MODESTUM
EURASIA Journal of Mathematics, Science and Technology Education, 2025, 21(10), em2709
ISSN:1305-8223 (online)
OPEN ACCESS
Research Paper
https://doi.org/10.29333/ejmste/17039

Emotions expressed by grade-8 students in STEM projects

Jesús Ramón Girón-Gambero [1*], Teresa Lupión-Cobos [1]

[1] Universidad de Málaga, Málaga, SPAIN

Received 06 November 2024 ▪ Accepted 19 August 2025

Abstract

This study analyses the emotions experienced by secondary school students when carrying out STEM projects, with activities that involve scientific practices of inquiry and argumentation to promote different dimensions of their critical thinking. The work emphasizes the dimension linked to decision-making, aiming to empower students in making rational and informed choices, integral to the decisions they employ in problem-solving. Interested in improving formative instruction for teachers and student learning, we have analyzed the positive and negative aspects associated with the emotions expressed by students (26 students, aged 13-14) during these projects. The analysis shows an increase in positive emotions as opposed to negative ones, with a key factor for the former being the practical activities and the teaching role and with a preponderance of the value given to the qualification in the latter.

Keywords: STEM, project-based learning, emotions

INTRODUCTION

Bringing science and technology closer to the school by supporting decisions involving the responsible use of scientific and technological advances is a key social objective in science education today to contribute to forming competent, free, participatory, reflective citizens with scientific attitudes. With this intention, developing critical thinking (CT) in students acquires importance due to its contribution to the cognitive processes involved in constructing the scientific knowledge to be promoted.

Over the past decade, research has shown a global rise in STEM education (Fatimah et al., 2024) which plays a vital role in promoting scientific literacy and is gaining increasing significance in the educational landscape, attracting attention from both educators and stakeholders (Bybee, 2013). With the growing demands of the 21st century, STEM education offers a pathway to apply theoretical concepts to real-world situations (Estapa & Tank, 2017; Sutaphan & Yuenyong, 2019), contributing to enhanced literacy skills (Susanta et al., 2023) and to develop critical skills such as problem-solving, creativity, and technological proficiency.

The latest education law in Spain (Government of Spain, 2020) introduces a new curricular framework in the Spanish education system that includes STEM competences (mathematical competence and competence in science, technology and engineering) in the compulsory stages. In this framework, a STEM education perspective seeks to make students literate to decide on complex problems by mobilizing key knowledge in science, engineering and mathematics (Perignat & Katz-Buonincontro, 2019).

Incorporating STEM treatment requires addressing an epistemological, scientific and didactic scenario that involves dealing with the inherent complexity and multidisciplinary approach to real-world problems, trying to promote an interrelated understanding of the processes involved and the very nature of the different disciplines, using models of different levels of curricular integration in the activities (Pérez-Torres et al., 2021). Integrated STEM education is popular worldwide due to its potential to increase student interest in STEM subjects, courses, and careers and develop important workforce skills (e.g., collaboration, communication, critical and creative thinking). It involves integrating knowledge and skills from multiple subjects using real-life topics and social constructivist pedagogies (Kelley & Knowles, 2016).

Furthermore, in this curriculum framework, implementing teaching-learning sequences involving STEM projects requires employing active and participatory teaching approaches. These approaches

✉ jrgiron@uma.es **(*Correspondence)** ✉ teluco@uma.es

Contribution to the literature

- The study provides empirical evidence that STEM projects, with activities that involve scientific practices of inquiry and argumentation to promote different dimensions of their critical thinking, develop positive emotions in students and reduce negative ones.
- This article proposes a constructs desing for PBL STEM projects that can be used in teacher training and with science students.
- The results identified key factors that influence the development of positive emotions, such as practical activities and the teaching role. However, for students to fully benefit from this training, it is essential to cultivate both their self-efficacy and positive achievement-related emotions through instructional strategies tailored to the specific context.

enable the utilization of socio-scientific contexts and issues (Sadler & Dawson, 2012) as effective learning scenarios. These situations can be addressed by employing inquiry-based science teaching that fosters students' interest and participation and nurtures their understanding of the nature of science. This contributes to the development of scientific competences and improves, among other aspects, motivation and interest in learning (Marshall & Alston, 2014). It also reduces the gender gap (Sjøberg, 2019), enhances scientific vocations and creates a lasting effect on attitudes towards science (Chen et al., 2014; Lupión-Cobos et al., 2022).

Implementing STEM projects requires establishing classroom relationships that facilitate learning from constructivist approaches (Crawford, 2014). In these models, students actively participate in science learning through inquiry, engaging in activities and processes similar to those used in scientific research. This approach involves solving real, contextualized problems (Herranen et al., 2018), allowing students to develop reflective judgement for informed decision-making (Blanco-López et al., 2017) around problems or contexts or authentic problems, engagement in engineering design, context integration and content integration of STEM disciplines, engagement with STEM practices and 21st century skills or promotion of STEM careers (Avraamidou, 2022; Dare et al., 2021; Roehrig, 2021),

These processes require an extended period due to the difficulty of influencing teachers' previous beliefs and values and to the changes that have to take place in the role of the students, with implications not only at a cognitive or procedural level but also at an affective level. Thus, they are associated with key aspects of scientific practices when going through the different phases of scientific work, from formulating questions to planning an experimental design or discussing the results (Pérez & Furman, 2016). This highlights the need to incorporate the emotional component in teaching and the interest in understanding and identifying the emotions experienced during the implementation of this type of project (Ritchie et al., 2013), as they are an irrational factor directly linked to the rational choices we make (Morgado, 2012).

EMOTIONS AS DISPOSITIONS IN STEM PROJECTS

European recommendations on key competencies for active learning emphasize scientific and technological literacy, fostering scientific knowledge, skills, and attitudes valuable for everyday life. In this context, STEM education aims to engage students across various fields, promoting pedagogies that connect disciplines through practical applications and encourage contextualized learning. This is essential for developing citizens who can navigate multicultural environments.

