Journal of Turkish Science Education, 2026, *23*(1), 133-163.
DOI no: 10.36681/tused.2026.007

Journal of Turkish Science Education
http://www.tused.org
© ISSN: 1304-6020

STEAM-5E: A new methodological approach to STEAM based on a critical literature review

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ABSTRACT
Educational institutions and organisations around the world recognise the STEM (Science, Technology, Engineering and Mathematics) and STEAM (A for Arts) paradigms as appropriate frameworks for achieving the key competences needed for the 21st century. However, there are ongoing debates within them and different methodologies to address these debates. First, this work aims to analyse these debates and the diversity of methodologies proposed through a narrative review of the literature following a qualitative content analysis methodology. Secondly, a new framework, STEAM-5E, is proposed to address this complexity. Its basic pillars are the 5E methodology, the integration of STEAM disciplines broadly, the development of creativity across its multiple facets, special consideration for equity, and the search for learner motivation through inquiry, manipulative activities, and collaborative work. Metacognitive and dialogic processes mediate all learning. Collaboration between researchers and teachers is particularly relevant, according to the basic principles of Design-Based Research, to develop classroom materials adapted to their real context. Several tools are included for implementation evaluation and assessment. Finally, a STEAM-5E project designed for upper primary education (9-11 years old) is presented, along with evidence of its validity and effectiveness. This model could serve as a guide for teachers and researchers in creating and evaluating new STEAM projects.

RESEARCH ARTICLE

ARTICLE INFORMATION
Received: 24.01.2024
Accepted: 27.05.2025
Available Online: 30.03.2026

KEYWORDS:
STEAM, STEM, 5E, methodology, review.

To cite this article: Ros, G., Rodríguez-Laguna,M. T., García-Varela, A. B., & Megías, C. (2026). STEAM-5E: A new methodological approach to STEAM based on a critical literature review. *Journal of Turkish Science Education, 23*(1), 133-163. http://doi.org/10.36681/tused.2026.007

Introduction

The STEM (Science, Technology, Engineering, and Mathematics) movement emerged in the early 1990s but gained significant momentum at the beginning of the 21st century. From a research perspective, numerous studies indicate a substantial increase in publications on STEM education in recent years, with a focus on goals, policies, curricula, evaluation, and assessment (Li et al., 2020).

Despite this growth, the National Academy of Sciences in the United States warned as early as 2014 that it is common to find inconsistent language, a lack of term definition, and, as a result, a theoretical framework that makes STEM education difficult to understand (NAS, 2014). In this regard, many studies have since highlighted the broad conceptual challenges within the STEM movement (Kelley & Knowles, 2016; Akerson et al., 2018; Toma & García-Carmona, 2021), which is not surprising given the field's complexity and the diverse objectives it seeks to achieve. For example, in a systematic review, Martín-Páez et al. (2018) found that 55% of the selected studies failed to provide a clear definition of STEM, and most did not incorporate such definitions into their theoretical frameworks. Additionally, Thibaut et al. (2018) reported that in another systematic review, less than one-third of the analysed studies referenced an underlying learning theory to support their instructional practices.

More recent systematic reviews indicate that varying perspectives on STEM integration persist, as well as differing views on the relative importance of each discipline within STEM education (Larkin & Lowrie, 2023; Wan et al., 2023). This epistemological debate extends to the question of whether there truly exists a "Nature of STEM" (NoSTEM). This discussion is examined by Aguilera et al. (2024), who argue that while most scholars recognize that STEM is not a single discipline and that a distinct NoSTEM does not exist, opinions on the issue differ. Some argue that STEM has a practical expression underlying its transdisciplinary integration, whereas others believe it emerges from the interaction of the individual disciplinary natures (NoS, NoT, NoE, and NoM).

The landscape becomes even more complex with the incorporation of the arts (represented by the "A") in the emerging STEAM movement. This shift was particularly fostered after the National Science Foundation organised a 2007 symposium on the relationship between the arts, STEM learning, and workforce development in the United States (Colucci-Gray et al., 2017). Over the past decade, the STEAM movement has attracted increasing interest in both educational research and practice (Khine & Areepattamannil, 2019) and has expanded globally (Belbase et al., 2021). However, the challenges previously identified in STEM education persist within STEAM. Marín-Marín et al. (2021) highlight that there is still a lack of sustained, robust research in this field, further complicating its theoretical and practical development.

The challenges are not solely conceptual and epistemological. Recent reviews indicate a wide variety of methodologies used to implement STEM/STEAM in classroom practice (Nugraha et al., 2024), though there remains some obscurity about how these approaches translate theoretical principles into practical applications (Portillo-Blanco, 2024). In addition, some systematic reviews have found that direct instruction remains the most commonly employed methodology, at least at the primary education level (Larkin & Lowrie, 2023).

In response to these challenges, some researchers have sought to identify the defining elements of STEM education. For instance, following a systematic review, Portillo-Blanco et al. (2024) conclude that there is broad consensus on key principles, including integration, real-world problems, inquiry, design, and teamwork. Other researchers have developed conceptual frameworks to provide both epistemological and practical support for the STEM approach. Aguilera et al. (2024) propose a model grounded in situated learning and co-teaching as its core pillars. Nugraha et al. (2024) stress integration, the use of multiple representations, engagement with realistic and relevant problems, application of the engineering design process, active collaboration, and student-centred learning approaches in their framework. Similarly, Ortiz-Revilla et al. (2022) develop a comprehensive model of integrated STEM education, structured around epistemological, psychological, and didactic dimensions. ElSayary (2021) proposes a model linking the design of a transdisciplinary STEAM curriculum to the implementation of authentic assessment. These more comprehensive and integrative proposals address the STEM approach, but only a few include concrete classroom implementation examples. Consequently, there is a clear need to expand the discussion to encompass a broader perspective—one that considers the STEAM approach and incorporates aspects that are not sufficiently addressed in existing conceptual frameworks, such as assessment and the evaluation of the validity of projects designed under these approaches.

This study conducts a narrative literature review using a content analysis methodology, aiming to shed light not only on the complex landscape of STEM and STEAM education but also on their essential components. Not only are the most common methodologies identified, but their principles and benefits are also discussed within the STEM/STEAM framework—an aspect absent in other reviews. Furthermore, they are categorised based on their epistemological origins. The ultimate goal is to design a methodological framework, called STEAM-5E, that brings coherence to the STEAM approach, addressing its practical challenges by establishing a clear connection between conceptual and epistemological foundations and their application in educational practice. The work includes assessment tools and questionnaires designed to gather feedback from both students and teachers, ensuring alignment with the proposed framework. Finally, the study illustrates the framework with a project designed for primary education and cites its effectiveness. Specifically, this paper addresses the following research questions:

1. What aspects are under debate within the STEM and STEAM communities?
2. What are the strengths and commonalities of the diverse existing methodologies?
3. How can this complexity be addressed from a methodological point of view?

To answer these questions, three research objectives are proposed:

O1. Summarise and categorise the diversity of open debates in STEM and STEAM education.

O2. Analyse and classify the variety of methodologies proposed.

O3. Develop a new, methodologically and theoretically well-supported framework for STEAM education, along with appropriate tools for its evaluation.

This model could serve as a guide for teachers and researchers in creating and evaluating new STEAM projects.

Method

We carried out a qualitative, narrative, and intentional literature review. The narrative review approach is particularly useful for exploratory reviews that seek to synthesize ideas with a broad focus (Sovacool et al., 2018). The analytical process is illustrated in Figure 1 and aligns with the qualitative content analysis approach (QCA), which is typically structured around four phases (Kleinheksel et al., 2020): identify, code, group, and describe.

The identification phase begins with data collection via searches of the WOS and SCOPUS databases. The search utilises keywords aligned with the research objectives: "education", "learning", "teaching", "approach", "framework", "methodology", or "review", combined with "STEM" or "STEAM." Figure 1 includes the inclusion and exclusion criteria applied in the selection process. The selection includes papers written in English and Spanish, as these are the two predominant languages in STEAM literature, with English being the most widely used (Marín-Marín et al., 2021), as is also the case for STEM research. References to books by highly relevant authors in the field were repeatedly cited in the selected articles. Therefore, it was decided to include these books in the selection process on an exceptional basis.

Following this, an initial evaluation of the articles is performed, excluding those with low epistemological or methodological quality and selecting studies based on relevance criteria, such as the number of citations and the relevance of the journals or the authors in the field. This evaluation is carried out independently by multiple authors and subsequently refined through consensus.

