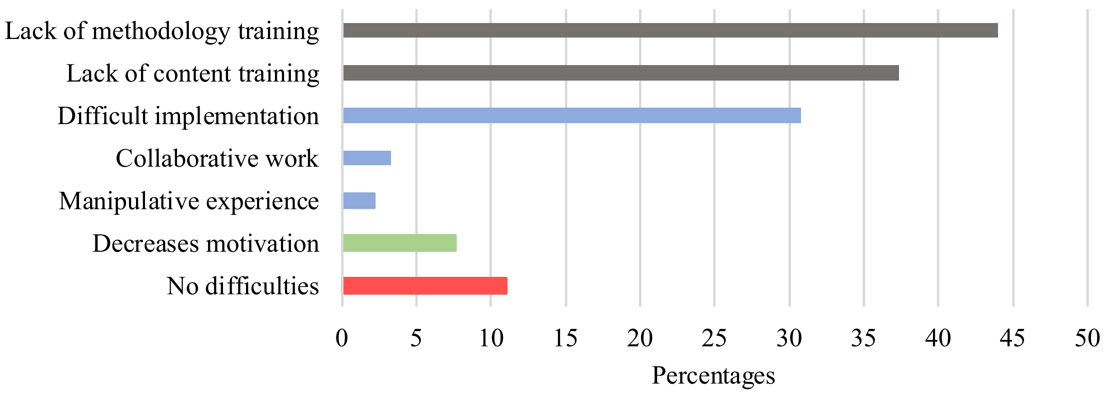

FIGURE 7
Percentages of negative responses relating to lack of training (gray), methodological aspects (blue), influence on motivation (green), and no difficulties (red).

with findings by Brígido et al. (2013a). Murphy et al. (2019) emphasize the predictive role of self-efficacy in STEM performance, while Guo et al. (2017) stress the importance of both self-efficacy and task value in promoting engagement and career aspirations in STEM fields. However, Andersen and Chen (2016) highlight inconsistencies, indicating that performance may not consistently align with self-efficacy or task value, showing a disconnect among students, including those with above-average abilities, in STEM subjects.

Participants with a scientific background tend to perceive themselves as more self-efficacious in content delivery, anticipate fewer negative emotions (both toward scientific content and methodology) and attribute higher subjective value to it compared to their peers with a social science background. These differences are significant and consistent with previous studies (Brígido et al., 2013a; Hernández-Barco et al., 2021; Marcos-Merino et al., 2022). Gender differences are also evident, with male participants demonstrating notably higher levels of self-efficacy in both content and methodology compared to females, in line with findings by Dávila-Acedo et al. (2021) and Riegle-Crumb et al. (2015). Although gender differences in achievement goals within STEM fields may not consistently emerge (Zeldin and Pajares, 2000), disparities persist in self-concept, interest, and utility value, particularly in mathematics where girls often exhibit lower self-concept and interest despite comparable performance levels.

Thus, the first hypothesis is partially supported: females report significantly lower self-efficacy in both simple machine content and STEM approaches compared to males, with no significant gender differences observed in emotions or subjective value. Regarding the second hypothesis, significant differences in negative emotions are observed toward both simple machine content and STEM approaches, with participants from scientific-technological backgrounds displaying fewer negative emotions and higher self-efficacy and subjective value in content delivery. However, no significant differences are found in self-efficacy toward STEM approaches.

The post-experience evaluation reveals significant shifts in emotional responses and self-efficacy among participants, offering insights into the impact of STEM activities. Participants experienced a substantial increase in all analyzed positive emotions, particularly joy and satisfaction, following STEM engagement, consistent with findings by Kim et al. (2015).

