Research in Science Education (2024) 54:549–572
https://doi.org/10.1007/s11165-023-10152-3

Integration of Engineering Practices into Secondary Science Education: Teacher Experiences, Emotions, and Appraisals

Antonio García-Carmona[1] · **R. Bogdan Toma**[2]

Accepted: 6 December 2023 / Published online: 5 January 2024

Abstract
STEM education is present in most recent curriculum reforms around the world. One of the main novelties of this educational movement is the integration of engineering practices into science education. In the Spanish educational context, this implies an important challenge for science teachers. So, this study analyzes whether secondary science teachers are sufficiently prepared for this purpose, as well as to find out their experiences, emotions, and appraisals in this regard. To this end, a questionnaire was designed and administered to 328 secondary science teachers as a representative sample of science teachers in Spain with a confidence level of just over 93%. The reliability of the questionnaire was evidenced by the high degree of internal consistency of the data ($\alpha = 0.88$). And its validity was determined by means of an exploratory factor analysis. The results reveal that secondary science teachers, in general, have low levels of pedagogical preparation and self-efficacy to integrate engineering practices into science classes, as well as a predominant emotion of insecurity about it. There is also a strong preference among teachers for this to be done in technology subjects. It is concluded that the effective integration of engineering practices into science education is currently a complex challenge that requires ad hoc teacher training plans.

Keywords Curricular integration · Engineering practices · Science education · STEM education · Secondary science teacher

Introduction

The STEM acronym has grown in popularity in recent years. It is frequently used to refer to entities or aspects of the sciences, technology, engineering, and mathematics disciplines. However, its pedagogical component, commonly referred to as "integrated STEM education," is what drew educators' attention (Kelley & Knowles, 2016). Its conceptualization is not univocal,

✉ Antonio García-Carmona
garcia-carmona@us.es

R. Bogdan Toma
rbtoma@ubu.es

[1] Departamento de Didáctica de Las Ciencias Experimentales y Sociales, Universidad de Sevilla, Calle Pirotecnia S/N, 41013 Seville, Spain

[2] Departamento de Didácticas Específicas, Universidad de Burgos, Burgos, Spain

and there are several alternatives and sometimes contradictory interpretations (Toma & García-Carmona, 2021). Yet, it is often defined as a teaching approach that promotes the integration of content and skills specific to science, technology, engineering, and mathematics within a unit or learning situation (Martín-Páez et al., 2019). It is currently one of the most prominent pedagogical approaches in the international educational landscape (Akerson & Buck, 2020; Takeuchi et al., 2020; Toma & García-Carmona, 2021), and it has strong support from the most prestigious educational institutions and associations worldwide (e.g., European Schoolnet, 2018; National Science Teacher Association [NSTA], 2020; Teo et al. 2021; US Department of Education, 2016). Not surprisingly, the education systems of many countries have explicitly incorporated it in their most recent curricular reforms (White & Delaney, 2021). In Spain, the latest curriculum establishes "STEM competence" as one of the eight new key competencies that students must develop by the end of compulsory education (Royal Decree 217/2022).

It is worth noting, however, that the notion of curricular integration proposed in the context of STEM education is not new, nor is there sufficient evidence to suggest that an integrated approach is more effective than one that proposes the teaching of individual subjects (Eurydice, 2011; Lehrer & Schauble, 2021; Tamassia & Frans, 2014), or which method is best for promoting effective learning outcomes (Honey et al., 2014; White & Delaney, 2021). As such, integrated STEM education stands as a significant challenge for teacher professional development programs (Luft et al., 2020).

What is particularly novel in STEM education is the explicit emphasis on engineering practices within science education (National Research Council [NRC], 2012; Roehrig et al., 2021; Zhang & Zhu, 2023). Indeed, various authors consider that engineering should be the focal point of authentic STEM education (Daugherty & Carter, 2018; Moore et al., 2014; Roehrig et al., 2021). Quinn et al. (2020) justified this by arguing that engineering is the discipline that best represents the integrated nature of STEM. In fact, Luft et al. (2020) found that most teacher professional development programs for STEM education focus on curricula integration through engineering practices.

Therefore, this presents a significant challenge for science teachers (García-Carmona, 2023; Mumba et al., 2023), who are usually only prepared to teach specific science subjects separately (Montero & García-Carmona, 2018; You, 2017), and the majority of whom have no specific training or background in engineering (Brand, 2020; Dare et al., 2018; Lederman & Lederman, 2013; Ring-Whalen et al., 2018; Zhang & Zhu, 2023). Indeed, some studies in other countries reveal the difficulties of science teachers in integrating engineering practices into their teaching approaches (Capobianco, 2016; Zhan et al., 2021). Additionally, integration between science and engineering is found to be even more problematic than favorable in elemental education (Schellinger et al., 2022; Wieselmann et al., 2020). Such difficulties are also encountered by teachers in other STEM disciplines. Thus, secondary technology teachers with engineering academic training, for example, face numerous challenges when integrating engineering practices into STEM education proposals (Ortega-Torres, 2022). Hence, it appears that addressing engineering in secondary education is a challenge for all STEM teachers.

Despite the many challenges of incorporating engineering practices into science education, various educational reforms worldwide require science teachers to do so. In the case of the new curriculum for compulsory secondary education in Spain, this aspect is explicitly stated when describing the new STEM competence, which "involves understanding the world using scientific methods, mathematical thinking and representation, technology and *engineering methods* to transform the environment in an engaged, responsible and sustainable way." (Royal Decree 217/2022, p. 41,598; emphasis in italics added). Similarly, the specific competencies for biology and geology subjects demand students to "Analyze and explain biological and geological phenomena by representing them through models and diagrams, using, when necessary, *the steps* *of engineering design (problem identification, exploration, design, creation, evaluation, and improvement).*" (Royal Decree 217/2022, pp. 41,610 and 41,613; emphasis in italics added).

Faced with this challenge, the question is whether Spanish science teachers are prepared to incorporate engineering practices into their lesson plans. As noted above, this issue has been analyzed in other countries but not yet in Spain. Therefore, we decided to conduct a study guided by the following research questions:

1. To what extent do Spanish secondary science teachers have sufficient training and professional development regarding the integration of engineering practices?
2. How prepared do secondary science teachers feel concerning integrating engineering practices?
3. What experiences do they have, and what kind of emotions does the call to integrate engineering practices trigger in science teachers?
4. How would secondary science teachers integrate engineering practices during science classes and what are their opinions about this approach?

Theoretical Underpinnings

Engineering Practices

In the Spanish educational system, as in many other places around the world, there is no specific school subject of engineering; instead, there is one regarding technology (Royal Decree 217/2022). Hence, engineering-related topics have been traditionally integrated into secondary education's technology curriculum (García-Carmona, 2020, 2023). Thus, the explicit emphasis on engineering in science education that is now being promoted globally, and particularly in Spain through the new education law, is due to the influence of the integrated STEM approach. Specifically, the educational reform advanced in the Next Generation Science Standards (NGSS) through the *A Framework for K-12 Science Education* report (NRC, 2012) is the most influential internationally, with Spain being no exception in its adoption. Such a *Framework* calls for engaging students in the eight engineering practices listed in Table 1. It should be mentioned that only practices 1 (Defining problems) and 6 (Designing solutions) are, however, regarded as exclusively engineering practices; the remaining are assumed to be applicable, with nuances, to both science and engineering.

Among the extensive list of engineering practices presented in Table 1, most integrated STEM educational proposals focus on engineering design (Antink-Meyer & Brown, 2019; Cunningham & Carlsen, 2014; Daugherty & Carter, 2018). In this regard, Vinck (2014) emphasizes that, while design activities are highly valued in engineering, this discipline also, and especially, includes less prestigious but critical activities such as responding to unexpected events and incidents. As a result, it is appropriate to include this last practice in the list proposed by the NGSS, which will serve as the framework for this study to investigate the knowledge, skills, and emotions of science teachers about engineering practices.

