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Systematic Review

A Systematic Literature Review of Integrated STEM Education: Uncovering Consensus and Diversity in Principles and Characteristics

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Abstract: Integrated STEM education is increasingly present in classrooms and in educational research, as it is proposed as a possible strategy to improve the problems of students' lack of interest in scientific–technological disciplines. However, this increased interest in STEM education has been paralleled by a loss of cohesion in the interpretations of its theoretical basis and by an ongoing discussion on integrated STEM education's foundations, making its understanding, translation into real projects, and evaluation difficult to undertake. Published articles defining a STEM theoretical framework have different descriptions, so the aim of this systematic literature review is to analyse these explanations and compare them with each other. Following the PRISMA 2020 guidelines, 27 articles of interest about STEM and STEAM education were obtained and analysed with a focus on the principles and characteristics described in the texts. After organising the information and analysing the similarities and differences in the principles and characteristics, we concluded that there is great consensus on the principles of "integration", "real-world problems", "inquiry", "design", and "teamwork". Nonetheless, this review identifies areas of discussion regarding both the principles and their characteristics that invite further analysis to refine our understanding of what integrated STEM education should entail.

Keywords: STEM education; integration; theoretical frameworks; principles; systematic literature review; primary and secondary education; integrated STEM

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1. Introduction

The increasing importance of the STEM education movement in our society, focused on the integration of its different fields (science, technology, engineering, and mathematics), is a response to social and labour market changes that have led states, education systems, and individuals to adapt to new challenges [1]. Given the impact of STEM sectors on the economic and social development of countries, several studies present the need to prepare qualified professionals for emerging STEM jobs [2–5]. Nevertheless, beyond workforce demands, STEM education also seeks to address a broader societal need focused on global STEM literacy, ensuring that all citizens acquire the essential knowledge and skills for active participation [6,7].

Nevertheless, the enrolment and interest of students in STEM disciplines has been declining [5,8–10]. Authors have suggested that this decrease could be due to a current education system based on outdated curricula and a teaching system that is far from developing essential skills [2,4,11]. Therefore, a unique approach to STEM education emerges as a possible solution that could stimulate students' interest in science and technology studies while addressing the problems and developing the skills demanded by today's society [4].

Recent education reforms have switched from a content-centred system to one that focuses on competence development [10]. This shift is crucially important, as it recognises that content knowledge and technical skills, in isolation, are of limited utility. To be truly effective, they must be complemented by so-called 21st century skills or competences, such as problem solving, communication, and critical thinking [11–13]. The competence development requires a change from the traditional transmission of theoretical content in learning and teaching methods towards a more contextualised approach applied to real-world scenarios and incorporating active educational strategies [14,15]. In integrated STEM education, the development of interdisciplinary projects emerges as a key factor to achieve contextualised competence development. The interdisciplinary project-based learning approach, among other methodologies, helps give students a tangible understanding of the interconnectedness between their learning, real-world applications, and the integration of knowledge across subjects [4]. Thus, it is presented as being an interesting and useful complementary educational methodology to use with students.

Although the concept of integrated STEM education originated as early as the 1990s, interest in it has grown in recent years, driven by changes in educational approaches, together with the growth of research in this field. Numerous studies have demonstrated the positive influence of the integrated STEM education approach on students' motivation, attitudes, and performance in related disciplines [16–19]. In particular, significant improvements have been observed among female students and minority groups, addressing the challenge of low diversity in STEM fields [20,21]. On the contrary, some cases remain in which such positive effects are not observed, but instead authors identify negative or neutral impacts when implementing integrated STEM education [22–25]. As Millar [4] highlighted in her study, the discrepancy underscores the need for research that compares high-quality disciplinary approaches with innovative integrated STEM education strategies. This is because the observed improvements in some studies may be more attributable to the innovative teaching methods used rather than the integrated STEM approach itself.

In addition, another interesting perspective on the use of integrated STEM education is the importance asymmetry between the S-T-E-M disciplines observed in projects. Mathematics, for instance, is one of the most damaged in this matter, as its integration in projects is often more difficult, resulting in mathematics being pushed aside as a single complementary tool for the content learning in the other disciplines [26–28]. The importance asymmetry problem shows that, depending on our educational objective at the time, the use of integrated STEM education may have certain limitations.