Conversely, changes in negative emotions are contradictory: while some emotions toward scientific content and methodology (such as boredom or worry) decrease, frustration toward scientific content increase after the intervention. This is consistent with previous works showing that the implementation of active approaches can generate negative emotions in students (Cooper and Brownell, 2020) and reflect persistent negative emotions crucial to constructing STEM educators' professional identity (Jiang et al., 2021). Notably, boredom decreased significantly for both content and methodology, suggesting areas for refining STEM methodologies to address specific learning challenges. Regarding self-efficacy (both toward scientific content and methodology) and subjective value attributed to the STEM approach, there is a significant positive shift in these variables, consistent with previous studies (Miller et al., 2018; Velasco et al., 2022), highlighting the positive influence of hands-on and inquiry-based activities (Hernández-Barco et al., 2022). Thus, the third hypothesis is partially confirmed: the intervention enhances positive affective responses toward both content and methodology, despite persistent frustrations suggesting areas for further STEM intervention refinement.

The application of correlation and network analysis offers a comprehensive understanding of how emotions and variables interact both before and after the STEM intervention. The grouping of emotions by valence observed in this study aligns with prior research on academic emotions (Ochoa de Alda et al., 2019; Marcos-Merino et al., 2022). Before the intervention, negative emotions such as frustration, worry, and nervousness clustered with their counterparts related to methodology, while positive emotions were concentrated around scientific content and methodology. Following the intervention, the pattern of interaction among negative emotions changed, indicating that the STEM experience not only altered the intensity of negative emotions but also their interrelationships. Post-intervention, negative emotions toward scientific content exerted less influence on negative emotions toward the STEM approach compared to pre-intervention. Moreover, the close interrelation between self-efficacies (toward scientific content and methodology) and their association with the subjective value of the STEM approach persisted both before and after the intervention. The notable interactions between reduced negative emotions and increased self-efficacy toward STEM activities support the fourth hypothesis. The role of boredom is particularly highlighted, as it positively interacts with other negative emotions and negatively affects self-efficacies and certain positive emotions such as fun or satisfaction. This modulatory role of boredom, previously highlighted in practical biology teaching with pre-service elementary teachers (Marcos-Merino et al., 2022; Ochoa de Alda et al., 2019), emphasizes the importance of educational interventions aimed at alleviating boredom to enhance positive emotions and self-efficacy. Furthermore, the positive correlations between uncertainty regarding simple machines and the STEM approach, alongside subjective value and self-efficacy, indicate that students experiencing more uncertainty during the intervention tend to report higher subjective value and self-efficacy toward the STEM approach post-experience. This finding is consistent with current understanding of academic emotions, underscoring the occasional benefit of encouraging specific negative emotions to promote learning (D'Mello et al., 2014; Marcos-Merino et al., 2022; Pekrun et al., 2017; Villavicencio and Bernardo, 2013). These studies demonstrate that certain stimulating negative emotions, such as moderate levels of nervousness, can enhance students' attention and improve information retention in memory, thereby facilitating learning. However, this positive effect does not extend to depressive negative emotions like frustration or fear, which typically hinder learning outcomes.

Analysis of student responses highlights the potentials and challenges of integrating STEM practices in primary school classrooms. Participants value the manipulative nature of STEM (41%) for enhancing learning and motivation, aligning with collaborative work (18%), interdisciplinary approaches (13%), and real-world problem integration (8%) (Ford et al., 2013; Ryu et al., 2019). Despite positive perceptions, challenges include content knowledge gaps (44%), methodological deficiencies (37%), and implementation difficulties (31%), consistent with previous findings (Berlin and White, 2012; Diana et al., 2021; Roehrig et al., 2012). Notably, initial positive aspects like manipulative and cooperative strategies can transform into execution challenges due to participants' unfamiliarity with STEM approaches, highlighting the importance of comprehensive training to address both content knowledge and practical implementation barriers (Shahali and Halim, 2024). This finding could explain why no significant variations were observed for negative emotions, except for boredom. Overall, these insights emphasize the need for comprehensive training in STEM methodologies and the importance of addressing both the content knowledge and practical implementation challenges that future teachers might face.