Finally, it is important to note that there is currently a lack of consensus on how to best integrate engineering and other STEM subjects into science education (Honey et al., 2014; Luft et al., 2020; White & Delaney, 2021). In fact, debates over whether engineering should be considered a separate academic discipline are still ongoing (Barak et al., 2022). Therefore, the manner in which engineering practices should be integrated in secondary school was addressed in this study from an exploratory perspective without ruling out a priori any curricular possibility; i.e., introducing engineering practices within a specific

Table 1 Engineering practices investigated in this study

Engineering practices
1. Defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using Mathematics and computational thinking
6. Designing solutions
7. Engaging in argument for evidence
8. Obtaining, evaluating, and communicating information
9. Response to unexpected events and incidents[a]

[a]Proposed by Vinck (2014). The remaining practices were proposed by the NRC (2012, p. 3)

school engineering subject, as part of technology subjects, transversally in all school science contents, or punctually with only some science contents.

Evaluation Framework

In recent years, there has been a surge of interest in science education research into variables that may be related to or influence the adoption of reform-oriented teaching practices. Teachers' emotions, self-efficacy, experiences, and perspectives on how to teach science have received particular attention (Ainley & Carstens, 2018; García-Carmona, 2022; Gresnigt et al., 2014; Margot & Kettler, 2019; Pekrun, 2021). Indeed, teachers experience a wide spectrum of negative, positive, and neutral emotions when teaching science (Mellado et al., 2014). Such emotions are linked to their professional decision-making, work engagement, occupational well-being, and teaching methodologies adopted (Lauermann & Butler, 2021). Consequently, teachers who lack expertise or training in a particular subject or teaching approach may experience negative emotions (Marcos-Merino et al., 2022), affecting students' learning and achievement-related outcomes (Frenzel et al., 2021; Keller & Becker, 2021).

Teachers' pedagogical beliefs and appraisals of reform-oriented teaching practices, on the other hand, are also critical (Kurup et al., 2019). In this sense, several studies indicate that teachers face many difficulties in conceptualizing integrated STEM education (Dare et al., 2019; Ring et al., 2017). This is a source of concern, especially given that teachers' beliefs and conceptions have been found to influence teaching practice and the implementation of curricular reforms (Ham & Dekkers, 2019; Reichert et al., 2021). Similarly, when it comes to curriculum integration, teachers' beliefs and pedagogical knowledge of such an approach have been discovered to also be of great importance (Taimalu & Luik, 2019).

Finally, recent research indicates that teacher self-efficacy beliefs play an essential role, particularly in moderating teachers' positive and negative emotions (Burić and Kim, 2020; Uzuntiryaki-Kondakci et al., 2022). In this regard, the TALIS project's (Teaching and Learning International Survey) conceptual framework distinguishes three types of teacher self-efficacy beliefs (Ainley & Carstens, 2018): classroom management, teaching efficacy, and student engagement. The current study focuses on the second dimension of the above, namely, teachers' beliefs about their ability to effectively integrate engineering practices when teaching science in secondary school. Regarding the assessment of self-efficacy, Lazarides and Warner (2020) concluded that most questionnaires draw on the pioneering work of Bandura, hence using Likert-type questions to determine teachers' agreement or disagreement with various teaching practices and contexts; this procedure will serve as the basis of the current study.

In summary, this literature review highlights such variables as salient within the current curricular reforms calling for the integration of engineering practices into science education teaching. Inadequate pedagogical training, unfavorable beliefs, low self-efficacy beliefs, and the development of negative emotions may, therefore, jeopardize the effectiveness of such an approach; ultimately, this would compromise the effectiveness of the educational reform. In this regard, it should be noted that the authors of this study have extensive experience in assessing such affective variables with both pre-service (García-Carmona & Cruz-Guzmán, 2016) and in-service (García-Carmona, 2022) teachers. The instruments used in our previous studies consisted of ordinal and categorical scales to explore teachers' positionings or preferences regarding the topic under study, following extant recommendations on measurement instruments (Cohen et al., 2018). These will, therefore, be used as a reference in the elaboration of the data collection instrument focused on inquiring about teachers' opinions on the integration of engineering practices.

Method

Participants

The population for this study is Spanish science teachers who teach in compulsory secondary education (students aged 12–16 years old). In Spain, the science curriculum for this educational stage is divided into two subjects (physics and chemistry, and biology and geology) which are taught separately by teachers with specific content and pedagogical training in such disciplines. Content background is obtained by finishing a 4-year-long science or engineering-related university degree. The pedagogical training, on the other hand, is achieved by completing a 1-year-long master degree in science education teaching.

Sample recruitment for this study was difficult because teachers' contact information is not made public due to data protection laws. As a result, several sampling strategies were required, while adhering to the ethical standards for the protection of personal data. First, the authors reached secondary school teachers and university colleagues for email contacts. Second, they tracked down secondary school science teachers' email addresses in Spanish science education publications. With these two strategies, the researchers collected 180 secondary school science teachers' email addresses. Next, in the message requesting collaboration with the study, teachers were asked to forward it to other science teachers they knew to promote a "snowball" effect (Cohen et al., 2018). The researchers then asked school administrators to contact secondary science teachers about participating in the study. This was not easy because not all schools provide a contact address on their websites. To ensure maximum representativeness of the Spanish educational context, researchers included secondary school science teachers from 17 autonomous communities, 50 provinces, and two autonomous cities. The researchers decided to send the request message to at least 10 schools from each province. In this selection, care was taken to ensure a balance between public and private schools, although this was limited by access to contact details. Similarly, many of the school e-mail addresses were inoperative, making it impossible to contact some of the schools. This process yielded a total of 328 responses, representing all autonomous communities and 46 of the 50 provinces from Spain. The sample size was analyzed using the Raosoft calculator, and the sample was found to be representative of the population studied with a margin of error of 5% and a confidence level of 93% (Raosoft Inc., 2004). Table 2 provides the characteristics of the sample.

Table 2 Characteristics of the secondary school science teacher participating in the study ($n = 328$)

Variable and percentages (%)		
Geographic distribution	Andalucía, 80 (24.4%) Aragón, 10 (3.0%) Asturias, 3 (0.9%) Canarias, 4 (1.2%) Cantabria, 2 (0.6%) Castilla La Mancha, 12 (3.7%) Castilla y León, 23 (7.0%) Cataluña, 19 (5.8%) Ceuta, 6 (1.8%) Comunidad de Madrid, 33 (10.1%)	Comunidad Valenciana, 84 (25.6%) Extremadura, 2 (0.6%) Galicia, 5 (1.5%) Islas Baleares, 10 (3.0%) La Rioja, 3 (0.9%) Murcia, 2 (0.6%) Navarra, 25 (7.6%) País Vasco, 3 (0.9%) Not indicated, 2 (0.6%)
Gender	Women, 209 (63.7%) Men, 119 (36.3%)	
Age	Range, 25–68 years old $M = 45.8$ years ($DE = 8.9$)	
Academic qualification*	University degree in physics, 42 (12.8%) University degree in chemistry, 104 (31.7%) University degree in life sciences (biology, biochemistry, biotechnology, medicine, etc.), 143 (43.6%) University degree in earth and environmental sciences (geology, marine sciences, etc.), 15 (4.6%) University degree in engineering or architecture, 30 (9.1%) University degree in primary education, with qualification to teach science in compulsory secondary education, 5 (1.5%)	
Teaching experience	1–5 years, 73 (22.3%) 6–10 years, 54 (16.5%) 11–15 years, 49 (14.9%) 16–20 years, 38 (11.6%) 21–25 years, 57 (17.4%) 26–30 years, 27 (8.2%) +30 years, 30 (9.1%)	
Type of educational center	Public/state funded, 74.3% Private, 25.7%	
Tenure in educational center	Yes, 67.9% No, 32.1%	

*Percentages exceed 100% because some participants had multiple degrees

Data Collection and Analysis

In accordance with the theoretical framework and research questions outlined above, the authors developed a two-part questionnaire (Appendix). The first part consisted of six demographic items (0.1–0.6), hence representing the independent variables in Table 2. This part integrates, therefore, the independent variables of the study and allowed the elaboration of the sample profile described in Table 2. The second part consisted of 19 items (1–11.i-ix), which include the dependent variables of the study (see the "Results" section). This part combines items with closed multiple-choice questions (items 8, 10), and items with closed single-choice questions. Within the latter, there are nominal scale items (6 and 9) and ordinal scale items (1, 2, 3, 4, 5, 7, 8, 10, 11.i-ix). The ordinal scale items include an even number of response options (four in this case) in order to force a respondent to give an opinion or appraisal either way and thus avoid intermediate or neutral responses (Cornell, 2023).