Before going into the review's details, it is essential to clarify certain theoretical assumptions that have been made for this study. Firstly, various terms are used in the literature within the same area of study, such as integrated STEM education, iSTEM education, STEM education, and STEAM education, among others. To distinguish between distinct disciplines and an integrated educational approach, we will adopt the term integrated STEM education. Secondly, while this paper may include references to STEAM education due to its characteristics shared with STEM education, our focus will be on the latter. Researchers defending incorporating the arts into STEM base their arguments on the recognition of creativity as a vital skill for the 21st century. Some argue that the inclusion of the arts serves to emphasise the importance of creativity [29]. In contrast, the latter perspective also implies that creativity is a characteristic exclusive to the arts and not inherently present in the S-T-E-M disciplines. As a result, certain authors question whether this inclusion is rooted in a marketing strategy to make integrated STEM education more attractive to schools [3,16]. Be that as it may, in this systematic literature review we will be using integrated STEM education.

The literature identifies a number of challenges that hinder both the practical application of and research on integrated STEM education. These obstacles include the absence of a unified STEM framework, the need for more comprehensive teacher training, and the development of new materials and research to analyse their impact. The first issue is a recurring concern in the field of integrated STEM education research, and disagreement about approaches remains problematic [27,30–33]. The problem is that the multitude of perspectives on integrated STEM education complicates the understanding of its essence and the implementation of plans to analyse its impact [31,34]. As a result, this issue directly affects subsequent processes, as the lack of clear theoretical guidance makes implementation and analysis more complex [7,16,35].

Moreover, implementing a STEM approach in classrooms depends on teacher involvement, and studies reflect a lack of confidence in doing so [7,10,36]. As the main focus is on fostering interdisciplinary understanding, this approach requires both knowledge and expertise in the different disciplines as well as the ability to integrate them effectively [7,37–39]. Thus, teachers express difficulties in understanding what exactly STEM teaching is and seek additional materials, more in-depth training, and continuous support throughout the process [40,41].

Additionally, it is essential to address the need for materials and research to analyse the impact of integrated STEM education on students [42]. However, the lack of consensus on their definition makes it difficult to systematically design materials and evaluate them [42,43]. Likewise, not having a common theoretical framework leads the researchers to the creation of diverse interpretations of what STEM education is [16]. That highlights the need to establish a common framework by analysing and comparing definitions, integrations, and principles defined by different authors.

Hence, the theoretical foundation of integrated STEM education has been one of the central topics in research in the area, addressed from different perspectives and by different authors. These varied approaches have resulted in the emergence of perspectives that, while seeking to respond to the same problem, have generated a great diversity of theoretical bases on STEM education, making it difficult to understand the principles that form the basis of the integrated STEM education strategy and hindering the development of innovative educational proposals [16].

There is already substantial literature addressing the diverse opinions on integrated STEM education definitions and integration types [17,26,42,44–50]. Additionally, there are also reviews focused on assessment of student learning [51], effects in students [24,25] and in minority social groups [52], STEM literacy [11], early childhood education [53], teachers' perceptions [38], teachers' professional development [40,54,55], and communities of practice [56]. In contrast, the same cannot be said for the principles of integrated STEM education from a design perspective. Thibaut, Ceuppens et al. [7] conducted the most recent systematic literature review on that topic, defining nine STEM principles based on the instructional practices detailed in the papers retrieved for their research. However, in their review, there is no comparison of how principles are elaborated by different authors, nor is there any discussion comparing their findings with the STEM principles defined by other authors. Moreover, since that publication, additional frameworks for STEM education principles have been published, where we can find a variety of classifications, terms, and descriptions. Consequently, the challenge persists, leaving uncertainty about which principles should guide the design process for integrated STEM education projects. By conducting a systematic literature review study, we aim to describe in a systematic and structured way different perspectives that have been taken in the literature. Therefore, this study aims to shed light on the principles of integrated STEM education presented in different studies to address a research gap in the area and to help tackle the challenges resulting from the lack of an overarching framework previously presented.

Lastly, in this article we will be talking about integrated STEM education principles and their characteristics. To clarify the difference between the two terms, the Cambridge Dictionary defines principle as "a basic idea or rule that explains how something happens or works", whereas characteristic is described as "a typical or noticeable quality of someone or something" [57]. Based on those explanations, we will use principle to refer to the overarching ideas that share commonalities, as Thibaut, Ceuppens et al. [7] did in their article. Likewise, characteristics will denote the specific details that describe each of the principles identified.