The coding phase is based on thematic notes, where ideas are organised through an inductive coding process. In the grouping phase, codes are clustered, allowing categories and sub-categories to emerge. This process was conducted collaboratively by the authors, through consensus, to enhance comprehension and define codes based on agreed-upon decisions. This inductive approach aligns with a conventional QCA.

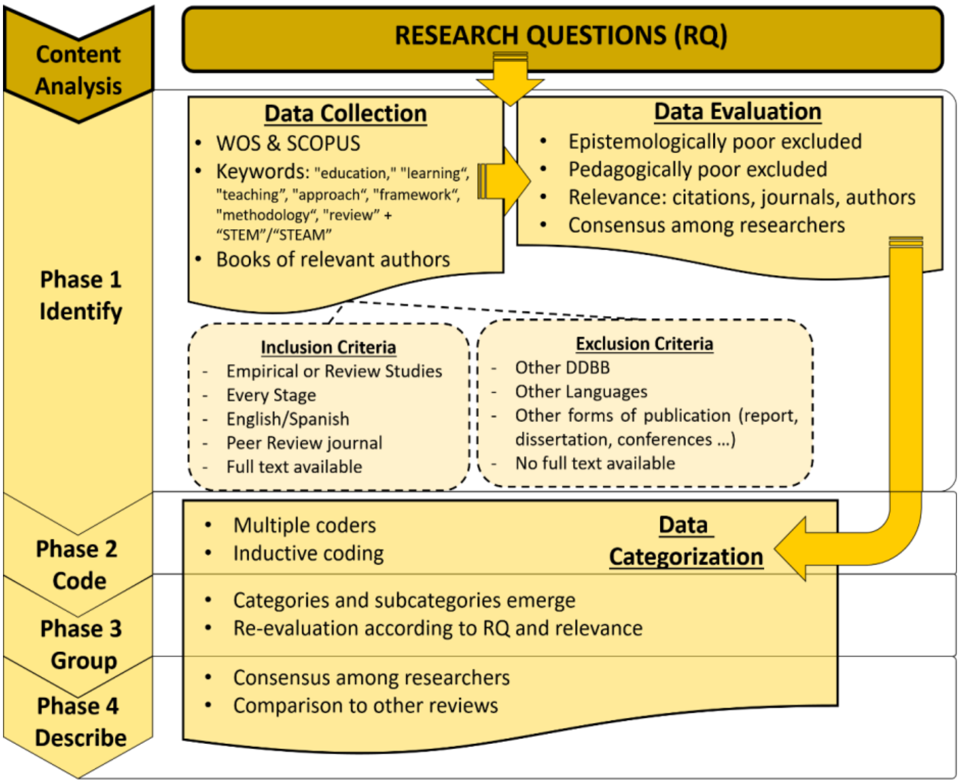
Finally, in the description phase, categories and sub-categories are reorganised based on their relevance and their connection to the research questions. They were also analysed alongside other systematic reviews on the topic to validate the final categorisation. These final steps constitute a more deductive classification and ordering process characteristic of directed QCA. The combination of both inductive and deductive processes is common in QCA (Kleinheksel et al., 2020).

The credibility of the results is ensured by selecting the most relevant databases and applying quality and relevance criteria in article selection. Reliability is achieved through a multi-step review process involving multiple authors, with consensus enhancing consistency. This approach also aims to reduce author bias, a common critique of narrative reviews (Sovacool et al., 2018). Although this study does not seek to conduct a systematic review, a degree of generalisability is achieved in the analysis categories by comparing the final selection with other existing reviews.

According to the last objective of the study, the new methodological approach presented in this work, called STEAM-5E, arose from meetings and discussions between the authors on the aforementioned topics. They were looking for a model that considers the most relevant elements found in the previous review and allows for addressing the problems encountered in a realistic and well-founded manner.

Figure 1

Flowchart of the narrative review process following the content analysis approach



Results

The results are presented below, organised in sub-sections according to the three objectives of the research.

Complexity in STEM and STEAM

The literature review identified five fundamental categories of topics under debate within the community of STEM/STEAM researchers and educators, along with their subcategories, summarised in Table 1 and presented in more detail below.

Table 1

Categories of topics under debate in STEM and STEAM education

Conceptualisation	STEM construct Definition and understanding of technology Definition and understanding of engineering Distinction between technology and engineering STEAM construct Role of the arts Consider various artistic manifestations. Inclusion of the humanities
Disciplinary Integration	Number of disciplines to be considered: STEM/STEAM Multi, inter, or transdisciplinary integration
Creativity	Diversity of conceptions and models Adaptation and concreteness in STEM/STEAM Implementation, measurement, and assessment
Equity	The role of STEM/STEAM in challenging inequalities The characteristics STEM/STEAM must have to effectively reduce the gender gap.
Difficulties of application	Teachers' knowledge and pedagogical content knowledge of STEAM disciplines Lack of support for the teachers Schedule and spaces Tested and valid materials, realistically connected with the curriculum Assessment Diversity of methodologies Evaluation of the application

Conceptualization

A general definition of STEM Pedagogy is given by Leung (2020, p.5): "STEM pedagogy is about situated contextual teaching and learning where participants from educational Communities of Practice (e.g., teachers, learners) socially co-construct solutions and knowledge for addressing relevant real-world problems through boundary crossing dialogical and problem-solving processes that involve more than one STEM discipline". Different projects developed within the STEM framework share this vision of situated learning (Aguilera et al., 2024), grounded in students' active participation in solving real problems (Portillo-Blanco et al., 2024), and a common integrated vision of science. However, each emphasises different aspects, and not all emphasise communities of practice.

On the other hand, a lack of an unequivocal conceptualization in STEM (Kelley & Knowles, 2016) and an epistemological foundation (Akerson et al., 2018) have been highlighted. For example, the idea of bringing science and mathematics education together dates back to the 1970s, and the science-technology-society education movement, which began in the same decade, already proposed integrating science and technology (Toma & García-Carmona, 2021). On the other hand, the concept of technology itself and its differentiation from engineering is complex (Cavanagh & Trotter, 2008), and it varies across different countries (Yata et al., 2020), often being approached only through the inclusion of ICTs (Information and Communication Technology) and through robotics and programming activities. Other authors suggest that engineering and technology are so closely related that they should be taught together (Barak, 2013).

The challenges increase as STEAM emerges. The construct of STEAM education itself has also been conceptualised in different ways: as a movement seeking innovative pedagogical experiences, as integrative classroom practices, as an integrated teaching approach, or as a complete educational model (Bautista, 2021). The inclusion of the 'A' alludes in principle to the Arts to highlight the importance of creativity in learners' development and learning (Perignat & Katz-Buonincontro, 2019). However, the role of the arts in the STEAM movement has been described from several perspectives (Lage-Gómez & Ros, 2021): as a disciplinary value; as a contribution to the teaching and learning processes of STEM areas fostering motivation; as a tool for the development of creativity, innovation, and invention; or as an instrument for narrowing the gender gap that exists in scientific-technological careers. In addition, visual and plastic arts, as well as music, are usually included in STEAM. However, other authors consider the arts in a broader sense, encompassing aesthetics and artistic design, as well as graphic design and performing arts (dance, theatre, film). Moreover, an extensive interpretation of the STEAM acronym has been encouraged to include the humanities and promote comprehensive knowledge (Ge et al., 2015), thereby demonstrating a more complex approach to creativity (Lage-Gómez & Ros, 2024).

Disciplinary Integration

There is no agreement on how many disciplines should be included to consider a project or activity to be truly STEM or STEAM. In fact, Roehrig et al. (2021) state that initially, STEM was concerned only with integrating the science and mathematics disciplines, and it was not until the inclusion of engineering concepts and practices in the US national science standards around 2012 that this integration began to expand. Several STEM curriculum models define STEM as primarily focused on a single subject, while others define it as encompassing two or more disciplines. These diverse conceptions are also found in surveys of teachers from different countries (Ritz & Fan, 2015). Moore et al. (2014) defined STEM education as "an effort to combine some or all of the four disciplines of science, technology, engineering, and mathematics into one class, unit, or lesson that is based on connections between the subjects and real-world problems" (p. 38). Moreover, a recent systematic review of STEM publications shows that more than 17% focus on a single subject area, although most consider all four areas (Li et al., 2020).