Google Forms was used for online data collection during the first 2 months of the 2022–2023 academic year (September 1 to October 26, 2022). Subsequently, data were processed and analyzed using SPSS v.26 software. Likewise, according to the purpose of the study, the analysis of the data was descriptive in nature.

The questionnaire was designed following contemporaneous validity and reliability standards for quantitative-type of instruments (Drost, 2011). Similarly, an attempt was made to keep the questionnaire short to reduce respondent fatigue and ensure a large sample size. Since the questionnaire was not assessed against psychometric properties before, its validity and reliability were first examined. Regarding reliability, Cronbach's alpha coefficient was calculated, and the result was very satisfactory ($\alpha = 0.88$). As a result, the designed questionnaire has a fairly high degree of internal consistency (Ursachi et al., 2015). As for its validity, items were subjected to exploratory factor analyses to establish their factor structure (Lloret-Segura et al., 2014). This was done using principal component analysis and oblique rotation (Oblimin) with Kaiser normalization, which is the procedure suggested for social variables commonly investigated in social science research (Frías-Navarro & Pascual, 2012). The Kaiser–Meyer–Olkin (KMO) test gave a value of 0.95, indicating adequate sampling, and data passed Bartlett's test of sphericity with a value of 0.00 (< 0.05). Consequently, it was feasible to subject the data to a factor analysis (López-Roldán & Fachelli, 2015). The findings indicated a four-factor latent structure with strong factor loadings and no cross-loadings (see Table 3), which explained 65.40% of the variance in teacher responses (F1 = 46.90%, F2 = 6.69%, F3 = 6.35%, and F4 = 5.46%). Given the research questions of the study, this factor structure was deemed adequate, and thus, the questionnaire has good content and constructs validity.

Results

Pedagogical Training Received and Teacher Initiative to Integrate Engineering Practices

Table 4 reports the results regarding the 1st research question, which are derived from the analysis of factor 2 items (i.e., items 1, 2, 3, and 5). Most science teachers reported a lack of training in engineering teaching and have not read any literature on the subject.

Table 3 Results of exploratory factor analysis ($n = 328$)

Item	F1	F2	F3	F4
11.vii Preparedness for selecting best solutions	0.92			
11.viii Preparedness for unexpected events and incidents	0.90			
11.ix Preparedness for obtaining, evaluating and communicating information	0.88			
11.iv Preparedness for analyzing and interpreting data	0.88			
11.vi Preparedness for designing solutions	0.83			
11.ii Preparedness for developing and using engineering models	0.82			
11.v Preparedness for using mathematics and computational thinking	0.80			
11.iii Preparedness for planning and carrying out engineering investigations	0.80			
11.i Preparedness for defining engineering problems	0.73			
4. Preparedness for integrating engineering practices	0.55			
5. Inclusion of engineering practices in lesson plans		−0.68		
2. Engineering practices training courses		−0.68		
3. Consulted literature on engineering education		−0.63		
1. Training in engineering education		−0.48		
10. Suitable curricular content for engineering integration			0.77	
9. Options for integrating engineering practices			0.59	
7. Engineering practices enhance students' competence			0.43	
6. Teaching experience with engineering practices				−0.77
8. Emotions about integrating engineering practices				0.59

Full version of the items can be found in the Appendix. F1: Self-estimated teaching preparation to integrate engineering practices (RQ 2). F2: Pedagogical training received and teacher initiative to integrate engineering practices (RQ 1). F3: Opinions on how to integrate engineering practices, and their educational value (RQ 4). F4: Teaching experience and emotions regarding the integration of engineering practices (RQ 3).

Table 4 Pedagogical training received and teacher initiative to integrate engineering practices ($n = 328$)

Items	Results
1. Teacher pedagogical training in engineering practices	Low, 63.1% Medium, 25.3% High, 10.7% Very high, 0.9%
2. Professional development courses completed regarding the integration of engineering practices	None, 82% One course, 11% Two courses, 2.1% Three or more courses, 4.9%
3. Literature accessed (book or articles) regarding the integration of engineering practices	None, 60.1% Few (one or two), 27.7% Some (three or four), 9.5% Many (five or more), 2.7%
5. Whether the teacher considered integrating engineering practices	Never, 40.9% Rarely, 49.7% Sometimes, 7.3% Often, 2.1%

Similarly, over 80% of science teachers have not taken a professional development course on integrating engineering practices. These marked shortcomings of teaching preparation for the integration of such practices are far from or are quite contrary to the desirable ideal to this aim (i.e., an inverse correlation), which would explain the negative factor loadings of the items referring to this aspect (factor 2, Table 1).

Additionally, only slightly more than 9% of science teachers consider incorporating engineering practices into their school science teaching. The remaining teachers stated that they had never (40.9%) or rarely (49.7%) considered doing so.

Self-Estimated Teaching Preparation to Integrate Engineering Practices

The 2nd research questions focused on the analysis of factor 1 items (i.e., item 4 and items 11.i to 11.ix), the results of which are recorded in Table 5. It can be observed that science teachers' self-efficacy to integrate engineering practices is low. Indeed, most teachers (above 70%) reported a poor or fair self-estimated teaching preparation for both the global estimation (item 4) and also in relation to each different engineering practice (items 11.i–11.ix).

Engineering practices such as "developing and using engineering models or prototypes," "planning and carrying out engineering-related investigations," and "responding to unexpected events and incidents in engineering problem solving" were considered to be particularly difficult to integrate, with more than 80% of teachers reporting the lowest levels of self-efficacy beliefs. The best levels of teacher self-efficacy (i.e., endorsing a "good" or "excellent" response) relate to "using mathematics and computational thinking" and "selecting the best solution following evidence-based arguments" engineering practices; however, it should be noted that very few teachers (between 27.1 and 29.2%) considered themselves to be so.

Teaching Experience and Emotions Regarding the Integration of Engineering Practices

With regard to the 3rd research question, the items analyzed were part of the factor 4 items (i.e., items 6 and 8), which is related to the experiences and emotions of science teachers with integrating engineering practices. Slightly more than a third of them have never done it, and only about 19% have had good teaching experiences with it (Fig. 1). Furthermore, the fact that most science teachers (about 56%) report in item 6 a bad or no experience in integrating engineering practices in their science classes could explain the negative load of this item on factor 4 (Table 3).

In relation to the emotions that the educational challenge of integrating engineering practices arouses in science teachers (Fig. 2), the most prominent is insecurity (nearly 46% of respondents); yet, it should be mentioned that one-third of science teachers also feel hope regarding its integration (32.30%). Overall, negative emotions are expressed by more teachers (38.7%) than positive emotions (26.8%), and only slightly more than 13% of teachers are emotionally indifferent (hence, displaying a "neutral" emotion) regarding integrating engineering practices into their science classes. Just over 23% of science faculty expressed a mix of positive and negative emotions.