The STEM perspective (Martín-Páez et al., 2019) serves as a foundational approach for cultivating critical skills in students (Couso & Simarro, 2020). This approach goes beyond mere information transfer, focusing instead on fostering CT and problem-solving abilities. It integrates scientific practices' content and processes, empowering students to pose questions, conduct investigations, and construct arguments–skills essential for shaping reflective citizens and educators. However, challenges remain in designing proposals that effectively integrate interdisciplinary STEM approaches into teaching practices.

From this orientation to implement an STE(A)M integrated learning situation related to the participation of key constructs from three focus: *STE(A)M itself nature*, *practices approaches selected for teaching*, and *classroom learning situations*.

Among the variety of teaching methods, related to the STEAM nature, the context-based teaching is a particularly effective approach, to choose a relevant situation or analyzing everyday life situations is not just a backdrop for learning; it is a vital part of the process to motivate students learning.

Regarding selected teaching approaches, the inquiry-based approach is considered highly relevant for student motivation, contributing to the development of encompassing skills such as decision-making, reasoning, problem-solving, arguing, and investigating (Vázquez-Alonso & Manassero-Mas, 2018).

Inquiry-focused STEM projects often provoke negative emotions such as confusion, boredom or frustration, as they require complex learning. Sánchez-

Martin et al. (2018) analyzed the emotional response when dealing with different innovative strategies, differentiating, in their case, inquiry (which they refer to as "guided inquiry") from practical "recipe" laboratory activities, which many teachers often consider as inquiry (Constantinou et al., 2018). In both strategies, a certain percentage of rejection (5%) is identified, which, in addition, in the case of inquiry, is associated with a lower percentage of positive emotions, which they attribute to the fact that the complexity involved in solving research problems is absent in a purely reproductive laboratory activity.

Thus, during inquiry processes, emotions, especially epistemic and achievement emotions and thematic emotions, become particularly relevant, as they are closely associated with reasoning in scientific practice (Bellocchi et al., 2017). It is important, therefore, to understand the emotions generated in students when participating in STEM projects in the medium term since an emotional rejection of scientific subjects has been observed, which even conditions their decisions about future studies, in many cases moving away from those of the scientific field (Mellado et al., 2014).

In building learning situations in the classroom, the project-based learning (PBL) methodology enables students to engage in experiences that foster STEM competencies, where they can identify and apply fundamental knowledge, as well as the ways of doing, thinking, speaking, and feeling in science, engineering, and mathematics (Pérez-Torres et al., 2021).

In this regard, these settings make it possible for students to make an intentional self-regulated judgement, leading to a subjective interpretation (Facione, 1998), which could be influenced by the emotions being experienced at the time, according to the capacity for emotional metacognition (Briñol et al., 2006; Ford & Yore, 2014). In this way, as previous research has recognized, the level of attention and reflection of students is higher in classes with an emotionally positive learning climate (Aydogan et al., 2015).

Social cognitive theory presents a model of triadic reciprocity, which suggests that environmental factors, personal characteristics such as cognition and motivation, and behaviors interact in a reciprocal manner. An individual's cognitive and motivational processes shape their decision to engage tasks, which in turn impacts their environment and behavior (Vongkulluksn et al., 2018).

After participating in academic tasks, students engage in self-reflection, processing new information about the consequences of their actions, their perceived abilities, and expectations of outcomes (Bandura, 2001, 2006). Consequently, involvement in STEM activities enhances students' confidence in their abilities and encourages future participation in similar tasks. Therefore, fostering a motivating learning environment that supports STEM learning has the potential to increase students' active engagement in STEM-related activities. In our study, we applied social cognitive theory to explore how motivational factors interact to influence students' academic decisions (Bandura, 2001, 2006).

Due to these premises, it is relevant for teachers to learn to design and select STEM PBL projects that contemplate characteristics such as arousing curiosity for the acquisition of knowledge, the graduation of the difficulty of the tasks and the development of skills that make them feel competent (Michaelian & Arango-Muñoz, 2014).

Enjoyment of science is associated with the diversity and frequency of tasks in the classroom (Hampden-Thompson & Bennett, 2013), as well as with the type of activities, finding that hands-on activities such as those that take place in STEM PBL projects are associated with self-efficacy and general interest in science learning (Grabau & Ma, 2017).

Considering emotional intelligence in science education has become increasingly relevant as a protective factor amidst the demands of constructing teaching-learning processes. It helps reduce stress levels among teachers and enhances the experience of positive moods (Extremera et al., 2019), consequently impacting their performance positively in the classroom. This fosters the development of conflict management skills, promotes school coexistence (Vila et al., 2021), and enables successful coping with adverse circumstances (Bellocchi et al., 2017; Bisquerra & García, 2018). Thus, in their construction, students and teachers participate in a series of academic emotions that refer to their learning and focus on knowledge (García-Ruiz et al., 2020), which are especially important during learning with new tasks, usually manifesting themselves in situations of contradictory or incongruent information, when students' cognitive representations are questioned, or new understandings are achieved (Pekrun et al., 2018).

Encountering novels or conceptually challenging situations often elicits an emotional response (Chiu et al., 2014). Given that emotions play a crucial role in processes linked to conflict situations and decision-making at both individual and collective levels (Morgado, 2012), it is relevant to orient the STEM PBL projects towards maximizing the occurrence of positive emotions, defined as short-lived pleasant feelings, and minimizing the manifestation of negative emotions, which entail unpleasant feelings and require considerable resources to address (Brígido et al., 2013; Hernández et al., 2021). This approach should be essential to enhance CT, as it would have a positive impact on the regulatory processes that are part of optimizing the foundations of judgments (deciding what to believe and what to do), essential elements for the formation of a reflective and critical citizen (Zohar &

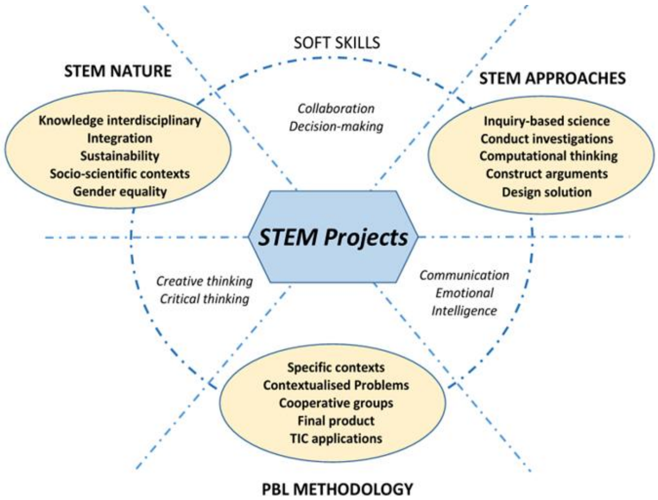

Figure 1. Constructs design of the STEM projects from PID2023-147028NB-I00 (Source: Authors' own elaboration)

Dori, 2014). Several factors are involved in the design of integrated STEM projects, both the nature of STEM itself and the STEM approaches, as well as soft skills including the mobilization of emotions. It is therefore important to analyze what kind of emotions, and to what extent, are aroused in students when working for a prolonged training. All these factors are shown in our orientation of STEM PBL projects (project PID2023-147028NB-I00) (**Figure 1**).