In addition, there is no agreement on the best method of integrating the different disciplines (Martín-Páez et al., 2018; Thibaut et al., 2018). In their review of 60 articles published between 2020 and 2022, Larkin & Lowrie (2023) analyse the level of integration in STEM/STEAM education. Many studies approach integration superficially, either through disciplinary projects (where only a single subject is truly involved) or multidisciplinary projects (where a problem is examined from multiple perspectives but without actual integration). As a result, fewer than 10% achieve high levels of integration. These high levels could be classified as: "Integrated STEM", in which various STEM disciplines are combined, either by emphasising one over the others (Sanders, 2015) or by treating them as a cohesive entity (Kelley & Knowles, 2016) (this approach extends to "Integrated STEAM" with the inclusion of A (Quigley & Herro, 2016)); interdisciplinary, which refers to the ability to tackle complex problems by integrating tools and theories from multiple disciplines, actively seeking connections between them; and transdisciplinary, where disciplinary boundaries dissolve, allowing for a holistic approach to problem-solving.

STEAM researchers usually advocate for transdisciplinary approaches (Costantino, 2018), for example, by using the concept of Big Ideas to develop their projects (Lage-Gómez & Ros, 2021). In any case, greater consideration of the pedagogical and curricular implications of a trans/interdisciplinary approach is recommended (Colucci-Gray et al., 2017).

Creativity

The inclusion of creativity is a key aspect of development and learning, and it is understood as essential for advancement and innovation (Perignat & Katz-Buonincontro, 2019). A thorough revision of the approach to creativity in education has been underway since the beginning of the 21st century (Hernández-Torrano & Ibrayeva, 2020). Several models with different dimensions have been proposed, as well as adaptations to the field of education (Glaveanu & Beghetto, 2020; Craft, 2001). Beyond its conception, the measurement and evaluation of creativity are also complex issues.

A systematic review conducted over the decade 2010-2020 on creativity in STEM and STEAM (Aguilera & Ortiz-Revilla, 2021) found that: the interventions have contradictory forms, both in theory and practice; that there is diversity in the measurement tools used; and that while STEM focuses more on the products created by learners, STEAM interventions pay greater attention to the context and the learning process, as well as the development of personal creativity. In relation to STEAM specifically, another systematic review found that the theme of "creativity" is a common thread in research on STEAM Education (Marín-Marín et al., 2021). Several studies show that the inclusion of the arts fosters creativity and self-efficacy, generating positive emotions and innovation (Conradty et al., 2020; Allina, 2018). Others highlight the positive interaction between creativity, motivation, and transdisciplinary integration (Lage-Gómez & Ros, 2023).

Equity and Vocations

From its inception, STEM education has been seen as an opportunity to encourage all students to be more engaged in their scientific and technological learning while also fostering interest in these fields. The concept of STEAM was introduced to better include girls, given their generally positive attitudes towards the arts. Girls tend to enjoy art more, exhibit greater confidence in their artistic abilities, and place greater value on art than boys (Pavlou & Kambouri, 2007). STEAM aims to address the well-documented decline in interest in science, particularly among girls and members of non-dominant cultures, during the middle school years (Baram-Tsabari & Yarden, 2011). Various recommendations have been made to promote equity within STEAM, such as fostering community engagement in STEAM learning environments, prioritising inclusive mentorship, integrating identity into maker pedagogies, advocating for the development of multi-institutional networks, and prioritising assessment plans that capture complexities, among others (Castek et al., 2019). As an example, Palid et al. (2023) show that interventions that focus on the successes of minoritised students represent a promising step towards diversity, equity, and inclusion in STEM. Although a systematic review found that gender equity and related topics are key drivers and themes in STEAM research (Marín-Marín et al., 2021), the role STEM/STEAM should play in addressing inequalities remains open to discussion. In addition, special attention is demanded not only when considering gender but also other minorities (Bruijnzeel et al., 2022).

Difficulties of Application

STEM and STEAM instruction in actual classrooms is still quite rare. After a systematic literature review, Margot & Kettler (2019) found that teachers reported barriers including pedagogical, curricular, and structural challenges, as well as a lack of teacher support. Furthermore, difficulties exist in selecting appropriate topics, developing educational materials (Hong, 2017), and assessing learning across multiple processes, instruments, and agents (Portillo-Blanco et al., 2024). Finally, there is a lack of knowledge about the content itself, about the pedagogical content knowledge related to it, and the competencies about the different disciplines that make up STEAM (Toma & Greca, 2018). These difficulties also appear in the meta-analysis by Wan et al. (2023). Additionally, there is a wide variety of methodological strategies for implementation (see the next section), many of which are not well known to teachers, who acknowledge having limited procedural knowledge (Haddad et al., 2022).

STEM education is on the educational agenda in many countries, but little action has been taken to appropriately modify educational systems (Ritz & Fan, 2015). In other countries, there is no national effort to implement STEM/STEAM. Instead, there are various programmes at the regional level or initiatives led by researchers, individual schools, or teachers. Consequently, the appropriateness and validity of many resources and materials labelled as STEM or STEAM are questionable, particularly at the pre- and school stages, where engineering, technology, and design are easily misunderstood and misrepresented (Bagiati et al., 2015). Furthermore, these STEAM activities are not usually well connected to curricular content, so they are often seen as extracurricular, and their assessment is of little relevance to teachers and students.

STEM and STEAM Methodologies

There are many methodological approaches for STEM, as already noted in the literature (NAS, 2014; Thibaut et al., 2018; Larkin & Lowrie, 2023; Portillo-Blanco et al., 2024). In addition, we found that the projects published under the STEAM framework are diverse and adopt different methodologies too. To better understand this complex reality, a classification is presented in Table 2 according to the pedagogical tradition from which they originate: science education, technology and engineering education, arts education, and others. A brief description, along with its strengths and benefits for STEM/STEAM projects, is included. The "Others" section includes additional methodologies considered relevant and/or proposed for more specific purposes, without aiming to be exhaustive.

As can be observed, no section on methodologies in mathematics education is included. Other studies already indicate that mathematics is less often considered within STEM and is sometimes used merely as a tool (Portillo-Blanco et al., 2024; Forde et al., 2023; Jumini et al., 2022). Few studies choose mathematics as the "backbone" of their projects (Martín-Páez et al., 2018) or as the axis of their methodological approach (Marín- Marín et al., 2021).

Table 2

Categorization of methodologies in STEM/STEAM education

	Description	Strengths
Methodologies from Science Education		
Inquiry and the 5E Instructional Model for STEM (Bybee, 2019; Leung, 2020; Conradty & Bogner, 2019; Bush, Cook et al., 2016; Toma & Greca, 2018)	The inquiry focuses on developing scientific research processes in the classroom, with an emphasis on promoting conceptual change. 5E has 5 phases with specific functions: engage-(preconceptions and motivation), explore (manipulation and inquiry), explain (new concepts and guided learning), elaborate (extend to a new challenge), and evaluate.	• One of the most widely used methodologies in Science Education • Strong support that enhances mastery of the subject and scientific reasoning, even long-term benefits on conceptual knowledge. Also fosters interest in science • Already adapted to STEM projects
Project-Based Learning (Capraro et al., 2013; Tseng et al., 2013; Lu et al., 2021; Han et al., 2015).	Learners construct knowledge through teamwork and problem-solving using scientific methods within a constructivist framework, creating a creative artefact.	• Widespread in Science and Engineering Education. In fact, it facilitates the connection between the two disciplines • Connected to real-world problems fosters positive attitudes to Science and Technology • Probably the most common methodology in STEM • Benefits for low-performing pupils.
Methodologies from Technology and Engineering Education		
Design Thinking and Design-Based Learning (Henriksen, 2017; Hynes et al., 2011; Chin et al., 2019).	A collaborative process to develop and test solutions to real problems. Typically follows an iterative process: defining problems, forming ideas, conducting research, creating prototypes, and testing solutions.	• Clear connection to real-world problems. • Address Engineering problems through design. • Emphasises learners' communication and collaboration. • Improve problem-solving even among lower-achieving pupils.
6E Learning byDeSIGN™	Proposed by the International	• Emphasise problem-based learning,