Table 5 Self-estimated teaching preparation regarding the integration of different engineering practices ($n = 328$)

Ítems	Response option			
	Poor	Fair	Good	Excellent
4. Overall self-estimated preparation for integration of engineering practices	46.0%	37.2%	14.9%	1.8%
11.i Defining engineering-related problems	41.5%	32.6%	23.2%	2.7%
11.ii Developing and using engineering models or prototypes	53.0%	31.4%	13.4%	2.1%
11.iii Planning and carrying out engineering-related investigations	52.7%	31.7%	13.4%	2.1%
11.iv Analyzing and interpreting data	39.0%	33.8%	24.4%	2.7%
11.v Using mathematics and computational thinking	37.2%	35.4%	23.2%	4.3%
11.vi Designing solutions (sketches, artifacts, prototypes, etc.)	47.0%	35.4%	14.9%	2.7%
11.vii Selecting the best solution following evidence-based arguments	37.8%	32.9%	26.2%	3.0%
11.viii Responding to unexpected events and incidents in engineering problem solving	49.4%	32.9%	15.9%	1.8%
11.ix Obtaining, evaluating and communicating information on engineering projects	43.0%	34.1%	18.0%	4.9%

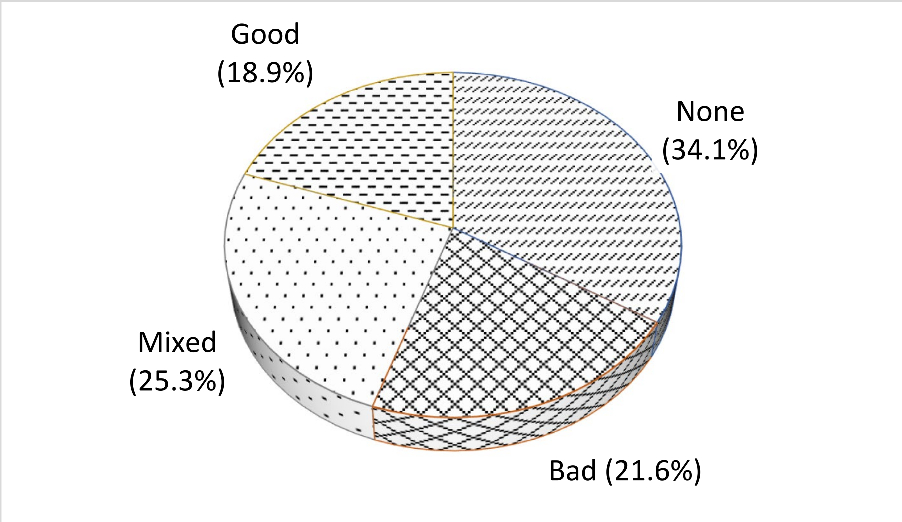

Fig. 1 Teaching experience reported by science teachers regarding integrating engineering practices (item 6, $n=328$)

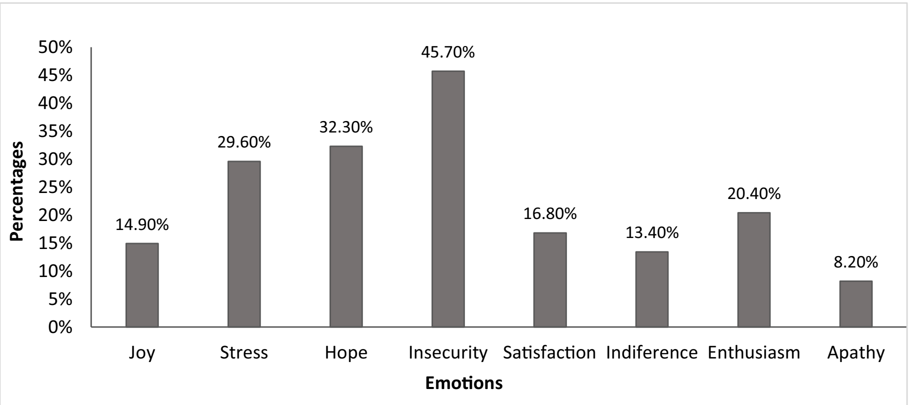

Fig. 2 Emotions expressed by teachers about the integration of engineering practices in science classes (item 8, $n=328$)

Opinions on How to Integrate Engineering Practices and Their Educational Value

The 4th research question focused on the analysis of factor 3 items (items 7, 9, and 10), which relate to the teachers' opinion about how to integrate engineering practices and whether such an approach has any educational value. The results revealed that more than half of the respondents reported that engineering practices may improve the development of students' scientific competence (Fig. 3); only 14.3% believe that the contribution will be low. There were no differences regarding teachers' background variables.

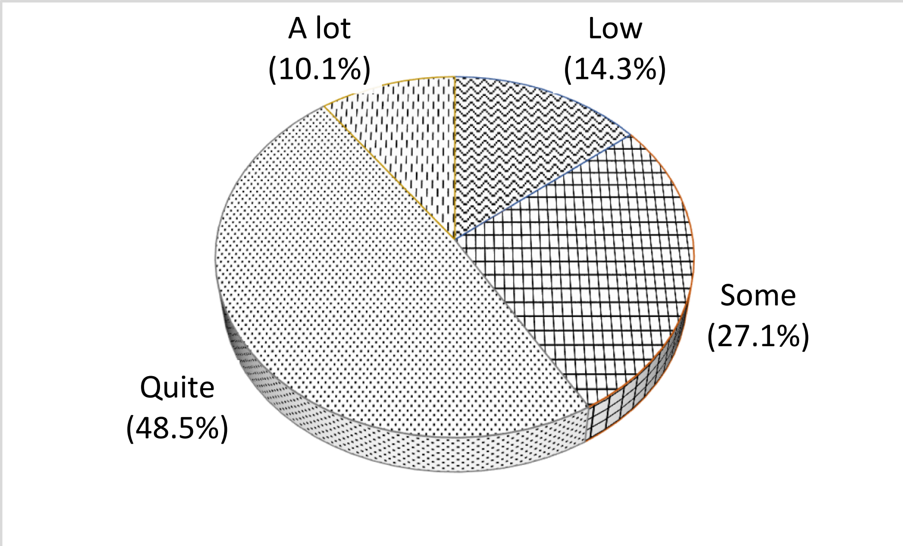

Fig. 3 Teachers' opinion about the contribution of engineering practices to the development of the scientific competence (item 7, $n = 328$)

Regarding how to integrate engineering practices (Table 6), most science teachers (43.9%) believe that this should be done within technology subjects. In other words, they advocate against the integration of engineering practices in science-related subjects. In this regard, only slightly more than 28% of teachers believe that such an approach could be integrated transversally across all science subjects, while roughly one-fifth believe that such integration should be done only sporadically within science subjects.

Table 6 Science teachers' views on how to integrate engineering practices in compulsory secondary education (item 9, $n = 328$)

Item 9 options	Results
In a new engineering-specific school subject	7.0%
Within technology subjects	43.9%
In a transversal way in all science subjects	28.4%
Through punctual integration with some contents of the science subjects	20.7%

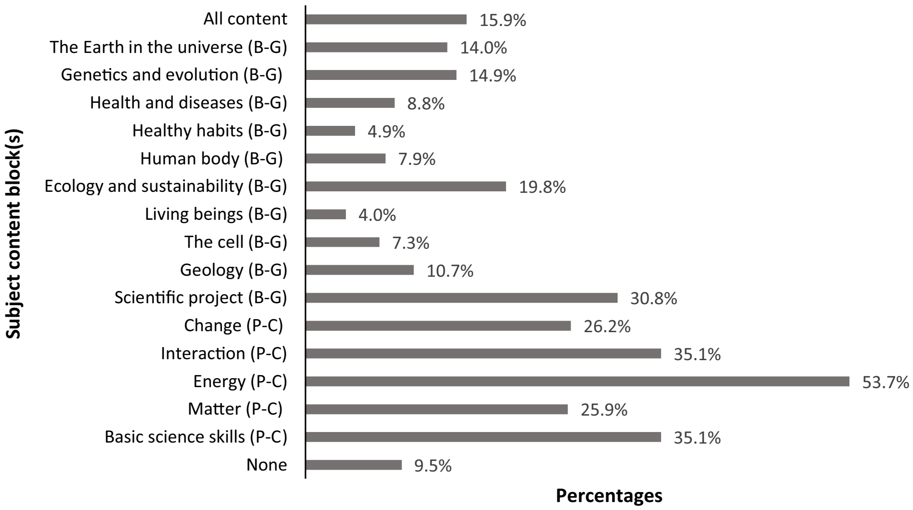

Fig. 4 Subject content is conducive, according to science teachers, to the integration of engineering practices (item 10, $n=328$). "B-G" refers to Biology and Geology subject; "P–C" refers to Physics and Chemistry subject

As for which school science content could be most conducive to integrating engineering practices, physics and chemistry stand out the most (Fig. 4). Indeed, the content block most frequently mentioned by science teachers is that related to "energy" (53.7%), followed to some extent by blocks related to "interaction" and "basic scientific skills," both chosen by 35.1% of teachers. The block dedicated to "science projects" receives the most attention from teachers in biology and geology (30.8%).