Conclusion and educational implications

Initially, academic emotions toward simple machines and the STEM approach exhibit similarities, with higher levels of negative emotions such as uncertainty and nervousness. Conversely, positive emotions are less prominent, underscoring low confidence levels in facing the challenges presented. Similarly, self-efficacy and subjective value are initially perceived as low. Students from social science backgrounds particularly express strong negative emotions toward both the content and methodology, highlighting frustration and worry. While background does not significantly affect their self-efficacy, gender does play a role: female participants feel less capable of engaging with the content and STEM methodology, emphasizing the importance of considering gender and background in initial science teacher education programs (Osborne and Dillon, 2008; Mellado et al., 2014).

The implementation of the intervention notably enhances positive emotions toward both content and methodology, alongside perceived self-efficacy and subjective value. Notably, boredom shows a significant decrease among negative emotions. These changes, while significant, result from a single activity. Exploring the impact of a more comprehensive educational intervention program would be valuable, as altering students' affective domain through a single practical activity can be challenging (Dávila-Acedo et al., 2021).

The intervention reshapes emotional interactions, with boredom notably influencing the modulation of other emotions, both positive and negative, as well as subjective value and self-efficacy perceptions. This outcome suggests that reducing boredom could potentially enhance learning through STEM experiences. Furthermore, uncertainty demonstrates a positive interaction with subjective value and self-efficacy toward the STEM approach, indicating that certain negative emotions can facilitate learning (Marcos-Merino et al., 2022).

Participants attribute the observed improvement in the affective aspects of the STEM approach to its manipulative, collaborative, and interdisciplinary nature. They believe these elements could motivate their future students and effectively enhance scientific content learning. However, participants express concerns about the practical implementation of this approach due to their limited scientific and pedagogical knowledge of STEM methodology. This aligns with the observed minimal changes in negative emotions and challenges in increasing self-efficacy toward the methodology (Garner et al., 2018; Murphy et al., 2019).

These findings highlight the necessity of incorporating more STEM-related activities and other active, interdisciplinary methodologies into teacher training programs. Moreover, efforts should focus on bridging these approaches with their real-world application in primary schools. It is crucial that proposed experiences are authentically STEM, integrating all relevant disciplines (Toma and García-Carmona, 2021).

Limitations and future research

Limitations of this research should be acknowledged, notably its focus on a specific sample with a high representation of female and from SS backgrounds, and from a particular geographical context and educational program (degree in primary education at the University of Extremadura). Future studies could explore how this intervention impacts the affective factors of trainee teachers in different contexts (other regions, countries, and universities), encompassing diverse educational backgrounds (including those with stronger representation of students from scientific-technological pathways in secondary education or more gender-balanced) and across various educational levels (such as future teachers of secondary education). For instance, it would be valuable to explore how the intervention affects trainee teachers from various educational backgrounds, including those with a more balanced representation of scientific-technological pathways from secondary education. Replicating this study with secondary education students is pertinent, as this stage often reveals emotional challenges toward subjects like physics (Mellado et al., 2014). Additionally, the gender imbalance within the sample could influence the generalizability of the findings regarding gender differences in affective factors related to STEM education. Future research should aim for more balanced gender representation to provide a comprehensive understanding of how these factors manifest across different groups.

Further research avenues could investigate how the intervention influences learning outcomes across different STEM disciplines and examine the relationship between STEM knowledge acquisition and the affective factors explored in this study. This exploration could shed light on whether variations in affective factors contribute to promoting STEM learning. Additionally, investigating the long-term effects of such STEM practical activities on affective factors (e.g., after several months or in subsequent academic years) would provide valuable insights.

Regarding the qualitative analysis conducted, it is important to note that it was prospective and superficial in nature, primarily aimed at exploring the causes of changes observed in affective variables. Future studies could benefit from more in-depth qualitative analyses, such as semi-structured interviews conducted with students both before and after activity implementation. Insights gained from these interviews could inform the refinement of intervention designs to enhance learning and motivation for STEM education among primary teachers in initial training.

Data availability statement

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

Ethics statement

The studies involving humans were approved by Comité de Bioética de la Universidad de Extremadura. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AM-L: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. JM-M: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

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

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1393711/full#supplementary-material

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