(Burke, 2014)	Technology and Engineering Educators Association, replaces the "elaborate" phase of the 5E model with "engineering" and "enrichment."	designing solutions to real problems. • Potentially share the benefits of the 5E methodology
Computational pedagogy (Psycharis et al., 2020; Chen et al., 2023)	Address real computational problems by using computers or unplugged activities.	• Fosters computational thinking and computational content knowledge • Develops modelling thinking
Digital game-based learning (Gui et al., 2023)	Creates an engaging learning environment that allows learners to interact with game mechanics in a virtual world and provides a meaningful gaming experience.	• Enhances learning motivation. • Learners practice problem-solving skills, develop critical thinking, and foster STEM literacy.
Methodologies from Arts Education		
Transdisciplinary integration (Costantino 2018; De la Garza & Travis, 2019)	The key concept is the usefulness of art in breaking down disciplinary barriers	• Integration of more disciplines. • Specific development of artistic creativities • Correlation between students' involvement in the arts and their performance in maths and science • A strong push from the STEAM movement
Experiential learning (Smith, 2006)	Construct meaning from lived experience	
Lincoln Center model (Holzer, 2005)	Focus on aesthetic education, inquiry and the imagination	
Artful Learning Model™ (LBC, 2008)	Arts are the central ingredient to learning, and using the arts across all disciplines	
Art and Design (Bequette & Bequette, 2012; Keane & Keane, 2016).	Connected to Design Thinking, but to foster creative artistic processes inside STEM, especially through visual solutions using design, and highlighting the value of aesthetics.	
Some other methodologies		
Situated STEM Learning (Kelley & Knowles, 2016)	Grounded within the situated cognition theory, with its key elements being scientific enquiry and engineering design	• Connected to real-world problems. • Potentially share the benefits of design and inquiry methodologies
Equity-oriented STEAM Framework (Jackson et al., 2021; Castek et al., 2019)	Equity is the central axis of the projects.	• Especially concerned with cultural and ethnic diversity. • Draw out relationships around identity in the design of the projects.
iSTEAM (Tsai et al., 2017)	Introduce imagination in the design thinking methodology.	• Try to foster creativity and design skills

The STEAM-5E framework

In the previous review, synthesised in Table 1, five categories of debated aspects in STEM/STEAM education have been identified. Additionally, the strengths of the most commonly used methodologies have been analysed (see Table 2). Based on these findings, this section develops a methodological model, STEAM-5E, that aims to provide a coherent framework aligned with the objectives of STEAM education and to address ongoing debates in the field.

First, the methodological foundation guiding the proposed framework is introduced: the 5E model. The subsequent sections address the debates and topics outlined in Table 1, specifically how STEAM-5E responds to key issues such as the conceptualization of STEAM, disciplinary integration, creativity, and equity—pillars of our framework. Regarding the final category of debate—difficulties of application—specific sections address the design and implementation of educational projects within the STEAM-5E framework. Additionally, guidelines and tools are provided for student assessment and for evaluating projects implemented under this framework from both student and teacher perspectives.

Altogether, this constitutes a coherent and comprehensive methodological proposal that has not been previously developed in STEAM education. An example of a STEAM-5E project designed for primary education is presented. However, it is important to stress that this framework is not limited to this educational stage; we believe it is equally applicable to secondary education.

Methodological Foundation of STEAM-5E

The 5E Instructional Model (Bybee et al., 2006), originating from Science Education in the 1980s, serves as the methodological foundation of this proposal. The model follows five phases: Engage (activating prior knowledge and stimulating interest), Explore (facilitating conceptual change through activities), Explain (constructing explanations), Elaborate (deepening understanding through new experiences), and Evaluate (assessing comprehension).

The 5E model was chosen due to its strong theoretical and empirical support: it is rooted in cognitive theories of memory and learning (NRC, 1999), emphasises motivation and prior conceptions (Bybee et al., 2006), and integrates manipulative and inquiry-based activities essential for science learning (NRC, 2006). The Explore-before-Explain approach promotes meaningful learning and conceptual change in science and mathematics (Sinha & Kapur, 2021), while the Elaborate phase enhances knowledge transfer (Hattie & Yates, 2013). Additionally, the model provides clear instructional guidelines and, despite its origins in science education, is easily adaptable to mathematics education, sharing features with the Singapore method (Yoong & Hoe, 2009).

Empirical studies confirm the effectiveness of the 5E model across multiple domains, including enhancing subject mastery, improving standardized test performance, developing scientific reasoning, fostering interest in science, strengthening understanding of the Nature of Science, and helping teachers implement more effective instructional practices (Bybee et al., 2006). Recent studies provide strong evidence of the long-term positive effects on conceptual learning (Garcia I Grau et al., 2021).

We consider inquiry-based learning the most appropriate methodology during the Explore and Explain phases, especially in science and mathematics disciplines (Crawford, 2000; Bybee, 2006). In contrast, Project-Based Learning and Design Thinking are particularly interesting when teaching Technology and Engineering. This is also considered an appropriate method for developing the arts (Graham, 2021; Henriksen, 2017). Therefore, in STEAM-5E, we propose developing the project for the Elaborate phase using these methodologies. In this phase, we also propose collaborative learning, in agreement with Jolly (2014), who states that STEM focuses more on teamwork and STEAM on collaboration, with the latter being a process with greater benefits for learners who can extend their critical thinking and reasoning skills by being involved in collaborative activities (Veldman & Kostons, 2019).

Finally, in accordance with a transversal perspective on arts, the use of Visual Thinking is proposed to create maps and graphical learning diaries (Rohde, 2013; Megías, 2018). This is an effective way to deepen metacognition through the processes of synthesising, organising, and linking information, and to connect with more emotional learning (Megías, 2020). In addition, the maps and diaries arising from this approach can also serve as an assessment tool, understood as a creative research process (Megías, 2020).

STEAM Conceptualisation in STEAM-5E

STEAM-5E strongly supports the inclusion of A within STEM, understanding A in a broad sense. This includes considering all the arts as valuable in Education (visual arts, architecture, music, performing arts, dance, etc.) but also expanding A in a globalising sense that leads to the consideration of the Humanities in the search for holistic and integrative learning.

Regarding the role of the Arts and Humanities, we view them as equal to the other STEM areas. We value both their own disciplinary sense and their integrative and cross-disciplinary potential. Root-Bernstein (2015) reports a strong correlation between interest in artistic, musical, literary, or craft areas and success in STEM fields.

Regarding technology and engineering, both must be included in STEAM-5E projects. Studies have shown that engineering is rarely addressed in STEM (Bagiati et al., 2015). One possible cause is that in many countries, engineering is not included in curricula, especially at the primary level. Therefore, we propose using the National Assessment of Educational Progress (NAEP) standards for Technology and Engineering Literacy as a guide (National Assessment of Educational Progress [NAEP], 2018).

Disciplinary Integration in STEAM-5E

We propose a progressive approach to disciplinary integration, starting at the discipline-specific level, progressing to interdisciplinary connections, and finally to transdisciplinary integration. Beginning with the Explore and Explain phases in each discipline enables learning to advance across subjects. It is necessary to respect the content, methods, and concepts of the individual disciplines (Kelley & Knowles, 2016). Research indicates that conceptual learning in mathematics benefits from a multidisciplinary approach, where each discipline is purposefully emphasized within a unit and aligned with explicit student learning outcomes (Baldinger et al., 2021). Later, it becomes possible to establish strong relationships between different disciplines, which must be explicitly addressed. In the elaboration phase, transdisciplinary integration is achieved, fostering collaboration between scientific-technological and artistic fields (Chapell et al., 2019) and approaching solutions to complex problems through creative thinking (Costantino, 2018). This progression of complexity and level of integration is supported by cognitive learning theory (Salden et al., 2006).

Creativity in STEAM-5E

As mentioned above, several models address creativity in education, and discussions within the STEAM community address its implementation. Among them, in STEAM-5E, we highlight two key aspects to consider about creativity in the design, development, and implementation of a STEAM project (Figure 2):

I. Creative Domain: Glaveanu (2018) proposes the existence of three creative domains based on a historical review of different models and constructs on creativity. These domains are artistic, scientific, and craft creativity. The main traits of each dimension are shown in Figure 2. This conceptual framework aligns with the STEAM-5E model, which necessarily includes arts, science, and engineering. Thus, creativity from all disciplines is demanded by several authors (Graham, 2021).

II. Creative person or group: the person or creative group is analysed considering both cognitive and conative traits following Lubart & Thornhill-Miller (2019). In this way, the dual analysis of creativity from individual and distributed (group) perspectives relates to the conception of the school as a social space.