Discussion

The advent of the STEM education movement confronts science teachers with a significant challenge: the incorporation of engineering practices in science education teaching. This goal is now being promoted in Spain with the implementation of a new educational reform (Royal Decree 217/2022); thus, this study aims at exploring the level of preparation, emotions, expectations, and opinions of secondary school science teachers regarding such an approach.

In response to the 1st research question (training and initiative to integrate engineering), this study found that, as in other educational contexts (Dare et al., 2018; Ring-Whalen et al., 2018; Zhan et al., 2021), Spanish science teachers lack pedagogical training to integrate engineering practices in their classes. Most of them have not participated in any professional development course addressing such aspects, nor have they taken the initiative to train themselves by reading specialized bibliography. Before the new educational reform, the integration of engineering practices was not part of science education curricula (García-Carmona, 2023); hence, science teachers were oriented to teach specific science subjects (García-Carmona, 2020; Montero & García-Carmona, 2018). Indeed, according to the findings of this study, most science teachers have never considered integrating engineering practices into their science teaching practices. Therefore, the fact that science teachers are now being challenged by this educational reform causes them negative emotions (Marcos-Merino et al., 2022; Uzuntiryaki-Kondakci et al., 2022), which may hinder their future intention to receive training for integrating engineering practices (Eurydice, 2011; Luft et al., 2020). In any case, the situation reveals a clear mismatch between the demands of a new curriculum reform and teacher professional development programs (García-Carmona, 2020). This is often the result of implementing "accelerated policy measures" in education (Adell et al., 2019), which widens the gap between the administration's curricular prescriptions and teaching practices enacted by science educators (Pattier & Olmos, 2021).

Concerning the 2nd research question (self-estimated teaching preparation to integrate engineering), the results suggest that science teachers hold low self-efficacy beliefs regarding the integration of engineering practices into their classes. According to research on teachers' self-efficacy, this aspect may affect the effectiveness of their teaching practices (Lazarides & Warner, 2020; Uzuntiryaki-Kondakci et al., 2022). For example, Brand (2020) found that science teachers who were new to integrating engineering expressed fears that they would not be able to address all student concerns in the context of engineering design-based activities. Hence, it may be that science education, at least as usually developed, would not favor the integration of engineering practices (Schellinger et al., 2022; Wieselmann et al., 2020). For this reason, improving the disciplinary and pedagogical engineering knowledge of science teachers is a key target to improving their self-efficacy to integrate engineering practices into their classes (Yesilyurt et al., 2021). As You (2017) notes, "If science teachers have insufficient knowledge in the specific discipline topics, they will also lack the ability to integrate the concepts." (p. 72).

So, professional development programs for STEM education should improve science teachers' self-efficacy by creating communities of practice where they work with engineering professionals and university faculty to design and implement teaching proposals (Brand, 2020; Kelley et al., 2020). However, this is currently almost utopia in Spanish science teacher training, which is still divided into science specialties (Montero and García-Carmona, 2018), without considering engineering. Moreover, it does little to help that most professional development plans in STEM education are developed with teachers who have initial training in only one STEM discipline, mainly science or mathematics (Zhang & Zhu, 2023). Therefore, it is necessary that STEM teachers begin acquiring preparation in integrated STEM education from their initial training (Anabousy & Daher, 2022; Berisha & Vula, 2021; Nasrudin et al., 2020) and not leave this training only for when teachers are already in practice.

Regarding the 3rd research question (teaching experience and emotions integrating engineering), this study found that few science teachers introduced engineering practices in their classes. These findings are not surprising given the lack of pedagogical training and the low levels of self-efficacy reported, as discussed previously. Likewise, these results signal that science teachers continue to prefer teaching science subjects without integrating engineering, coinciding with what has been pointed out by authors from other educational contexts (Lederman & Lederman, 2013; You, 2017). In addition, among those teachers reporting previous efforts to integrate engineering practices, regardless of whether or not it was demanded by curricular standards, most of them did not have a good experience. This is in line with some studies in the literature that point out that science teachers often integrate engineering into their science classes superficially or with poor curricular significance in connecting the two disciplines (Schellinger et al., 2022; Zhan et al., 2021). But apart from saying that behind it would be science teachers' lack of pedagogical training for teaching engineering (Dare et al., 2018; Ring-Whalen et al., 2018; Zhan et al., 2021), the specific causes that could explain such results in this study were not analyzed. Future research addressing such an aspect is, therefore, warranted. Furthermore, findings suggest that, when faced with the challenge of integrating engineering practices, science teachers often feel insecure. This is reasonable because they are not used to this type of teaching approach (Borrachero et al., 2019).

With respect to the 4th research question (how to integrate engineering and educational value), most teachers believe integrating engineering practices into science classes would improve students' scientific competence, consequently recognizing the educational potential that such an approach may have, at least from a theoretical point of view (Cunningham & Carlsen, 2014; Moore et al., 2014). When asked how such practices should be integrated, however, most concluded that it would be best to do so within technology subjects, revealing that they shy away from an integrated approach to science teaching. Indeed, very few teachers reported that engineering practices should be integrated across all science subjects. Therefore, this study's results contribute to the ongoing debate over whether engineering should be a separate school subject from science (Barak et al., 2022).

Conclusions, Limitations, and Prospective

The findings of this study are not limited to the Spanish context but can resonate with other countries that are also implementing or planning to implement engineering education initiatives. According to the Johnson and Czerniak's (2023) literature review, STEM education, with a clear focus on engineering practices, has become a global movement, with the USA, Asia, and European countries leading the way. However, this trend has also gained momentum in the education plans of countries such as Australia and some African countries.

Therefore, given that the current educational reforms promoted worldwide are focused on boosting STEM education, science teachers face the challenge of integrating engineering practices into their science classes. For this reason, the present study explored the experiences, emotions, and appraisals of secondary science teachers in relation to this educational objective. The findings reveal that science teachers are not used or feel prepared to integrate engineering practices into their classes. They also feel negative emotions that can affect their teaching practice about it. Furthermore, they have low self-efficacy beliefs and perceive a lack of support for the pedagogical training that is needed for this educational challenge.

These findings have implications and relevance for different stakeholders. Schools should provide a supportive environment and adequate resources for science teachers to use engineering practices in their classes. Regarding professional development, universities should offer programs that address science teachers' emotional and cognitive needs and help them improve their self-efficacy beliefs regarding enacting engineering practices. Finally, education policymakers should establish clear guidelines for how this integration of engineering should be performed in science education.

That said, the findings of this study should be interpreted considering the following limitations. The first one relates to the sample size. Although the participation of teachers from all Spanish autonomous communities was achieved, a more balanced representation of all of them would have been desirable. However, access to the sample of this study hampered this aspect. It should be mentioned, nonetheless, that a 93% confidence level was achieved when recruiting the sample size. With a small margin of error, the results can, therefore, be generalized to all Spanish secondary school science teachers.

Second, the data collection questionnaire used is limited. Integration of engineering in science education is a new research area, especially in the Spanish educational context, so an ad hoc questionnaire was designed. This instrument has been subjected to psychometric standards to ensure valid and reliable results; however, to achieve a large sample size, only a small number of easy-to-answer items were considered. The results provide a fair overview of the issues addressed, but the number and type of items do not allow more in-depth analyses to be performed. To overcome this limitation, future studies could include teacher interviews to complement the quantitative data collected. Furthermore, more research should be done to analyze the design and effectiveness of science teacher training programs to implement engineering practices, which are still rare in the Spanish educational context despite the new curricular reform (García-Carmona, 2023). Some existing precedents in other countries (e.g., Brand, 2020; Capobianco, 2016; Mumba et al., 2023; Yesilyurt et al., 2021; Zhan et al., 2021) may be good references for planning and conducting this future research with Spanish science teachers.