Within this context, this study aims to analyze the emotions experienced by Spanish students in grade-8 of compulsory secondary education (13-14 years old) when carrying out different STEM PBL projects during a school year.

RESEARCH QUESTIONS

This study aims to answer the following research questions (RQ):

RQ1. What emotions are most strongly aroused in students in grade-8 after working with STEM projects during a school year?

RQ2. What causes these emotions in students?

METHOD

Participants and Context

The research was conducted with 26 grade-8 students from the Isaac Albéniz Secondary School, a small school in Malaga (Spain). The participants were 16 girls and 10 boys, aged 13-14 years, taking the compulsory physics and chemistry subjects during the 2020-2021 academic year. The students' performance was medium-low in STEM subjects, and they did not usually work with this teaching approach in the classroom.

Experience Description

The students worked during the school year on three major STEM projects. Each project was designed to solve a socially relevant issue in the context of health and the environment, using the inquiry approach for the sequence of tasks. The nature of the projects, in turn, allowed for developing different CT skills, such as critical analysis of information, argumentation, and decision-making.

Each project involved various activities, during which students actively participated in developing specific processes that arose and mobilized their emotions. Knowing which positive and negative aspects are associated with emotions is of interest for improving performance in formative instruction, both on the part of teachers and in the students' motivation towards learning (Pekrun et al., 2018).

The sequencing of STEM projects was as follows.

STEM project 1. Can masks be reused using physical methods?

This project, which lasted two months (Girón-Gambero & Franco-Mariscal, 2022), aimed to make students aware of and respond to the problem of the possible reuse of masks to avoid environmental pollution caused by the intensive use of masks. The final product consisted of an oral presentation in which the students gave positive and negative reasons to reuse masks following physical sterilization processes using ultraviolet-C light and heat. In the first part, the contents covered were those relating to the electromagnetic spectrum, wave parameters and the particularities of ultraviolet radiation. The second part relates to the nature of heat and its forms of transmission. The sequence of tasks was designed around an inquiry involving a commercial ultraviolet-C light device applied to the masks used by the students. Secondly, a homemade dryer was used following a supposed sterilization protocol disseminated through social networks. This procedure consisted of placing the used mask in a pharmacy paper bag, applying the hot air flow of the homemade dryer for 10 seconds and then leaving it to rest for a day. In both cases, its effectiveness was tested by counting microorganisms on a mask sample before and after applying the sterilization process using the corresponding physical method.

STEM project 2. The coronavirus

This month-long project was designed to help students understand the scientific aspects involved in the COVID-19 pandemic. The final product was the production of a homemade hydroalcoholic gel. The scientific knowledge addressed were mixtures and dissolutions. The sequence of tasks ranged from classifying the physical systems formed by microorganisms with air, the separation mechanisms used by masks, to the effectiveness of hydroalcoholic gels of different concentrations. The end of the project was confirmed by testing the effectiveness of the hydroalcoholic gels made by applying them to the students' hands and the number of microorganisms present in them (Girón-Gambero et al., 2023), which provided them with criteria for a possible purchase of the product or their manufacture.

STEM project 3. A walk around your city

The final result of the third project, which coincided with the last month of the school year, consisted of developing a digital tourist guide of a city in Andalusia (Spain) designed specifically for people with visual and motor disabilities (Girón-Gambero & Alarcón-Orozco, 2024). In this guide, using knowledge of basic kinematics, the students calculated travel times between monuments or emblematic places in the city. The sequence of activities began with a practical phase in the school playground, where travel times between points of known distance were measured. This made it possible to apply the formula for uniform rectilinear motion and calculate the speed, simulating three scenarios: a non-disabled person, a blind person and a person in a wheelchair. This speed data was then used to determine travel times between points in the city, the distances of which were known, using the Google Maps application.

In order to assist in implementing the projects, the teacher designed a task booklet for the students, which served as a scaffold for the proper development of the STEM projects. This task book allowed students to take control of their learning and to collect information, evidence, and data throughout the tasks, which enabled them to make decisions about using physical procedures to sterilize masks, making or buying hydroalcoholic gel, or selecting optimal routes when moving around a city. Their involvement in the tasks, in turn, aroused a series of positive and negative emotions inextricably linked to the whole cognitive process, which are analyzed in this study. Likewise, the classroom methodology, the aspects to be assessed, and the attitude adopted by the teacher in tackling the different STEM projects are elements that form part of the instruction received by the pupils and, therefore, of the emotions aroused in them.

Data Collection and Analysis

For the development of the questionnaire, the categorizations of emotions and their classification into positive or negative were reviewed in depth, selecting the 7 positive and 7 negative emotions most frequently repeated in all the studies (Bisquerra, 2009; Casacuberta, 2000; Damasio, 2010; Fernández Abascal et al., 2001; Goleman, 1996; Rebollo et al., 2008). Furthermore, it has been shown (Borrachero et al., 2011) that students at this educational stage manifest a typology of emotions whose perception cannot be measured in an absolute manner, but by means of a frequency scoring system, using a Likert scale. With these premises, the first RQ was designed:

1. Question A. How often have you felt these emotions during the projects? For each emotion, please rate the frequency felt on a Likert scale (0: indifferent, 1: fairly, 2: somewhat, 3: very).