In light of this background, this article seeks to explore the multitude of principles established for integrated STEM education approaches and examine both their commonalities and distinctions. Through a systematic literature review, we address the following research questions:

1. What principles do various authors use to define integrated STEM education?
2. What are the characteristics of the principles identified?

2. Materials and Methods

We address these research questions by conducting a systematic literature review, wherein the inclusion of works is determined through well-defined and elucidated criteria. The selection process adheres to the guidelines outlined in the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) Declaration [58], as it is a well-established tool in research to develop systematic literature reviews in order to produce a standardised, transparent, and reproducible review that answers our research questions.

2.1. Search Strategy

The search was conducted in January 2024 using the databases of Web of Science, Scopus, and ERIC to maximise the retrieving of target papers. A search was conducted to find only articles that had "STEM" or "STEAM" on the title as well as "framework" or "principle". Moreover, the search was limited to papers published in English or Spanish. In addition, for the Web of Science database, the terms "STEM education" or "STEAM education" were fixed as the topic, and the articles were filtered to only include articles from the "Education Educational Research" research area. For Scopus, the terms "STEM education" or "STEAM education" were also defined in the category ALL. No timespan was defined for the articles.

2.2. Inclusion and Exclusion Criteria

The goal was to identify articles discussing STEM education frameworks and elaborating on their principles or characteristics for project design. This review considered research methodologies encompassing both theoretical and empirical papers, along with reviews. The emphasis was put on describing these principles and the associated teaching approaches. Additionally, for the screening and selection of papers based on their title and abstract, the following exclusion criteria were defined:

1. Articles focused on a specific educational topic such as robotics, artificial intelligence, environmental studies, etc.;
2. Articles talking about STEM education addressing specific minority social groups and gender perspectives;
3. Articles analysing attitudes towards STEM education;
4. Articles about out-of-school learning or informal STEM education;
5. Articles not focused on STEM education for primary or secondary education;
6. Articles addressing teacher training or professional development;
7. Articles presenting a specific teaching–learning sequence on STEM and the analysis of its performance or impact;
8. Articles not focused on the design of integrated STEM education

Thus, the overarching objective was to include articles providing in-depth insights into the foundational principles defined by authors for an integrated STEM education framework.

2.3. Data Screening

The data screening process is described in Figure 1 [59]. Data from various databases were imported into the Zotero reference management software, retrieving 88 articles from

Web of Science, 95 from Scopus, and 78 from ERIC. Once the duplicates were removed (n = 107), title and abstract screening was performed following the exclusion and inclusion criteria explained above. This process was conducted independently by two of the researchers that participated in this article, and the agreement percentage was 86%. In cases where the two researchers disagreed on the selection of articles for review, they engaged in discussion about the inclusion and exclusion criteria and the article's content until they reached a consensus. Therefore, after analysing and discussing the differences, the researchers agreed on the final selection of 37 articles for further examination. Although one article was not available to read, both researchers read the remaining 36 independently to select the ones that had information relevant to this study. Following the same strategy as for the selection of the title and abstract, the percentage of agreement was 88.89% after reading the full articles independently. We reached a consensus after discussing the four articles in question, which resulted in 22 articles being accepted for the final review. During this phase, the main reason for exclusion was that the articles were not for primary or secondary education (n = 4) or that they did not focus on the design of integrated STEM education projects (n = 6). The rest of the eliminated articles were excluded by criteria 3, 4, 6, and 7 presented in the previous Section 2.2.