Appendix: Questionnaire

This questionnaire, completely anonymous, aims to know your opinion, experience, and expectations as a low-secondary science education teacher about integrating engineering practices in science education.

As the questionnaire is addressed to both "biology and geology" and "physics and chemistry" teachers, the term "science" will be used in the questions to refer to both subjects or specialties.

Please answer all questions honestly.

Thank you very much for your collaboration!

Demographic information

0.1 Age: ______

0.2 Gender: Woman / Man

0.3 Academic qualification:

a. University degree in physics
b. University degree in chemistry
c. University degree in life sciences (biology, biochemistry, biotechnology, medicine, etc.)
d. University degree in earth and environmental sciences (geology, marine sciences, etc.)
e. University degree in engineering or architecture
f. University degree in primary education, with qualification to teach science in compulsory secondary education

0.4 How many years of teaching experience do you have? _____

0.5 Do you work in a public or private institution?

a. Public
b. Private

0.6 Do you have a permanent placement in your current school?

a. Yes
b. No

Questions

1. How would you estimate your level of training in engineering education?

a. Low
b. Medium
c. High
d. Very high

2. How many teacher training courses have you received lately on how to integrate engineering practices in low-secondary science education?

a. None
b. One course
c. Two courses
d. Three or more courses

3. How much educational literature (books or articles) have you recently consulted on the integration of engineering practices in low-secondary science education?

a. None
b. Few (one or two)
c. Some (three or four)
d. Many (five or more)

4. In general, to what extent do you feel prepared to integrate engineering practices into your science classes?

a. Poor
b. Fair
c. Good
d. Excelent

5. Do you include engineering practices in your science lesson plans?

a. Never
b. Rarely
c. Sometimes
d. Often

6. How is your teaching experience in integrating engineering practices into science classes?

a. Bad
b. Mixed
c. Good
d. None

7. To what extent do you think that the integration of engineering practices in your science classes can improve the competence development of your students?

a. Low
b. Some
c. Quite
d. A lot

8. As a teacher, the fact that the official science curriculum for low-secondary education proposes to deal with engineering practices in science subjects generates (select the one(s) you consider):

☐ Joy
☐ Stress
☐ Hope
☐ Insecurity
☐ Satisfaction
☐ Indiference
☐ Enthusiasm
☐ Apathy

9. If engineering practices are to be introduced in science education, what would be, in your opinion, the best option?

☐ In a new engineering-specific school subject
☐ Within technology subjects
☐ In a transversal way in all science subjects
☐ Through punctual integration with some contents of the science subjects

10. With which content block(s) of the low-secondary science curriculum do you think engineering practices can be best integrated (please select the option(s) you consider):

- ☐ None
- ☐ The Earth in the universe (biology and geology)
- ☐ Genetics and evolution (biology and geology)
- ☐ Health and diseases (biology and geology)
- ☐ Healthy habits (biology and geology)
- ☐ Human body (biology and geology)
- ☐ Ecology and sustainability (biology and geology)
- ☐ Living beings (biology and geology)
- ☐ The cell (biology and geology)
- ☐ Geology (biology and geology)
- ☐ Scientific Project (biology and geology)
- ☐ Change (physics and chemistry)
- ☐ Interaction (physics and chemistry)
- ☐ Energy (physics and chemistry)
- ☐ Matter (physics and chemistry)
- ☐ Basic science skills (physics and chemistry)
- ☐ All content

11. Of the following engineering practices, indicate how prepared you feel to integrate them in your low-secondary science classes:

i. Defining engineering-related problems

a. Poor
b. Fair
c. Good
d. Excelent

ii. Developing and using engineering models or prototypes

a. Poor
b. Fair
c. Good
d. Excelent

iii. Planning and carrying out engineering-related investigations

a. Poor
b. Fair
c. Good
d. Excelent

iv. Analyzing and interpreting data
  a. Poor
  b. Fair
  c. Good
  d. Excelent

v. Using mathematics and computational thinking
  a. Poor
  b. Fair
  c. Good
  d. Excelent

vi. Designing solutions (sketches, artifacts, prototypes, etc.)
  a. Poor
  b. Fair
  c. Good
  d. Excelent

vii. Selecting the best solution following evidence-based arguments
  a. Poor
  b. Fair
  c. Good
  d. Excelent

viii. Responding to unexpected events and incidents in engineering problem solving
  a. Poor
  b. Fair
  c. Good
  d. Excelent

ix. Obtaining, evaluating, and communicating information regarding engineering projects
  a. Poor
  b. Fair
  c. Good
  d. Excelent

Acknowledgements The authors would like to thank all of their colleagues who assisted them during the data collection process, as well as all of the teachers who took the time to fill out the questionnaire and provide valuable information on this timely topic.

Funding Funding for open access publishing: Universidad de Sevilla/CBUA This study was funded by MCIN/AEI/10.13039/501100011033 (Government of Spain) under Grant PID2022-137471NB-I00.

Declarations

Ethical Statement This study met the ethics requirements for research that involves human subjects at the time the data was collected.

Conflict of Interest The authors declare no competing interests.

References

Adell, J. S., Llopis, M. A. N., Esteve, M. F. M., & Valdeolivas, N. M. G. (2019). El debate sobre el pensamiento computacional en educación [The discussion on computational thinking in education]. *Revista Iberoamericana De Educación a Distancia, 22*(1), 171–186. https://doi.org/10.5944/ried.22.1.22303

Ainley, J., & Carstens, R. (2018). *Teaching and learning international survey (TALIS) 2018 conceptual framework*. OECD Publishing.

Akerson, V. L., & Buck, G. A. (eds.). (2020). *Critical questions in STEM education*. Springer.

Anabousy, A., & Daher, W. (2022). Pre-service teachers' design of STEAM learning units: STEAM capabilities' analysis. *Journal of Technology and Science Education, 12*(2), 529–546. https://doi.org/10.3926/jotse.1621

Antink-Meyer, A., & Brown, R. A. (2019). Nature of engineering knowledge. *Science & Education, 28*(3–5), 539–559. https://doi.org/10.1007/s11191-019-00038-0

Barak, M., Ginzburg, T. & Erduran, S. (2022). Nature of engineering. *Science & Education*https://doi.org/10.1007/s11191-022-00402-7

Berisha, F., & Vula, E. (2021). Developing pre-service teachers conceptualization of STEM and STEM pedagogical practices. *Frontiers in Education, 6*, 585075. https://doi.org/10.3389/feduc.2021.585075

Borrachero, A. B., Brígido, M., Dávila, M. A., Costillo, E., Cañada, F., & Mellado, V. (2019). Improving the self-regulation in prospective science teachers: The case of the calculus of the period of a simple pendulum. *Heliyon, 5*(12), e02827. https://doi.org/10.1016/j.heliyon.2019.e02827

Brand, B. R. (2020). Integrating science and engineering practices: Outcomes from a collaborative professional development. *International Journal of STEM Education, 7*(1), 1–13. https://doi.org/10.1186/s40594-020-00210-x

Burić, I., & Kim, L. E. (2020). Teacher self-efficacy, instructional quality, and student motivational beliefs: an analysis using multilevel structural equation modeling. *Learning and Instruction*, 66(January 2019), 101302. https://doi.org/10.1016/j.learninstruc.2019.101302

Capobianco, B. M. (2016). Uncertainties of learning to teach elementary science methods using engineering design: A science teacher educator's self study. In G. A. Buck & V. L. Akerson (Eds.), *Enhancing professional knowledge of preservice science teacher education by self-study research: Turning a critical eye on our practice* (pp. 215–232). Springer.