Joy, confidence, happiness, admiration, tranquility, satisfaction, engagement, surprise, love, worry, shame, anxiety, fear, disgust, culpability, sadness, anger, nervousness.

On the other hand, in relation to the possible causes that provoked these emotions, three dimensions of categories were established related to: the teaching-learning process of enquiry (which considered aspects such as classroom interaction, experimental activities or the importance of enquiry), the student (motivation, the ability to learn or their own self-improvement) and the subject (knowledge, the contribution to the development of scientific competences and the evaluation system) (García-Ruiz et al., 2022; Jiménez Liso et al., 2019). It was these aspects that articulated the second RQ:

2. Question B. For the following items, mark *yes* or *no* as possible reasons why you think you have felt positive or negative emotions during the projects developed:
   a. The way of working is used by the teacher.
   b. The theoretical content of the project.
   c. The grade I have obtained.
   d. The teachers´ attitude.
   e. How to solve practical problems or issues.
   f. My ability to learn the subject.
   g. The evaluation system.
   h. The practical activities carried out during the project.
   i. My motivation is to learn physics and chemistry.

The research was carried out using the pre-test/post-test case study methodology, internally and externally validating the experimental design followed.

Thus, the factors that could affect the internal validity of the research and the administration of the questionnaire used were minimized, in accordance with the parameters established by Campbell (1986):

1. History: It was carried out during the same morning session in the same academic year where no event occurred that could interfere emotionally with the sample.
2. Maturation: It was carried out for 5 continuous months so that the students did not experience any significant maturational changes.

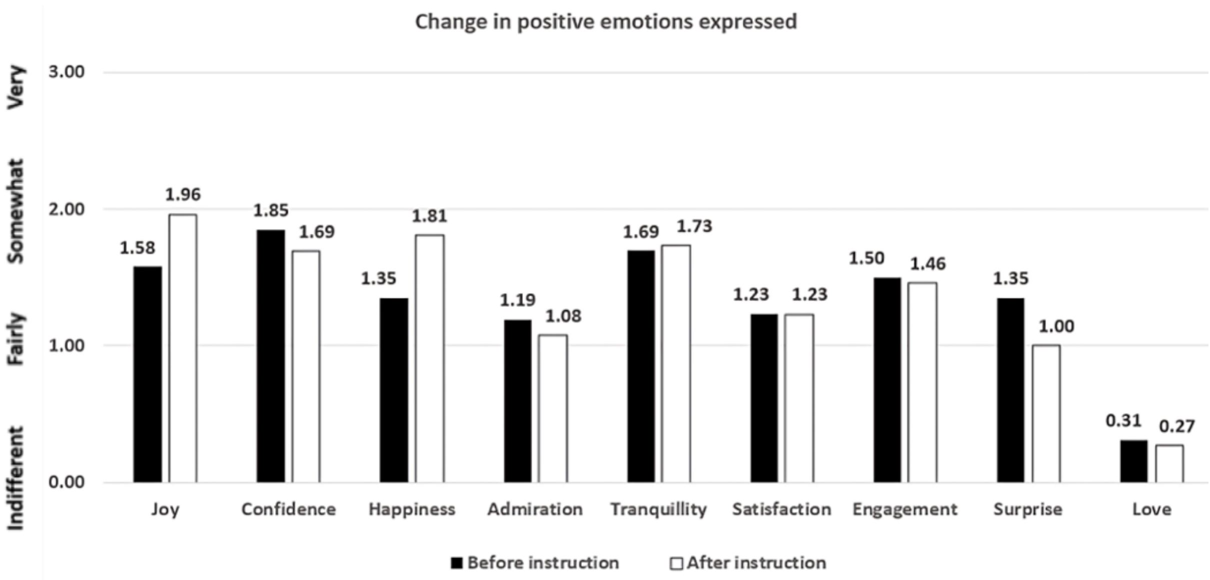

Figure 2. Positive emotions were expressed at the beginning and end of the training (Source: Authors' own elaboration)

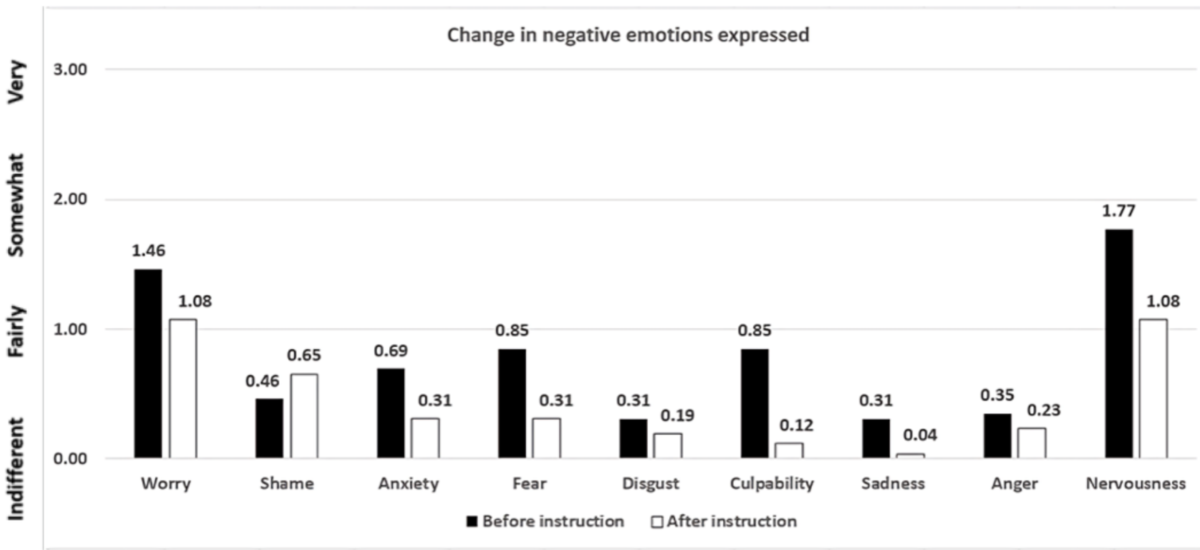

Figure 3. Negative emotions were expressed at the beginning and end of the training (Source: Authors' own elaboration)

3. Administration of the test: The measurement itself did not influence the manifestations of emotions, as it was not binding for the assessment of learning.