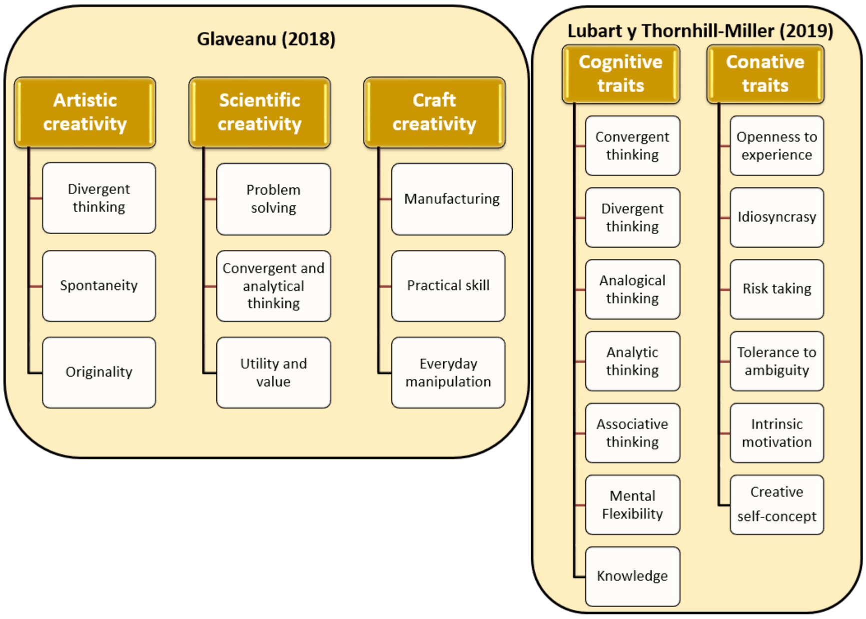
This conceptual framework has already been recognised for analysing creativity across various STEAM projects, both by examining how different disciplines contribute to distinct traits of creativity and by studying the interrelationships between them (Lage-Gómez & Ros, 2024).

Equity in STEAM-5E

In the STEAM-5E framework, equity is a fundamental pillar, as it should be a primary goal of education in the 21st century. Several recent studies note that these aspects of equity and diversity are not sufficiently addressed in current projects (Bruijnzeel et al., 2022; Palid et al. 2023). Therefore, any STEAM-5E project must explicitly include activities, discussions, and attitudes that demonstrate a commitment to equity, particularly gender equity. Research such as that done by Bian et al. (2017) demonstrates that gender stereotypes about intellectual abilities arise during childhood and impact the later interests of boys and girls. It is therefore essential for a STEAM project to create opportunities and visibility for the work of women scientists, mathematicians, and engineers to encourage girls' interest in experimental science and engineering.

Figure 2

Conceptual framework for creativity in STEAM-5E



Design and Implementation of a STEAM-5E Project

There are many difficulties in implementing a STEAM project as discussed previously. From the STEAM-5E perspective, we propose the Design-Based Research (DBR) approach as a guide for the design and implementation of STEAM-5E projects.

Design-Based Research (Design-Based Research Collective [DBRC], 2003) is a design and research methodology that guides the educational research process, aiming to connect major theories of teaching and learning with specific conceptual challenges in real-world contexts. Its goal is to bridge the gap between research and practice. DBR places significant importance on involving teachers in the research, fostering communities of practitioners, and promoting partnerships between university researchers and schoolteachers. Essentially, DBR proposes a design phase that considers theoretical evidence, followed by an iterative implementation phase for refinement.

In the STEAM-5E model, projects should be led by teams of researchers specialising in the relevant educational fields. This ensures that the projects are designed with adequate pedagogical content knowledge of each discipline. These researchers also serve as guides for teachers, helping them correctly apply the methodology. It is recommended to organise coordination meetings and training courses that allow teachers to expand their conceptual and pedagogical knowledge and strategies. This helps them overcome the challenges raised by various authors (Quigley & Herro, 2016; Toma & García-Carmona, 2021).

Teachers bring deep knowledge of the classroom and curriculum requirements, and collaborate with researchers in the essential process of translating content into teaching materials. They ensure the sequencing and appropriate cognitive and procedural levels of the content, ensuring coherence (Roehrig et al., 2021). This collaboration results in valid materials that can be used in other contexts. Establishing this relationship from the beginning of the process also ensures the indispensable collaboration of schoolteachers and the management team in terms of using appropriate spaces and adapting schedules, which may be necessary to carry out the project.

Assessment

Figure 3 summarises the assessment approach in STEAM-5E, which is based on continuous, processual, and formative assessment. Feedback and metacognition play a central role in dialogical interactions among students and between students and teachers. Feedback should go beyond the task itself to include the process, metacognitive strategies, and students' approach to learning (Martín, 2020). Qualitative feedback is preferred over quantitative assessment (Martín, 2020).

Metacognition is developed throughout the project via discussions, group debates, and guided questioning, allowing learners to reflect on their learning. The Visual Thinking methodology is implemented at the end of each subject's activities (after the Explain phase) and at project completion (during the Evaluate phase). During the Elaborate phase, pupils engage in metacognitive processes such as planning tasks, selecting strategies, executing plans, monitoring progress, and making adjustments (Martín, 2020).

Regarding what to assess, STEAM-5E projects align with educational curricula, enabling teachers to use their standard tools (e.g., observations, written tests, assignments, and presentations) to evaluate both conceptual and procedural learning. A marking key (see Supplementary Material) is proposed in the Elaborate phase to assess group performance (e.g., project planning, design, construction, and communication) and individual contributions (e.g., motivation, participation, and teamwork). A dual individual and group evaluation approach is recommended as the most suitable and complementary method for assessing complex STEM projects (Han et al., 2021).

Finally, a crucial aspect of assessment is the development of positive attitudes, including enjoyment, interest, self-efficacy, and expectations toward the disciplines involved. Attitudes play a key role in fostering future vocations (Archer et al., 2020) and in preventing early dropout (Vázquez & Manassero, 2008). We propose using three statistically validated questionnaires from the literature to assess the impact of STEAM-5E projects on learners' attitudes (see Table 3). These questionnaires are validated for similar age groups and use a consistent scale, ensuring a uniform and reliable analysis.

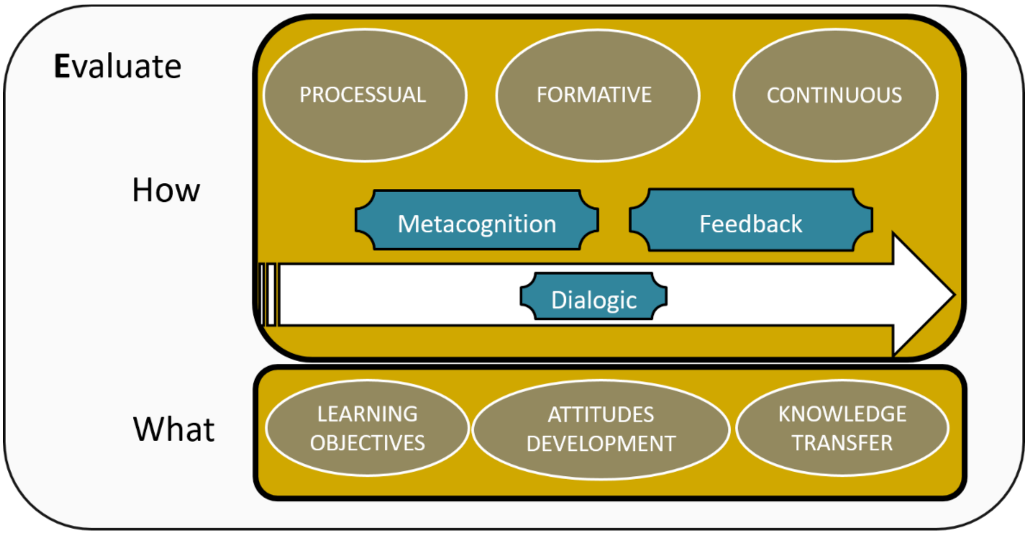
Table 3

Questionnaires are needed to assess the development of attitudes towards STEAM areas.