Cohen, L., Manion, L., & Morrison, K. (2018). *Research methods in education* (8th ed.). Routledge

Cornell, J. (2023, July 24). Likert scale: definition, types, questions & advantages. https://www.proprofssurvey.com/blog/likert-scale/#:~:text=Pros%20of%204%20Point%20Likert,for%20recently%20used%20products%2Fservices

Cunningham, C. M., & Carlsen, W. S. (2014). Teaching engineering practices. *Journal of Science Teacher Education, 25*(2), 197–210. https://doi.org/10.1007/s10972-014-9380-5

Dare, E. A., Ellis, J. A., & Roehrig, G. H. (2018). Understanding science teachers' implementations of integrated STEM curricular units through a phenomenological multiple case study. *International Journal of STEM Education, 5*(1), 1–19. https://doi.org/10.1186/s40594-018-0101-z

Dare, E. A., Ring-Whalen, E. A., & Roehrig, G. H. (2019). Creating a continuum of STEM models: Exploring how K-12 science teachers conceptualize STEM education. *International Journal of Science Education, 41*(12), 1701–1720. https://doi.org/10.1080/09500693.2019.1638531

Daugherty, M. K., & Carter, V. (2018). The nature of interdisciplinary STEM education. In M. J. de Vries (Ed.), *Handbook of technology education* (pp. 159–172). Springer.
Drost, E. A. (2011). Validity and reliability in social science research. *Education Research and Perspectives, 38*(1), 105–123. https://doi.org/10.3316/ielapa.491551710186460
European Schoolnet. (2018). *Science, technology, engineering and mathematics education policies in Europe*. *Scientix Observatory report*. Author.
Eurydice. (2011). *Science education in Europe: national policies, practices and research*. Publications Office of the European Union.
Frenzel, A. C., Daniels, L., & Burić, I. (2021). Teacher emotions in the classroom and their implications for students. *Educational Psychologist, 56*(4), 250–264. https://doi.org/10.1080/00461520.2021.1985501
Frías-Navarro, D., & Pascual, M. (2012). Prácticas del análisis factorial exploratorio (AFE) en la investigación sobre conducta del consumidor y marketing [Exploratory factor analysis (EFA) in consumer behavior and marketing research]. *Suma Psicológica*, *19*(1), 47–58. https://www.redalyc.org/articulo.oa?id=134224283004
García-Carmona, A. (2020). STEAM, ¿una nueva distracción para la enseñanza de la ciencia? (STEAM—A new distraction for science education?). Ápice. *Revista de Educación Científica*, *4*(2), 35–50. https://doi.org/10.17979/arec.2020.4.2.6533
García-Carmona, A. (2022). Spanish science teacher educators' preparation, experiences, and views about nature of science in science education. *Science & Education*, *31*(3), 685–711. https://doi.org/10.1007/s11191-021-00263-6
García-Carmona, A. (2023). Integración de la ingeniería en la educación científico-tecnológica desde un prisma CTS (Integration of engineering in science and technology education from an STS perspective). *Enseñanza de las Ciencias*, *41*(1), 25–41. https://doi.org/10.5565/rev/ensciencias.5611
García-Carmona, A., & Cruz-Guzmán, M. (2016). ¿Con qué vivencias, potencialidades y predisposiciones inician los futuros docentes de Educación Primaria su formación en la enseñanza de la ciencia? (What personal experiences, potentialities and predispositions do prospective primary teachers manifest when they start their training in science teaching?) *Revista Eureka sobre Enseñanza y Divulgación de las Ciencias*, *13*(2), 440–458. https://doi.org/10.25267/Rev_Eureka_ensen_divulg_cienc.2016.v13.i2.15
Gresnigt, R., Taconis, R., van Keulen, H., Gravemeijer, K., & Baartman, L. (2014). Promoting science and technology in primary education: A review of integrated curricula. *Studies in Science Education, 50*(1), 47–84. https://doi.org/10.1080/03057267.2013.877694
Ham, M., & Dekkers, J. (2019). What role do teachers' beliefs play in the implementation of educational reform? Nepali teachers' voice. *Teaching and Teacher Education, 86*, 102917. https://doi.org/10.1016/j.tate.2019.102917
Honey, M., Pearson, G., & Schweingruber, H. (2014). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. National Academies Press.
Johnson, C. C., Peters-Burton, E. E., & Moore, T. J. (2016). *STEM road map: A framework for integrated STEM education*. Routledge.
Johnson, C. C., & Czerniak, C. M. (2023). Interdisciplinary approaches and integrated STEM in Science Teaching. In N. G. Lederman, D. L. Zeidler, & J. S. Lederman (Eds.), *Handbook of Research on Science Education* (Vol. III, pp. 559–585). Routledge.
Keller, M. M., & Becker, E. S. (2021). Teachers' emotions and emotional authenticity: Do they matter to students' emotional responses in the classroom? *Teachers and Teaching: Theory and Practice, 27*(5), 404–422. https://doi.org/10.1080/13540602.2020.1834380
Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(11), 1–11. https://doi.org/10.1186/s40594-016-0046-z
Kelley, T. R., Knowles, J. G., Holland, J. D., & Han, J. (2020). Increasing high school teacher's self-efficacy for integrated STEM instruction through a collaborative community of practice. *International Journal of STEM Education, 7*(1), 1–13. https://doi.org/10.1186/s40594-020-00211-w
Kurup, P. M., Li, X., Powell, G., & Brown, M. (2019). Building future primary teachers' capacity in STEM: Based on a platform of beliefs, understandings and intentions. *International Journal of STEM Education, 6*(1), 1–4. https://doi.org/10.1186/s40594-019-0164-5
Lauermann, F., & Butler, R. (2021). The elusive links between teachers' teaching-related emotions, motivations, and self-regulation and students' educational outcomes. *Educational Psychologist, 56*(4), 243–249. https://doi.org/10.1080/00461520.2021.1991800
Lazarides, R. & Warner, L. M. (2020). Teacher self-efficacy. In *Oxford Research Encyclopedia, Education* (pp. 1–22). Oxford University Press.
Lederman, N. G., & Lederman, J. S. (2013). Is it STEM or "S & M" that we truly love? *Journal of Science Teacher Education, 24*(8), 1237–1240. https://doi.org/10.1007/s10972-013-9370-z