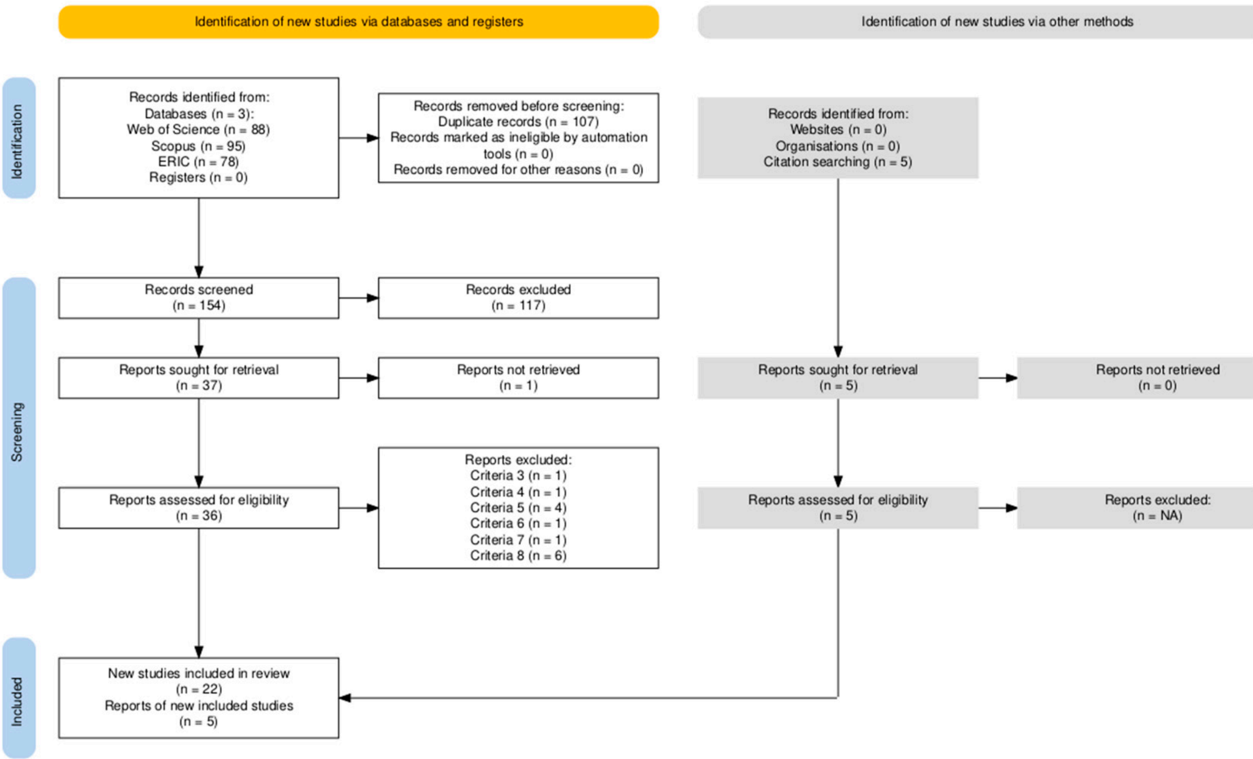

Figure 1. PRISMA flow diagram of article selection [59]. Screening criteria are defined in the Section 2.2.

Beyond these, additional records, totalling 5, were identified through citations in the reviewed articles or recognised as crucial information sources for this systematic literature review, meeting the content criteria [7,27,43,60,61]. Consequently, a total of 27 papers were utilised in this study.

2.4. Data Analysis

To respond to the research questions of this study, the analysis of the selected articles' content involved identifying the principles and characteristics outlined. This process was carried out independently by two researchers to determine whether they identified the same principles and characteristics. As in the previous section, points of disagreement were discussed in a series of meetings until consensus was reached.

Knowing that not all the authors presented their theoretical frameworks based on the concept of principles and characteristics, the analysis was conducted in an Excel file as follows: For the first research question regarding the principles, the five principles identified by Thibaut, Ceuppens et al. [7] were the starting point of the analysis as it was the latest systematic literature review on the topic. Each principle was placed in a column, and if, during the reading process, the authors defined principles that were not analogous to those five in Thibaut, Ceuppens et al. [7], they were established as new principles in separate columns.

On the other hand, when it came to the characteristics analysis for the second research question, each article had its own row in the Excel file, and the identified characteristics were placed in the column of the principle they were related to.

All information found related to the theoretical basis of integrated STEM education was taken into account for the analysis, regardless of the depth of their explanation. In other words, all information related to the topic of study was collected in this document. This approach implied that certain principles or characteristics, that were simply mentioned but not explained in some articles, were also registered in the analysis. The authors of this study believed that the fact that an idea that was not developed in depth in an article did not mean that it did not contribute to the theoretical framework presented.

With that in mind, the results were organised in two ways. For the first research question, we recorded the different principles found in the reviewed articles and the frequency of appearance of each principle. For the second research question, on the other hand, we analysed the explanations found for each principle, i.e., the characteristics. Similar characteristics were grouped together. To facilitate the understanding of this information in the Section 3, for those principles with more characteristics, the information is presented in tables. The citations next to each of the characteristics indicate that the information appears in all these articles. If some of the information appeared only in certain articles, it is indicated by a numerical superscript in both the characteristic and the citation. That numerical superscript means that the article marked in that manner is related to the general characteristic of that section and that it also added new information that did not appear in the rest of the articles cited there.