Questionnaire	Dimensions	Comments
S-STEM questionnaire (Unfried et al., 2014)	Attitudes towards STEM areas (Science, Mathematics, Engineering, and Technology)	• It focuses on self-efficacy and utility • Two versions: one for primary school (4-5th grade) and the other for high School (6-12th grade) with little differences • 26 items (8 for maths, 9 for science, 9 for engineering) • 1-5 Likert scale • Also includes 13 items about 21st-century skills
Students' attitudes towards art teaching in primary school (Pavlou & Kambouri, 2007).	Enjoyment, confidence, usefulness, and support are needed	• We consider here only the first three dimensions • 34 items (9 for enjoyment, 8 for confidence, 10 for usefulness, and 7 for support needed). • 1-5 Likert scale • We think it could also be appropriate for junior high school
Pupils' attitudes to school and music at the start of secondary school (Kokotsaki, 2016).	Liking music and making music	• We think it could also be appropriate for the last years of primary school • 13 items (7 for liking music and 6 for making music) • 1-5 Likert scale

Figure 3

Assessment in STEAM-5E



Evaluation of the STEAM-5E Project by Students, Teachers, and Researchers

The evaluation of the project itself is an essential element in STEAM-5E. The way it is carried out must necessarily be the product of joint reflection by teachers and researchers, again in accordance with the spirit of the DBR, and must include the students' perspective. Two questionnaires have been designed for this evaluation: one to collect students' perspectives (Appendix 2) and the other for the teachers involved in the implementation (Appendix 3). A description of the dimensions and items of both questionnaires is given in Table 4.

Table 4

Description of the questionnaires designed to evaluate STEAM-5E projects

Questionnaire for students (see Appendix 2 in supplementary material)	
Dimension	Number of items
Self-regulation (Metacognition, emotions, and motivation)	9
Disciplinary integration	6
Creativity	7
Contextualisation and transfer of knowledge	4
Working groups	4
Global assessment	7
Questionnaire for teachers (see Appendix 3 in supplementary material)	
Dimension	Number of items
Motivation	5
Disciplinary integration	3
Creativity	16
Collaboration	3
Competences and contents	13
21st century skills	18
Methodology	9
Timing and Resources	7
Support and relationship of the researchers and schoolteachers	11

As can be seen, both questionnaires are multidimensional and address the fundamental pillars that these projects aim to develop (self-regulation, motivation, creativity, and disciplinary integration) and include an in-depth evaluation by the teachers on the methodology, the compliance of the curriculum, and other aspects related to the implementation (spaces, schedules, relationship with the researchers. Both questionnaires use a 4-point Likert scale, so there is no 'neutral' option. The content validation of the questionnaires followed a structured process:

1. Expert Self-Assessment (Cruz Ramírez & Martínez Cepena, 2012): Experts' competence coefficient (ranging from 0 to 1) was determined based on their self-reported knowledge of the research problem and the sources supporting their evaluation criteria. A minimum threshold of 0.75 was required for inclusion in the validation process, resulting in the exclusion of three of the nine pre-selected experts.
2. Item Review: Experts were invited to provide comments on each item, which facilitated minor revisions for improved clarity.
3. Content Validity (Escobar-Pérez & Cuervo-Martínez, 2008): The selected experts rated each item on a 1-to-4 scale across four dimensions: clarity, sufficiency, relevance, and coherence. The Content Validity Index (CVI) was calculated as the ratio of the total points obtained to the maximum possible score. A CVI above 0.80 indicates a high level of agreement (Sangoseni et al., 2013). Only three items narrowly fell below this threshold. However, given their minor deviations and the need to maintain questionnaire completeness for reliability purposes, these items were retained with slight wording modifications.

Finally, we recommend that researchers conduct interviews with several groups of pupils and teachers after analysing the questionnaires. Qualitative information is highly valuable for improving the project in future implementations, as it helps to understand the quantitative results better and evaluate the processes developed during project implementation.

STEAM-5E at a Glance

Figure 4 summarises the core principles of the model, where all STEAM disciplines are considered equally, and the A represents the potential inclusion of all disciplines. The methodological foundation is the 5E model, with Project-Based Learning (PBL) and Design Thinking (DT) incorporated into the Elaborate phase. Activities should primarily be manipulative and guided by inquiry-based learning, supplemented with collaborative work, visual thinking tools, and dialogic processes to foster student motivation, metacognition, and meaningful learning.

For disciplinary integration, the model begins with a disciplinary approach, progressing to interdisciplinary connections in the Explore and Explain phases, and culminating in transdisciplinary integration in the Elaborate phase. The development of STEAM-5E projects should adhere to Design-Based Research (DBR) principles to ensure rigorous design, implementation, and evaluation.

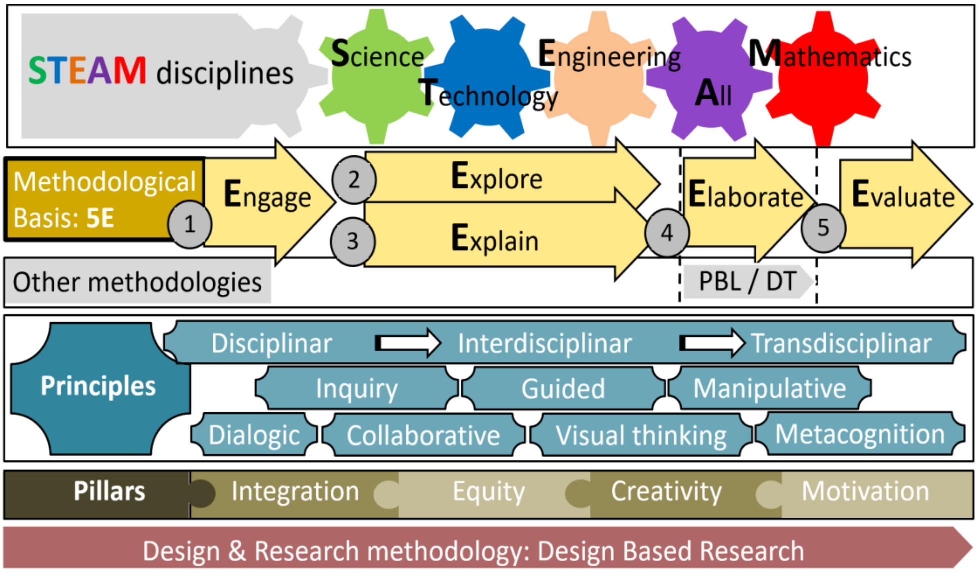
This approach aims to fulfil the core objectives of STEAM education, including effective disciplinary integration, fostering diverse forms of creativity, promoting equity, and cultivating positive attitudes toward learning.

A STEAM-5E Project for Elementary Education – "Machining" in Ancient Egypt

This section presents "Machining in Ancient Egypt," a STEAM-5E project designed for pupils aged 9-11. Developed by specialists in mathematics, science, music, arts, engineering, and technology education—alongside an expert in educational psychology—the project also involved collaboration with three primary school teachers. To facilitate implementation, video tutorials and worksheets for both teachers and students have been created (https://youtube.com/GRUPO-ICC-UAH, see list "Maquinando en el Antiguo Egipto"), ensuring accessibility for other schools.

Figure 4

The STEAM-5E methodological framework



The project spans around 50 one-hour lessons over 7-8 weeks, following the 5E instructional model (see Figure 5):

✓ Engage (2 hours): A gymkhana activity introduces key concepts through card games and manipulative materials, fostering motivation. Themes such as the plundering of Egyptian heritage and the role of female pharaohs are introduced.

✓ Explore & Explain (30 hours): Each subject covers specific content aligned with the official syllabus, including simple machines (Science), fractions and decimals (Maths), and musical instruments, voices, and qualities of sound (Music). A digital music score reader is created using a Microbit card and MakeCode, integrating programming and electronics. Inquiry-based, hands-on, and interdisciplinary activities reinforce learning.

✓ Elaborate (10 hours): Following Project-Based Learning (PBL) principles, pupils collaboratively reconstruct Abu Simbel using educational materials, applying knowledge from previous phases. The project emphasises teamwork, planning, and organisation while revisiting cultural heritage and gender roles in Ancient Egypt.

✓ Evaluate (8 hours): Pupils create a visual notebook and a collaborative visual map based on Visual Thinking principles. Traditional assessments, along with rubrics and questionnaires, measure knowledge transfer, attitude development, and overall project effectiveness.

This project was implemented in two schools during the 2021–22 academic year. Previously, activities related to simple machines and the digital music score reader were tested, reassessed, and redesigned following the Design-Based Research process. As a result, one article has already been published (Ros et al., 2022) and another is currently under development. Additionally, another publication has analysed pupils' self-regulation processes within this project using the instruments outlined in previous sections (López-Carrillo et al., 2024). Furthermore, aspects such as creativity, disciplinary integration, the associations between these dimensions, and the evaluation by participating teachers have been analysed and presented preliminarily at several national and international conferences (Ros et al., 2022, Ros et al., 2023). Several articles on these topics are currently being prepared for submission.