4. Instrumentation: A single questionnaire was used for the pre- and post-test, which was administered by the same researcher.

5. Statistical regression, subject selection and experimental mortality: These were not applied for the selection of our sample.

Regarding the external validity of the questionnaire, Cronbach's alpha statistics for both the frequency of emotions (positive and negative) and the causes of emotions (positive and negative), reach values in all STEM subjects (biology, physics, geology, technology, and mathematics) between 0.8 and 0.9, which is considered a good level of reliability (Borrachero, 2015).

This questionnaire was administered to students in digital format (Google Form) at the beginning of the course and after completing the STEM projects. The students were given 15 minutes to answer the questionnaire using mobile devices. In order to familiarize students with the meaning of the emotions mentioned in the questionnaire, an introductory session was conducted using images depicting individuals displaying various facial expressions. This exercise enabled students to explore and discuss the emotions they might encounter, addressing any uncertainties that arose during the discussion. The analysis was carried out with a spreadsheet by finding the mean values of each emotion, which were in the range of 0 to 3. For the different causes, the relative frequencies of affirmative or negative responses were calculated for each item.

RESULTS

Figure 2 and **Figure 3** illustrates the findings from question A, showing the changes in positive and negative emotions before and after participation in

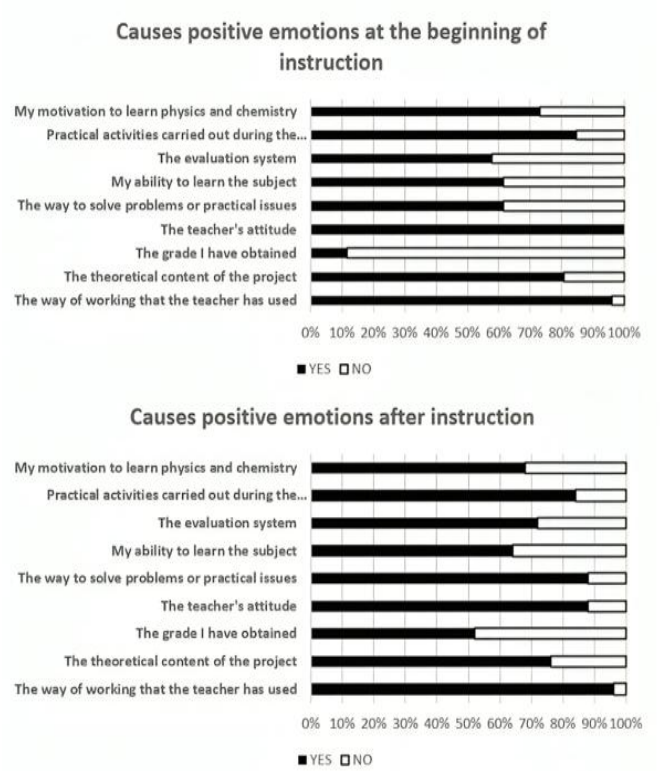

Figure 4. Possible causes of positive emotions at the beginning and end of training (Source: Authors' own elaboration)

Figure 5. Possible causes of negative emotions at the beginning and end of instruction (Source: Authors' own elaboration)

STEM projects. There is an increase in the average score given to the emotions joy, tranquility, and happiness, which are close to 2 (*somewhat* on the questionnaire). It is also observed that, except for shame, students, on average, evaluated their emotions with lower scores than the initial ones after participating in STEM projects.

It is also noteworthy that, except for worry and nervousness, the means of the remaining emotions are situated after the intervention at values between 0 and 1 (options *indifferent* and a *fairly*, respectively). Most of the emotions show final values very close to the initial ones.

Figure 4 and **Figure 5** illustrates the findings from question B, as possible reasons why they think they have felt positive or negative emotions before and after participation in STEM projects.

The increase in the percentages of the items corresponding to the marks and the evaluation system reveals that the students felt more positive emotions with the projects carried out and that these were well designed methodologically (item *the way of working that the teacher has used*).

The grade I obtained was the item that decreased the most regarding the contribution of negative emotions, which corresponds to the findings found for positive emotions. This item appears linked to two other items lessened as negative causes: *motivation to learn physics and chemistry* and *my ability to learn the subject*. Finally, *the teacher's attitude* and *the way of working that the teacher has used* had a very low contribution to manifesting negative emotions.

DISCUSSION AND EDUCATIONAL IMPLICATIONS

STEM PBL instruction has resulted in an increase in positive emotions compared to negative ones, as other authors have also reported with the implementation of other projects (Hernández et al., 2021). The positive emotions that were most improved with the instruction were joy, happiness, and tranquility. This suggests that students have a strong emotional disposition to develop CT skills through the activities proposed in the various projects. This will allow them to analyze information more critically, make better decisions or craft better arguments.

Regarding the causes of positive emotions, practical activities appear as a key factor, probably linked to achieving objectives (Bellocchi et al., 2017). However, the role of the teacher is the one that had the most weight in triggering positive emotions, as both the teacher's attitude and the methodology used are the causes that appear with the highest frequency of responses, coinciding with the conclusions of other studies (Hernández et al., 2021). Other aspects related to evaluation also had a positive impact, reflected in STEM projects with the application of knowledge to interpret and make decisions about contextualized situations (Sanmartí, 2007).

From our perspective, this behavior can be interpreted by considering that the design of STEM projects, which include practical tasks with appropriate classroom executions and are linked to developing CT skills that foster student argumentative and inquiry skills, provides an instructional environment conducive to decision-making. In addition, they are instrumental in generating a positive emotional predisposition towards learning.

Within the spectrum of negative emotions, a more significant presence of nervousness and worry was highlighted, supporting such emotions when conducting isolated inquiries (Sánchez-Martin et al., 2018). However, these emotions decreased after the instruction, suggesting a possible relationship with the continued application of the inquiry methodology to which the students were subjected throughout the school year.