3. Results

In this section, we present the results obtained from the analysis of the selected articles following the screening process described above. The results are therefore organised into three main sections. We open with a first section dedicated to the description of the selected studies, followed by two sections focused on answering each of the research questions.

3.1. Overview of the Selected Studies

In this study, 27 articles retrieved from the three databases and included by the snowball mechanism have been analysed. Detailed information on the general characteristics of the selected studies can be found in the Supplementary Material (Table S1). All 27 articles were published from 2016 onwards, indicating a recent increase in publications on integrated STEM education principles or frameworks (Figure 2). These results suggest a growing interest in the topic, with an increased research focus.

Articles were published in eighteen different journals, and three of them were specifically dedicated to STEM (*International Journal of STEM Education*, *European Journal of STEM Education*, and *STEM Education*). Of the remaining journals, six covered multiple disciplines (e.g., *Journal of Science Education and Technology* or *International Journal of Science and Mathematics Education*), while the rest were discipline-specific or general education journals (*Education Sciences* or *Frontiers in Education*). This diversity suggests that studies related to the integrated STEM education framework are scattered across a variety of journals.

Examining the leading authors' countries reveals a similar diversity, with contributions stemming from thirteen different countries. The most prolific contributors were the USA and Australia, with six articles each.

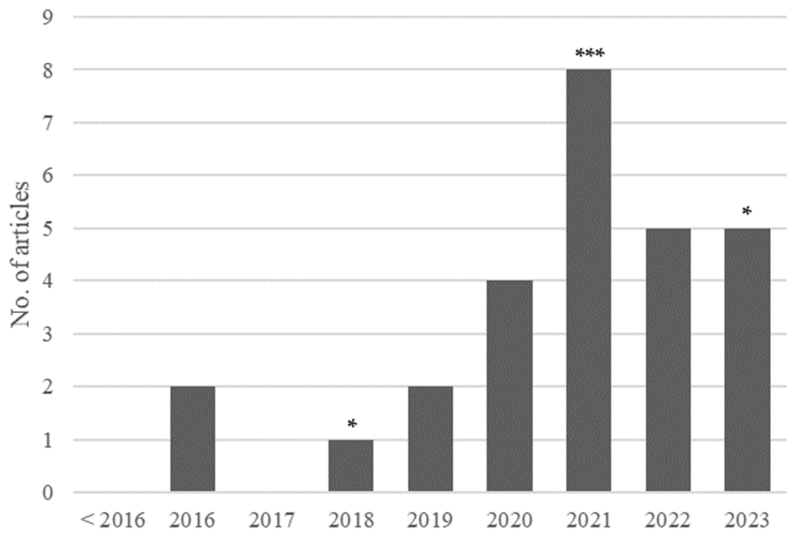

Figure 2. Publication dates of the selected articles. * Their presence refers to the snowball additions and the number of asterisks to the number of articles in that year.

In terms of the content of the studies analysed, 10 articles did not specify the education level they contextualised the research in, 3 linked their explanations to the primary education context, 6 to secondary, and 8 to both. Furthermore, among the studies identified, 13 offered valuable insights by providing examples in the same article of integrated STEM projects or teaching strategies associated with the principles, thus reinforcing and clarifying the theoretical concepts expressed. From those examples, four were focused on primary education students, six on secondary education, and three gave examples for both levels.

3.2. RQ1: What Principles Do Various Authors Use to Define Integrated STEM Education?

To answer the first research question, we analysed which principles appear in each of the analysed articles. As explained in the Section 2.4, we identified and recorded the principles described by the authors in their articles, noting the frequency of their appearance regardless of the depth of explanation. Based on this, we compiled the list of principles shown in Table 1.

The analysis resulted in 16 different principles extracted from the articles, occurring with varying frequencies. In fact, there are seven principles that occur in more than half of the articles: integration, problem-based design, real-world context, inquiry, teamwork, and centrality of engineering.

3.3. RQ2: What Are the Characteristics of the Identified Principles?

The second research question involves the analysis of the characteristics used for the principles' description in the articles. For this purpose, the following results are organised in sections dedicated to the individual principles where all the characteristics found are presented, together with the articles in which they appear. To facilitate the organisation of the information, a table listing the details accompanies the explanation of the characteristics of the most frequently mentioned principles.