Conclusions and Implications

Given the diversity of definitions, goals, objectives, methodologies, and proposals within the STEM and STEAM paradigms, and given the demand for coherence within the community, this paper analyzes the main issues currently under debate in these paradigms, as well as the methodologies proposed. The analysis is conducted through a narrative and critical review of the literature following the qualitative content analysis approach. Other reviews have recently been conducted in the STEM field (Potillo-Blanco, 2024; Aguilera et al., 2024; Wan et al., 2023; Larkin & Lowrie, 2023). However, this work delves into the STEAM approach, incorporating a broader, more critical perspective that enables categorization and deeper exploration of the current points under discussion within the scientific community. Thus, this work sheds light not only on the complex landscape of STEM and STEAM education but also on their essential components.

First, we identify several key points of debate within the community: i) conceptualization, including the diversity of conceptual interpretations of STEM and STEAM, the discussion on the role of the Arts, the possible inclusion of the Humanities, and the conception of Engineering and Technology; ii) the disciplines included and their different modes of curricular integration (multi-, inter-, and transdisciplinary); iii) how to understand and address creativity; iv) how to promote equity; and v) difficulties in implementation, including challenges related to student assessment and project evaluation.

Second, we classify methodologies by educational tradition and summarize their strengths. We distinguish between those coming from Science Education (Inquiry, 5E, PBL), Engineering Education (Design Thinking, Design Learning, 6E Learning by Design, Computational Pedagogy, Digital game-based learning), those focused on arts (Transdisciplinary approaches, Experiential Learning, Arts and Design, the Lincoln Center Model and the Artful Learning Model), and some other approaches.

Third, a new methodological model is proposed to address the issues discussed and to bring together the benefits of the methodologies analysed. Essentially, it is based on the 5E methodology adapted to STEAM, with the real integration of all STEAM disciplines in a broad sense, the development of creativity from its multiple facets, special consideration for equity, and the search for student motivation through inquiry, manipulative activities, and collaborative work. All of this is guided through metacognition and dialogic processes. We propose the Design-Based Research methodology guide as a tool for designing educational projects under this model and for subsequent research analysis. Additionally, a project developed within the STEAM-5E model and implemented in primary education is presented, along with references to the results.

The study presents some methodological limitations. As with any narrative review, it is not exhaustive and may be subject to author bias, although we have detailed the criteria and procedures used to minimise such bias. Furthermore, the analysis is not intended to be generalizable; however, the rigorous process and the comparison with recent meta-analyses help ensure a certain level of consensus.

This work contributes to educators and researchers by providing a model for developing both teaching practices and educational research. In the first case, the model serves as a guide for creating educational materials and projects, including criteria and a rubric for students' assessment. We believe it is also sufficiently flexible to adapt to both primary and first-year students in secondary education, despite differences in teacher training and the organisational structures of their institutions.

Figure 5

Pictures of the STEAM-5E Prosubject "Machining" in ancient Egypt

In the second case, the model proposes a methodological research process based on DBR, offering tools (validated questionnaires for teachers and students) to evaluate the success of projects in various aspects that are currently hot topics in educational research, such as curriculum integration, the development of creativity, and the promotion of positive attitudes towards the diverse areas of STEAM. Moreover, several results from the implementation of a project under the STEAM-5E model have already been published, with others in progress, underscoring the feasibility and validity of the proposed model.

Acknowledgment

The authors would like to thank the Instituto Universitario Mixto de Investigación en Educación y Desarrollo Daisaku Ikeda (IEDDAI) (https://institutoikeda.uah.es/), associated to the University of Alcalá, for their support.

Funding

This work was supported by Comunidad de Madrid and Universidad de Alcalá under Grant CM/JIN/2019-024.

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Appendix 1

Rubric for the Elaborate Phase

PHASE	**Can be improved**	**Satisfactory**	**Excellent**
Group Evaluation			
A) Approach, planning, and design	1. They understand the problem posed with help. 2. Identify necessary tasks and order them with assistance. 3. Establish some criteria for success with help.	1. They understand with little help the problem posed. 2. Identify necessary tasks and order them with little assistance. 3. Establish some criteria for success.	1. Understands without help the problem posed and/or can support other classmates who have more difficulties. 2. Identify and correctly order the necessary tasks. 3. They establish valid and sufficient success criteria. 4. They can perceive and raise
B) Information search	1. They consult a single source of information. 2. They have difficulties in selecting the most relevant information.	1. They consult a few sources of information. 2. They select the most relevant information.	1. They consult various sources of information. 2. They select very relevant information. 3. They value the information
C) Construction	1. They have difficulties applying what they have learned in the project for the construction of the temple. 2. There is no logical order in the construction of your section. 3. The division of tasks has not been clear.	1. They apply in part what they have learned in the project for the construction of the temple. 2. They follow a logical order in the construction according to the established stages most of the time. 3. The distribution of tasks is valid but can be optimized. 4. Errors have been corrected, but with little foresight.	1. They apply what they have learned correctly in the construction of the temple. 2. They follow a logical order in the construction according to the established stages. 3. They carry out an adequate distribution of tasks and use of time. 4. Evaluate the process to correct mistakes and make new decisions.

D) Evaluation	1. The result of your template section is correct, but very improvable. 2. They check the result and correct some mistakes promptly. 3. They collaborate in a not very active way with the rest of the groups in the construction of the temple. 4. The result is technically and artistically valid	. The result of your temple section is adequate. 2. They check the result and correct some mistakes. 3. They collaborate with the rest of the groups in the construction of the temple. 4. The result is technically and artistically adequate.	1. The result of your section of the tem999ple is entirely satisfactory. 2. They check the result, re-evaluate, and correct errors satisfactorily. 3. They collaborate optimally with the rest of the groups in the construction of the temple. 4. The result is optimal from the technical and artistic point of view.
E) Communication	1. They consult the source of the information provided. 2. They have an idea to answer the question posed. 3. They have some idea about the conclusions of the project.	1. They consult the source of the information provided and know how to explain it adequately. 2. They have several ideas to answer the question posed and discuss them. 3. They have several ideas about the conclusions of the project and discuss them.	1. They consult the source of information provided and other additional information and know how to explain it adequately. 2. They have several ideas to answer the question posed, discuss them, and decide on the most relevant ones. 3. They have several ideas about the conclusions of the project, discuss them, and decide on the

Individual Evaluation	
1. Show interest in the project. 2. Helps the group to achieve the objectives. 3. Collaborate with peers.	1. Shows a high level of interest in the project. 2. Strives to achieve goals. 3. Promotes interest among peers. 4. Argue based on acquired knowledge
1. Takes responsibility for the work assigned to them and carries it out appropriately. 2. Participates in group discussions and decision-making. 3. Supports your peers.	1. Takes responsibility for the work assigned to them and performs it to the best of their ability. 2. Actively participates in group discussions and decision-making. 3. Supports peers and exercises some leadership in the group.
1. Adequate participation in a small group. 2. Appropriate large group participation. 3. Collaborate in class discussion.	1. Active participation in a small group. 2. Active participation in a large group. 3. Collaborate in class discussion by expressing ideas with fluency and rationale.

Note: the teacher must assign a level of achievement by assessing the aspects indicated, considering which level is closest, i.e., it is not necessary to 5 meet all the items of the "excellent" level to achieve that assessment.

	Motivation Transfer	1. Shows moderate interest in the project. 2. Moderately helps the group to achieve the objectives. 3. Does not collaborate actively with
	Teamwork	1. Takes partial responsibility for the work assigned to them. 2. Participates little in group discussions and decision-making. 3. Little support for their teammates.
	Participation	1. Little participation in a small group. 2. Little participation in a large group.

Appendix 2

Questionnaire on STEAM-5E Projects for Students

Likert scale. 1 means minimum agreement, and 4 means maximum agreement (except questions V2 to V7 as indicated).