Regarding the negative emotions, the ability to learn and motivation towards the subject are important aspects to consider in future projects. According to Sanmartí (2007), an exclusively qualifying assessment lacks motivation. Consequently, in the projects, we adopt a formative assessment approach, which affirms that this type of initiative empowers students and persuades them of their ability to acquire scientific knowledge (Michaelian & Arango-Muñoz, 2014), also establishing a significant connection with their motivations. However, the final conception that students have about their learning is widely rooted, presenting their consideration of the achievement in the qualification as the determining emotional factor in the behavior manifested.

In terms of educational implications, the goal is to help students understand the reality of the design process, and that failure in this context is expected and not solely reflective of their ability or effort.

It appears that developing almost the entire curriculum for grade-8 students through STEM projects that use an inquiry-based methodology awakens positive emotions in students and decreases negative ones, which has a favorable impact on learning science knowledge and developing CT, as it develops skills in students that make them feel competent (Michaelian & Arango-Muñoz, 2014) and contribute to help students to develop CT skills, learn STEM concepts and trigger students' interest in STEM.

However, for students to fully benefit from this training, it is essential to cultivate both their self-efficacy and positive achievement-related emotions through instructional strategies tailored to the specific context. Integrating STEM tasks into the curriculum plays a crucial role in nurturing students' interest in STEM. Positive experiences with STEM activities can lead to a lasting interest in the field, which may influence their decision to pursue STEM careers as they continue their education (Vongkulluksn, et al., 2018).

Limitations and Future Directions

Like any research study, the present study was constrained by contextual and logistic factors. We note that the focus of our research is on motivational variables, which could only be gathered via self-report. We also understand complex motivational reactions to STEM-projects requires integrating results from multiple studies with different methodological lens, suggesting a need for more varied future research in this area attempting to meet the internal validity criteria established by Campbell (1986), minimizing possible interference from external factors to the research sample. We also considered the advisability of applying quasi-experimental designs with comparable control groups.

Given the intrinsic coherence and extrapolation of the questionnaire, we understand that the proposed research methodology is generally applicable. However, both the sample size and the student profile influence whether the results obtained can be reproduced, not necessarily to the same extent, in other educational settings.

Therefore, we believe this research helps enhance instructional practices for teachers and student learning. It aids in understanding the emotions expressed by students in this age group and educational stage, which is particularly relevant when teachers apply scientific inquiry and argumentation practices in the design and implementation of STEM PBL proposals (project PID2023-147028NB-I00) to foster CT.

CONCLUSIONS

Despite these limitations, our study was one of a few that have examined motivational implications of a STEM-focused, design-based projects. Overall, results from this study point to the potential to support elementary students' learning in STEM, albeit with a cautionary note that such experiences should include efficacy- and emotion-related scaffolding. With this motivational support system in place, the STEM projects have the potential to be an effective instructional medium for developing both STEM-related knowledge and interest.

Author contributions: JGG & TLC: design, methodology, data curation, formal analysis; **JGG:** writing – original draft; **TLC:** writing – review & editing. Both authors agreed with the results and conclusions.

Funding: This study is part of the Spanish National Plan R+D+i project entitled "STE(A)M y CIUDADANÍA. Desarrollo con procesos de indagación y argumentación en la formación del docente de ciencias y su enseñanza. Estudio identitario, entornos y género [STE(A)M and CITIZENSHIP. Development through inquiry and argumentation processes in the training of science teachers and their teaching. Identity, environment, and gender study], EduCA-STE(A)M", reference PID2023-147028NB-I00 funded by MICIU/AEI/10.13039/501100011033 and FEDER, UE.

Ethical statement: The authors stated that the study does not require any ethical approval. The study involved students who voluntarily responded to an anonymous questionnaire without physical procedures or sensitive data collection. Written informed consents were obtained from the participants.

AI statement: The authors stated that no generative AI or AI-based tools were used in any part of the study, including data analysis, writing, or editing.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Avraamidou, L. (2022). Identities in/out of physics and the politics of recognition. *Journal of Research in Science Teaching, 59*(1), 58-94. https://doi.org/10.1002/tea.21721

Bandura, A. (2001). Social cognitive theory: An agentic perspective. *Annual Review of Psychology, 52*(1), 1-26. https://doi.org/10.1146/annurev.psych.52.1.1

Bandura, A. (2006). Guide for constructing self-efficacy scales. In F. Pajares, & T. C. Urdan (Eds.), *Self-efficacy beliefs of adolescents* (pp. 307-337). Information Age Publishing.

Bellocchi, A., Quigley, C., & Otrel-Cass, K. (2017). *Exploring emotions, aesthetics and wellbeing in science education research*. Springer. https://doi.org/10.1007/978-3-319-43353-0

Bisquerra, R. (2009). *Psicopedagogía de las emociones* [Psichopedagogy of emotions]. Síntesis.

Bisquerra, R., & García, E. (2018). La educación emocional requiere formación del profesorado [Emotional education requires teacher training]. *Participación Educativa, 5*(8), 15-27.

Blanco-López, A., España, E., & Franco-Mariscal, A. J. (2017). Estrategias didácticas para el desarrollo del pensamiento crítico en el aula de ciencias [Teaching strategies for the development of critical thinking in the teaching of science]. *Ápice, Revista de Educación Científica, 1*(1), 107-115. https://doi.org/10.17979/arec.2017.1.1.2004

Borrachero, A. B. (2015). *Las emociones en la enseñanza y el aprendizaje de las ciencias en educación secundaria* [Emotions in the teaching and learning of science in secondary education] [PhD thesis, University of Extremadura].

Borrachero, A. B., Brígido, M., Gómez, R., Bermejo, M. L., & Mellado, V. (2011). Las emociones de los futuros profesores de secundaria sobre el aprendizaje y la enseñanza de las ciencias [The emotions of future secondary school teachers regarding the learning and teaching of sciences]. *INFAD Revista de Psicología, 3*(1), 521-530.

Brígido, M., Borrachero, A. B., Bermejo, M. L., & Mellado, V. (2013). Prospective primary teachers' self-efficacy and emotions in science teaching. *European Journal of Teacher Education, 36*(2), 200-217. https://doi.org/10.1080/02619768.2012.686993

Briñol, P., Petty, R. E., & Rucker, D. D. (2006). The role of meta-cognitive processes in emotional intelligence. *Psicothema, 18*(Suppl), 26-33.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities*. NSTA Press.