Lehrer, R., & Schauble, L. (2021). Stepping carefully: Thinking through the potential pitfalls of integrated STEM. *Journal for STEM Education Research, 4*(1), 1–26. https://doi.org/10.1007/s41979-020-00042-y
Lloret-Segura, S., Ferreres-Traver, A., Hernández-Baeza, A., & Tomás-Marco, I. (2014). Exploratory item factor analysis: A practical guide revised and updated. *Annals of Psychology, 30*(3), 1151–1169. https://doi.org/10.6018/analesps.30.3.199361
López-Roldán, P., & Fachelli, S. (2015). *Metodología de la investigación social cuantitativa* [Methodology of quantitative social research]. UAB.
Luft, J. A., Diamond, J. M., Zhang, C., & White, D. Y. (2020). Research on K-12 STEM professional development programs. In C. C. Johnson, M. J. Mohr-Schroeder, T. J., Moore, & L. D. English (eds.), *Handbook of research on STEM education* (pp. 361–374). Routledge.
Marcos-Merino, J. M., Gallego, R. E., & de Alda, J. A. G. O. (2022). Conocimiento previo, emociones y aprendizaje en una actividad experimental de ciencias [The interplay of prior knowledge, emotions and learning in a science experiment activity]. *Enseñanza De Las Ciencias, 40*(1), 107–124. https://doi.org/10.5565/rev/ensciencias.3361
Margot, K. C., & Kettler, T. (2019). Teachers' perception of STEM integration and education: A systematic literature review. *International Journal of STEM Education, 6*(1), 1–16. https://doi.org/10.1186/s40594-018-0151-2
Martín-Páez, T., Aguilera, D., Perales-Palacios, F. J., & Vílchez-González, J. M. (2019). What are we talking about when we talk about STEM education? A review of literature. *Science Education, 103*(4), 799–822. https://doi.org/10.1002/sce.21522
Mellado, V., Borrachero, A. B., Brígido, M., Melo, L. V., Dávila, M. A., Cañada, F., Conde, M. C., Costillo, E., Cubero, J., Esteban, R., Martínez, G., Ruiz, C., Sánchez, J., Garritz, A., Mellado, L., Vázquez, B., Jiménez, R., & Bermejo, M. L. (2014). Las emociones en la enseñanza de las ciencias [Emotions in science teaching]. *Enseñanza De Las Ciencias, 32*(3), 11–36. https://doi.org/10.5565/rev/ensciencias.1478
Montero, L., & García-Carmona, A. (2018). Políticas, investigación y prácticas en la formación inicial del profesorado de ciencias en España (Policy, research and practice in initial science teacher training in Spain). In A. Cachapuz, A. Shigunov, & I. Fortunato (Eds.), *Formação inicial e continuada de professores de ciências: o que se pesquisa no Brasil*, *Portugal e Espanha* (pp. 318–345). Edições Hipótese.
Moore, T. J., Stohlmann, M. S., Wang, H. H., Tank, K. M., Glancy, A. W., & Roehrig, G. H. (2014). Implementation and integration of engineering in K-12 STEM education. In Ş Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 35–60). Purdue University Press.
Mumba, F., Rutt, A., Bailey, R., Pottmeyer, L., van Aswegen, R., Chiu, J., & Ojeogwu, J. (2023). A model for integrating engineering design into science teacher education. *Journal of Science Education and Technology*, 1–12. https://doi.org/10.1007/s10956-023-10055-y
Nasrudin, D., Rochman, C., Suhendi, H. Y., Helsy, I., Rasyid, A., Aripin, I., Utami, W., & Mayasri, A. (2020). STEM education for pre-service teacher: Why and how? *Journal of Physics: Conference Series, 1563*, 012039. https://doi.org/10.1088/1742-6596/1563/1/012039
National Research Council [NRC]. (2012). *A framework for K-12 science education*. National Academies Press.
National Science Teacher Association [NSTA]. (2020). *STEM education teaching and learning* (Position statement). https://www.nsta.org/nstas-official-positions/stem-education-teaching-and-learning
Ortega-Torres, E. (2022). Training of future STEAM teachers: Comparison between primary degree students and secondary master's degree students. *Journal of Technology and Science Education, 12*(2), 484–495. https://doi.org/10.3926/jotse.1319
Pattier, D., & Olmos, P. (2021). La Administración y el profesorado: Prácticas educativas basadas en la evidencia [Administration and teachers: Evidence-based educational practices]. *Revista De Educación, 392*, 35–62. https://doi.org/10.4438/1988-592X-RE-2021-392-478
Pekrun, R. (2021). Teachers need more than knowledge: Why motivation, emotion, and self-regulation are indispensable. *Educational Psychologist, 56*(4), 312–322. https://doi.org/10.1080/00461520.2021.1991356
Quinn, C. M., Reid, J. W. y Gardner, G. E. (2020). S+ T+ M= E as a convergent model for the nature of STEM. *Science & Education*, *29*(4), 881–898https://doi.org/10.1007/s11191-020-00130-w
Raosoft, Inc. (2004). Sample size calculator. http://www.raosoft.com/samplesize.html
Reichert, F., Lange, D., & Chow, L. (2021). Educational beliefs matter for classroom instruction: A comparative analysis of teachers' beliefs about the aims of civic education. *Teaching and Teacher Education, 98*, 103248. https://doi.org/10.1016/j.tate.2020.103248

Ring, E. A., Dare, E. A., Crotty, E. A., & Roehrig, G. H. (2017). The evolution of teacher conceptions of STEM education throughout an intensive professional development experience. *Journal of Science Teacher Education, 28*(5), 444–467. https://doi.org/10.1080/1046560X.2017.1356671

Ring-Whalen, E., Dare, E., Roehrig, G., Titu, P., & Crotty, E. (2018). From conception to curricula: the role of science, technology, engineering, and mathematics in integrated STEM units. *International Journal of Education in Mathematics, Science and Technology*, *6*(4), 343–362. https://www.ijemst.net/index.php/ijemst/article/view/257/157

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*(1), 1–18. https://doi.org/10.1186/s43031-021-00041-y

Royal Decree 217/2022, of 29 March, which establishes the organisation and minimum teaching of compulsory secondary education. *Spanish Official State Gazette, 76*, 41571–41789. https://www.boe.es/eli/es/rd/2022/03/29/217

Schellinger, J., Jaber, L. Z., & Southerland, S. A. (2022). Harmonious or disjointed?: Epistemological framing and its role in an integrated science and engineering activity. *Journal of Research in Science Teaching, 59*(1), 30–57. https://doi.org/10.1002/tea.21720

Takeuchi, M. A., Sengupta, P., Shanahan, M.-C., Adams, J. D., & Hachem, M. (2020). Transdisciplinarity in STEM education: A critical review. *Studies in Science Education, 56*(2), 213–253. https://doi.org/10.1080/03057267.2020.1755802

Taimalu, M., & Luik, P. (2019). The impact of beliefs and knowledge on the integration of technology among teacher educators: A path analysis. *Teaching and Teacher Education, 79*, 101–110. https://doi.org/10.1016/j.tate.2018.12.012

Tamassia, L., & Frans, R. (2014). Does integrated science education improve scientific literacy? *Journal of the European Teacher Education Network, 9*, 131–141. https://doi.org/10.5281/zenodo.1343895

Teo, T. W., Tan, A. L., & Teng, P. (eds.). (2021). *STEM education from Asia: trends and perspectives*. Routlegde.

Toma, R. B., & García-Carmona, A. (2021). «De STEM nos gusta todo menos STEM». Análisis crítico de una tendencia educativa de moda («Of STEM we like everything but STEM». A critical analysis of a buzzing educational trend). *Enseñanza de las Ciencias*, *39*(1), 65–80. https://doi.org/10.5565/rev/ensciencias.3093

US Department of Education. (2016). *STEM 2026: a vision for innovation in STEM education*. Author.

Uzuntiryaki-Kondakci, E., Kirbulut, Z. D., Sarici, E., & Oktay, O. (2022). Emotion regulation as a mediator of the influence of science teacher emotions on teacher efficacy beliefs. *Educational Studies, 48*(5), 583–601. https://doi.org/10.1080/03055698.2020.1793300

Vinck, D. (2014). Engineering practices. The knowledge of action. *Revue d'Anthropologie des Connaissances*, *8*(2), 225–243. https://www.cairn.info/revue-anthropologie-des-connaissances-2014-2-page-225.htm

Wieselmann, J. R., Dare, E. A., Ring-Whalen, E. A., & Roehrig, G. H. (2020). "I just do what the boys tell me": Exploring small group student interactions in an integrated STEM unit. *Journal of Research in Science Teaching, 57*(1), 112–144. https://doi.org/10.1002/tea.21587

White, D., & Delaney, S. (2021). Full STEAM ahead, but who has the map for integration? – a PRISMA systematic review on the incorporation of interdisciplinary learning into schools. *International Journal on Math, Science and Technology Education*, *9*(2), 9–32. https://doi.org/10.31129/LUMAT.9.2.1387

Yesilyurt, E., Deniz, H., & Kaya, E. (2021). Exploring sources of engineering teaching self-efficacy for preservice elementary teachers. *International Journal of STEM Education, 8*(1), 1–15. https://doi.org/10.1186/s40594-021-00299-8

You, H. S. (2017). Why teach science with an interdisciplinary approach: History, trends, and conceptual frameworks. *Journal of Education and Learning, 6*(4), 66–77. https://doi.org/10.5539/jel.v6n4p66

Zhan, X., Sun, D., Wan, Z. H., Hua, Y., & Xu, R. (2021). Investigating teacher perceptions of integrating engineering into science education in mainland China. *International Journal of Science and Mathematics Education, 19*(7), 1397–1420. https://doi.org/10.1007/s10763-020-10117-2

Zhang, Y., & Zhu, J. (2023). STEM pre-service teacher education: a review of research trends in the past ten years. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7), em2292. https://doi.org/10.29333/ejmste/13300