Name:

Class:

Gender:

Indicate your degree of agreement with the following statements related to the project:

Code	Item	CVI
1) SELF-REGULATION (Metacognition, emotions, and motivation) During the activities:		
A1	I was aware of what was clear and what was not	.91
A2	I noticed the mistakes I made and tried to fix them	.90
A3	I think I learn more by working this way than the usual way	.85
A4	I found the project very attractive	.84
A5	I had fun and enjoyed the proposed activities	.85
A6	I have felt capable of carrying out the proposed tasks	.88
A7	I believe that what I have learned will be useful to me in the future	1
A8	I have been able to make choices when doing the activities	.81
A9	I felt guided by the teachers	.92
2) DISCIPLINARY INTEGRATION		
I1	We have related content from different areas (Mathematics, Science, Plastic Arts, Music, Engineering, and Technology).	.79
I2	I have enjoyed working on Mathematics, Science, Art, Music, Engineering, and Technology in the same project.	.95
I3	This way of working has helped me better understand the content.	.90
I4	In the final project, we have applied what we have learned during the previous project classes	.85
I5	In the final project, we have extended what we have learned during the previous project classes	.85

I6	In the final Visual Thinking, we have represented what we have learned in the whole project	.97
3) CREATIVITY		
C1	During the project, I have acted as an engineer (designing, constructing, and testing)	1
C2	During the project, I have acted as a scientist (experimenting, formulating hypotheses, and drawing conclusions).	.86
C3	During the project, I have acted as a mathematician (working with numbers and representing data).	.89
C4	During the project, I have acted as an artist using various art forms	.88
C5	What I have learned has allowed me to do something new.	.89
C6	I felt free to propose ideas and solutions	.84
C7	I enjoyed creating things with my hands and seeing them work	.78
4) CONTEXTUALIZATION AND TRANSFER OF KNOWLEDGE		
CT1	The project has included elements that connect to real-world situations or problems.	.85
CT2	I think I can apply what I have learned to other similar situations	.99
CT3	Now it is clearer to me what engineering is and what it does.	.97
CT4	I think what I have learned will be useful in the future.	.88
5) WORKING GROUPS		
G1	I enjoyed working on individual tasks on my own.	.97
G2	I enjoyed working as part of a team with my colleagues.	.98
G3	I enjoyed solving problems as part of a team.	.95
G4	I felt part of the team in the group work.	.99
6) GLOBAL ASSESSMENT		
V1	I would like to continue learning in this way in the future	.99
V2	I have felt guided by the teachers.	.98
V3	I found the project fun.	.92
V4	I found the project easy.	.88
V5	I found the project original.	.89
V6	I found the project useful.	.93
V7	I found the project innovative.	.99

Appendix 3

Questionnaire on STEAM-5E Projects for Teachers

Likert scale. 1 means minimum agreement, and 4 means maximum agreement.
Age:
Gender:
Years of teaching experience:
Civil servant/interim/employee:
Indicate the subject(s) you teach at the school:
Number of years in the school:
Type of centre where you work (public, private):

1. Assessment of the project from the teachers' own perspective

Code	Item	CVI
1) MOTIVATION		
Mot1	I find the project stimulating as a teacher	.96
Mot2	It motivates me to work in this way	.82
Mot3	It has given me a feeling of satisfaction	.87
Mot4	This way of working has brought new elements to my teaching practice	.88
Mot5	My expectations have been largely fulfilled	.76
2) DISCIPLINARY INTEGRATION		
I1	An inter/transdisciplinary integration has been achieved in the project	1
I2	The different areas have been worked on in a balanced way	1
I3	A holistic approach has been used in the project.	.97
3) CREATIVITY		
CR1	The project has provided the right environment for the proposal of ideas	.99
CR2	Students have been able to develop divergent thinking strategies.	.97
CR3	Problem solving strategies have been applied.	.97
CR4	There have been several creative processes throughout the project.	1
CR5	Students have been able to develop analogical thinking strategies (seeing and using structural, logical or symbolic parallels or similarities between ideas or systems).	.97

CR6	Students have been able to develop convergent thinking strategies (identifying the best solution among possible solutions).	1
CR7	Students have been able to develop analytical thinking strategies (examining information and evaluating its strengths and weaknesses).	.97
CR8	Students have been able to develop associative thinking strategies (making connections between ideas or areas).	.95
CR9	Students have been able to develop cognitive skills such as flexibility (diversity of perspectives) and the ability to adjust their thinking to new information.	.95
CR10	Students have been able to develop cognitive skills such as using their own knowledge (to understand a problem and synthesize a solution).	.94
CR11	The project has encouraged students to interact with the world around them in new ways.	1
CR12	The project has fostered a taste for new experiences and stimuli.	1
CR13	The project has encouraged a taste for risk in the face of a new challenge.	.99
CR14	The project has fostered tolerance of ambiguity (with experiences that could be relatively uncertain).	.99
CR15	The project has fostered the development of intrinsic motivation (e.g., satisfaction with achievements or generating interest in certain topics).	1
CR16	The project has fostered a high creative self-concept (the student has felt creative, in general or in a specific domain).	1
4) COLLABORATION		
Co1	Collaborative situations between students have been encouraged	.98
Co2	Teamwork skills have been fostered.	.99
Co3	The development of positive values among the students has been encouraged	.95
5) COMPETENCES and CONTENTS		
CC1	The project adequately covered many of the curricular evaluable learning standards established for the course, term, and subjects included in the project.	.9
CC2	The fact that this project is embedded in the curriculum is a very important positive element	.8
CC3	The conceptual contents (knowledge) have been worked satisfactorily	1
CC4	The procedural content (know-how) has been satisfactorily worked on.	1
CC5	Attitudinal contents (knowing how to be) have been worked satisfactorily.	1
CC6	Technology and engineering content have been successfully incorporated.	.94
CC7	The key competence of *learning to learn (LL)* has been satisfactorily developed	1
CC8	The key competences in *mathematics and basic competences in science and technology (CM)* have been satisfactorily developed.	1
CC9	The key competency of *cultural awareness and expression (CC) has been* satisfactorily developed.	1
CC10	The key competences, *social and civic competences (CS),* have been satisfactorily developed.	1
CC11	The key competence of *sense of initiative and entrepreneurship (SI)* has been satisfactorily developed	1
CC12	The key competence, *linguistic and communicative competence (CL),* has been satisfactorily developed.	1
CC13	The key competence, *digital competence (CD),* has been satisfactorily developed	1
6) 21st CENTURY SKILLS: Assesses whether the project has developed the following skills in students:		
S1	Curiosity	1
S2	Critical thinking	.92
S3	Troubleshooting	.92
S4	Quantitative Reasoning	1
S5	Logical thinking	.97
S6	Innovation ability	.97
S7	Apply and create technology	.98
S8	Decision-making and autonomy	1
S9	Initiative and entrepreneurship	.99
S10	Communication skills	.95
S11	Organizational skills	.87
S12	Empathy	1
S13	Adaptability	1
S14	Leadership	1
S15	Acceptance of diversity	.95
S16	Social, cultural, and environmental responsibility	.80
S17	Scientific, numerical, technological, and cultural language.	.86
S18	Gender equality	.97
7) METHODOLOGY		
Me1	The methodological framework of the project (5E) seemed to me to be the right one.	1
Me2	The approach of the project encourages students to learn the contents in a meaningful way	1
Me3	The methodological techniques and tools were appropriate to each type of activity	1
Me4	Activities have been carried out in which the students are the main subject of their learning	1

Me5	Students have developed experimentation and manipulation skills	.94
Me6	Students have developed logical and mathematical reasoning skills	.94
Me7	Students have developed artistic and musical expression skills	.94
Me8	The project has enabled adaptation to students' different skills and abilities.	1
Me9	The project has been adapted to the different learning rhythms of the students	1
8) TIMING AND RESOURCES		
TR1	The timing of the project has been adequate	.99
TR2	Working in the proposed way has not meant spending much more time in class to develop the syllabus as usual.	.97
TR3	The resources (materials, digital, personal, and spaces) used for the project have been adequate.	1
TR4	The worksheets and materials designed for the project have been appropriate for the level	1
TR5	The worksheets and materials designed for the project have been attractive	1
TR6	The worksheets and materials designed for the project have been coherent	.99
TR7	The cards and materials designed for the project have been original	.92
2. Assessment of the support and relationship of the researchers to schoolteachers		
Code	**Item**	**CVI**
SR1	Throughout the project's development, teachers have been involved in decision-making.	1
SR2	The opinions and suggestions of the teachers and the school have been included.	1
SR3	The project as a whole has been an enrichment for my professional work.	1
SR4	The project has been well adapted to the needs of the school	1
SR5	I believe that it has been a project of mutual collaboration between the school and the University	.99
SR6	The interrelation between the University researchers and the teachers has been very fruitful.	1
SR7	The involvement of the University researchers has been high.	1
SR8	The training courses have been very fruitful	1
SR9	The help of the University researchers during the lectures has been a great support	1
SR10	I would recommend that other schools implement this project.	1
SR11	I feel able to do the project on my own in the future.	.99