Campbell, D. T. (1986). Relabeling internal and external validity for applied social scientists. *New Directions for Program Evaluation, 1986*(31), 67-77. https://doi.org/10.1002/ev.1434

Casacuberta, D. (2000). *Qué es una emoción* [What is an emotion]? Crítica.

Chen, H. T., Wang, H. H., Lin, H. S., Lawrenz, F. P., & Hong, Z. R. (2014). Longitudinal study of an after-school, inquiry-based science intervention on low-achieving children's affective perceptions of learning science. *International Journal of Science Education, 36*, 2133-2156. https://doi.org/10.1080/09500693.2014.910630

Chiu, M. H., Chou, C. C., Wu, W. L., & Liaw, H. (2014). The role of facial microexpression state (FMES) changes in the process of conceptual conflict. *British Journal of Educational Technology, 45*(3), 471-486. https://doi.org/10.1111/bjet.12126

Crawford, B. A. (2014). From inquiry to scientific practices in the science classroom. In N. G. Lederman, & S. K. Abell (Eds.), *Handbook of research on science education*. Routledge. https://doi.org/10.4324/9780203097267

Damasio, A. (2010). *Y el cerebro creó al hombre* [The Brain Created Man]. Destino.

Dare, E. A., Keratithamkul, K., Hiwatig, B. M., & Li, F. (2021). Beyond content: The role of STEM disciplines, real-world problems, 21st century skills, and STEM careers within science teachers' conceptions of integrated STEM education. *Education Sciences, 11*(11), Article 737. https://doi.org/10.3390/educsci11110737

Dolfing, R., Prins, G., Bulte, A., Pilot, A., & Vermunt, J. D.(2021). Strategies to support teachers' professional development regarding sense-making in context-based science curricula. *Science Education, 105*(1), 127-165. https://doi.org/10.1002/sce.21603

Estapa, A. T., & Tank, K. M. (2017). Supporting integrated STEM in the elementary classroom: A professional development approach centred on an engineering design challenge. *International Journal of STEM Education, 4*(1), Article 6. https://doi.org/10.1186/s40594-017-0058-3

Extremera, N., Mérida-López, S., & Sánchez-Gómez, M. (2019). La importancia de la inteligencia emocional del profesorado en la misión educativa: Impacto en el aula y recomendaciones de buenas prácticas para su entrenamiento [The importance of teachers' emotional intelligence in the educational mission: Impact in the classroom and recommendations for good practices in training]. *Voces de la Educación, 2*, 74-97.

Facione, P. A. (1998). *Critical thinking: What it is and why it counts: A resource paper*. California Academic Press.

Fatimah, S., Sarwi, S., & Haryani, S. (2024). Artificial intelligence in STEM education: A bibliometric analysis. *International Journal of Multicultural and Multireligious Understanding, 11*(1), 186-200.

Fernández-Abascal, E., Martín, M., & Domínguez, J. (2001). *Procesos psicológicos* [Psychological processes]. Pirámide.

Ford, C. L., & Yore, L. D. (2014). Toward convergence of critical thinking, metacognition, and reflection: Illustrations from natural and social sciences, teacher education, and classroom practice. In A. Zohar, & Y. J. Dori (Eds.), *Metacognition in science education* (pp. 251-271). Springer. https://doi.org/10.1007/978-94-007-2132-6_11

Franco-Mariscal, A. J., Cano-Iglesias, M. J., España-Ramos, E., & Blanco-López, A. (2024). Theoretical perspectives and approaches for the development of critical thinking. In A. J. Franco-Mariscal (Ed.), *Critical thinking in science education and teacher training* (pp. 3-42). Springer. https://doi.org/10.1007/978-3-031-78578-8_1

García-Ruiz, C., Lupión-Cobos, T., & Blanco-López, Á. (2020). Emociones y percepciones sobre indagación de profesorado en formación inicial [Emotions and perceptions about inquiry of initial teacher education]. *Investigación en la Escuela, 102*, 54-70. http://doi.org/10.12795/IE.2020.i102.04

García-Ruiz, C., Lupión-Cobos, T., & Blanco-López, Á. (2022). Effects of an inquiry-based science education training program on pre-service teachers. A mixed-methods case study. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(12), Article em2186. https://doi.org/10.29333/ejmste/12578

Girón-Gambero, J. R., & Alarcón-Orozco, M. (2024). "La guía de tu ciudad": Una situación de aprendizaje destinada al alumnado de física y química del primer ciclo de la ESO ["Your City Guide": A learning situation for physics and chemistry students in the first cycle of secondary school.]. In *Indagación científica escolar y educación STEAM: formación del profesorado y enseñanza para la transferencia a las aulas* (pp. 159-176). Graó.

Girón-Gambero, J. R., & Franco-Mariscal, A. J. (2022). Esterilización de mascarillas higiénicas con métodos físicos. Un estudio de caso con estudiantes de secundaria españoles [Sterilization of hygienic masks using physical methods: A case study with Spanish high school students]. *Revista de Estudios y Experiencias en Educación, 21*(47), 428-450. https://doi.org/10.21703/0718-5162202202102147023

Girón-Gambero, J. R., López-Castilla, R., & Lupión-Cobos, T. (2023). *Propuesta ABP para el aula de ciencias en 2º ESO: El coronavirus* [PBL proposal for the science classroom in 2nd year of secondary school: The coronavirus]. RIUMA: Repositorio Institucional de la Universidad de Málaga. https://hdl.handle.net/10630/27778

Goleman, D. (1996). *Inteligencia emocional* [Emotional intelligence]. Cairos.

Government of Spain. (2020). Ley orgánica 3/2020, de 29 de Diciembre, por la que se modifica la ley orgánica 2/2006, de 3 de Mayo, de educación [Organic law 3/2020, of December 29, amending organic law 2/2006, of May 3, on education]. *Boletín Oficial del Estado*. https://www.boe.es/boe/dias/2020/12/30/pdfs/BOE-A-2020-17264.pdf

Grabau, L., & Ma, M. (2017). Science engagement and science achievement in the context of science instruction: A multilevel analysis of U.S. students and schools. *International Journal of Science Education, 39*(8), 1045-1068. https://doi.org/10.1080/09500693.2017.1313468

Hampden-Thompson, G., & Bennett, J. (2013). Science teaching and learning activities and students' engagement in science. *International Journal of Science Education, 35*(8), 1325-1343. https://doi.org/10.1080/09500693.2011.608093

Hernández, M., Sánchez, J., Corbacho, I., & Cañada, F. (2021). Emotional performance of a low-cost eco-friendly project based learning methodology for science education: An approach in prospective teachers. *Sustainability, 13*(6), Article 3385. https://doi.org/10.3390/su13063385

Herranen, J., Kousa, P., Fooladi, E., & Aksela, M. (2019). Inquiry as a context-based practice–A case study of pre-service teachers' beliefs and implementation of inquiry in context-based science teaching. *International Journal of Science Education, 41*(14), 1977-1998. https://doi.org/10.1080/09500693.2019.1655679

Jiménez-Liso, M. R., Martinez-Chico, M., Avraamidou, L., & López-Gay, R. (2019). Scientific practices in teacher education: The interplay of sense, sensors, and emotions. *Research in Science and Technological Education, 39*(1), 44-67. https://doi.org/10.1080/02635143.2019.1647158

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(1), Article 11. https://doi.org/10.1186/s40594-016-0046-z

Kokotsaki, D., Menzies, V., & Wiggins, A. (2016). Project-based learning: A review of the literature. *Improving Schools, 19*(3), 267-277. https://doi.org/10.1177/1365480216659733

Lupión-Cobos, T., Girón-Gambero, J. R., & García-Ruiz, C. (2022). Building STEM inquiry-based teaching proposal through collaborations between schools and research centres. Perceptions on students' learning and predictors of vocational careers. *European Journal of Educational Research, 11*(2), 899-915. https://doi.org/10.12973/eu-jer.11.2.899

Marshall, J. C., & Alston, D. M. (2014). Effective, sustained inquiry-based instruction promotes higher science proficiency among all groups: A 5-year analysis. *Journal of Science Teacher Education, 25*, 807-821. https://doi.org/10.1007/s10972-014-9401-4

Mellado, V., Borrachero, B., Melo, L. V, Dávila-Acedo, M. A., Cañada, F., Conde, M. C., Costillo, E., Cubero, J., Esteban, R., Martínez, G., Ruiz, C., Sánchez, J., Garritz, A., Mellado, L., Vázquez-Bernal, B., Jimenez-Pérez, R., & Bermejo, M. L. (2014). Las emociones en la enseñanza de las ciencias [Emotions in science education]. *Enseñanza de las Ciencias, 32*(3), 11-36. https://doi.org/10.5565/rev/ensciencias.1478

Michaelian, K., & Arango-Muñoz, S. (2014). Epistemic feelings, epistemic emotions: Review and introduction to the focus section. *Philosophical Inquiries, 2*(1), 97-122.

Morgado, I. (2012). *Emociones e inteligencia social. Las claves para una alianza entre los sentimientos y la razón* [Emotions and social intelligence. Keys to an alliance between feelings and reason]. Ariel.

Pekrun, R., Muis, K. R., Frenzel, A. C., & Goetz, T. (2018). *Emotions at school*. Routledge. https://doi.org/10.4324/9781315187822

Pérez, M. C. B., & Furman, M. (2016). What is a scientific experiment? The impact of a professional development course on teachers' ability to design an inquiry-based science curriculum. *International Journal of Environmental and Science Education, 11*, 1387-1401. https://doi.org/10.12973/ijese.2016.353a

Pérez-Torres M., Couso, D., & Márquez, C. (2021). ¿Cómo diseñar un buen proyecto STEM? Identificación de tensiones en la co-construcción de una rúbrica para su mejora. How to design a good STEM project? [Identification of tensions in the co-construction of a rubric for its improvement]. *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias, 18*(1), Article 1301. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2021.v18.i1.1301

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity, 31*, 31-43. https://doi.org/10.1016/j.tsc.2018.10.002

Rebollo, M. A., García, R., Barragán, R., Buzón, O., & Vega, L. (2008). Las emociones en el aprendizaje online [The emotions in online learning]. *RELIEVE, 14*(1). https://doi.org/10.7203/relieve.14.1.4201

Roehrig, G. H., Dare, E. A., Ellis, J. A., & Ring-Whalen, E. (2021). Beyond the basics: A detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research, 3*, Article 11. https://doi.org/10.1186/s43031-021-00041-y

Sadler T. D., & Dawson V. (2012). Socio-scientific issues in science education: Contexts for the promotion of key learning outcomes. In B. J. Fraser, K. G. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 799-809). Springer. https://doi.org/10.1007/978-1-4020-9041-7

Sánchez, J., Cañada, F., & Dávila, M. A. (2018). Emotional responses to innovative science teaching methods: Acquiring emotional data in a general science teacher education class. *Journal of Technology and Science Education, 8*(4), 346-359. https://doi.org/10.3926/jotse.408

Sanmartí, N. (2007). *10 ideas clave. Evaluar para aprender* [10 key ideas. Assessing for learning]. Graó.

Sjøberg, S. (2019). Critical perspectives on inquiry-based science education (IBSE) in Europe. *European Schoolnet*. https://www.researchgate.net/publication/331529566_Critical_Perspectives_on_Inquiry-Based_Science_Education_IBSE_in_Europe

Vázquez-Alonso, Á., & Manassero-Mas, M. A. (2018). Más allá de la comprensión científica: Educación científica para desarrollar el pensamiento [Beyond scientific understanding: Science education to develop thinking]. *Revista Electrónica de Enseñanza de las Ciencias, 17*(2).

Vega, V. (2015). Project-based learning research review: Evidence-based components of success. *Edutopia*. https://www.edutopia.org/pbl-research-evidencebased-components

Vila, S., Gilar-Corbí, R., & Pozo-Rico, T. (2021). Effects of student training in social skills and emotional Intelligence on the behaviour and coexistence of adolescents in the 21st century. *Environmental Research and Public Health, 18*, 5498. https://doi.org/10.3390/ijerph18105498

Zohar, A., & Dori, Y. J. (2014). *Metacognition in science education*. Springer.