3.3.1. Integration

Integration is a fundamental principle closely associated with STEM education, and it appears in various discussions regarding the classification of different integration levels [3,45,46,49,62]. The importance of integration in the literature is also reflected in the articles selected for this review, as it is one of the principles that we have identified the most during the analysis. Examining in detail the information provided by the studies on integration, we find the following characteristics (Table 2): Firstly, there is a debate in the literature on the optimal number of disciplines to integrate. According to the articles retrieved, for some authors, it is sufficient for the project to integrate at least two disciplines. Aligned with that idea, Pérez-Torres et al. [43] specifically say that at least two disciplines involved in the integrated STEM education sequence should be of similar importance, while the rest of the articles include no details on the relative importance of the integrated disciplines. In addition, other papers stress that integration is not exclusive to content, encouraging also the inclusion of competences or procedures.

Table 1. List of principles and occurrences in articles.

	Integration	**Problem-Based**	**Design**	**Real-World Context**	**Inquiry**	**Teamwork**	**Engineering Centrality**	**Student Centred**	**Mathematical Thinking**	**21st C. Skills**	**Assessment**	**Hands-on**	**Modelling**	**STEM Career**	**Technology Literacy**	**STEM Practices**
Al-Mutawa et al. (2021) [17]	x	x	x	x	x	x				x		x				
Chu et al. (2019) [31]			x		x	x		x				x				
Doğan et al. (2019) [63]	x	x		x	x				x	x			x			
English (2023) [61]	x	x	x	x	x		x		x				x			
Falloon et al. (2020) [11]	x	x	x	x	x	x		x		x						
Fan et al. (2021) [36]	x	x	x	x	x	x	x	x			x	x				
Fang et al. (2023) [64]	x	x	x	x	x			x		x	x					
Gale et al. (2020) [65]	x	x	x	x				x						x	x	
Hallström and Ankiewicz (2023) [66]	x	x	x	x	x		x		x				x		x	
Hu and Guo (2021) [67]	x	x		x	x	x				x	x					
Kelley and Knowles (2016) [42]	x	x	x	x	x	x	x	x	x			x		x	x	
Ong et al. (2023) [68]	x	x	x	x	x	x	x	x	x		x					
Ortiz-Revilla et al. (2022) [32]	x	x	x	x	x	x	x			x			x			
Priemer et al. (2020) [69]	x	x	x		x	x			x					x		
Reaves et al. (2022) [70]	x	x		x	x	x		x	x		x					x
Roehrig, Dare, Ellis et al. (2021) [27]	x	x	x	x			x	x		x				x		x
Roehrig, Dare, Ring-Whalen et al. (2021) [60]	x	x	x	x		x	x	x	x					x		
Smith et al. (2022) [71]	x	x	x	x	x	x		x		x	x					
Spikic et al. (2023) [48]	x	x	x	x	x	x	x						x			
Sujarwanto et al. (2021) [72]	x	x	x		x	x	x		x			x				
Teo et al. (2021) [73]	x	x	x	x	x	x	x									
Thibaut, Ceuppens et al. (2018) [7]	x	x	x	x	x	x	x	x		x	x	x	x			
Pérez-Torres et al. (2021) [43]	x	x	x	x	x	x							x			
Tytler et al. (2023) [28]	x	x	x	x	x	x	x		x	x				x		x
Wells (2016) [74]	x	x	x	x	x	x	x					x				
Yata et al. (2020) [33]	x	x	x	x	x		x		x							
Zhou et al. (2022) [50]	x	x	x	x		x	x	x			x	x				
27	26	26	25	24	23	20	16	13	11	10	8	8	7	6	3	3

Based on the frequency of mentioning, content and context integration seem to be important characteristics of this principle. These characteristics indicate that the relationship between the disciplines can be grounded in the links between concepts or ideas (content integration) as well as from the support a context in one discipline provides for a better understanding of the main topic rooted in another discipline. Likewise, some authors explain the need to show the links between the disciplines explicitly since the students struggle to identify these on their own. Concept mapping or related representations appear as a recommended strategy for facilitating this process, helping students visualise and understand the interrelations between concepts from different disciplines.

To conclude, Hu and Guo [67] discuss the starting point of the integration process, explaining that one option could be to choose first a complex learning situation, such as all earth's place in the universe [75], and then identify the core disciplinary concepts that relate to it. Another option is to select an interdisciplinary idea that exists in several disciplines; for example, the concept of energy exists simultaneously in the fields of physics, chemistry, biology, and geography [76], and use that to build the context for the integrated STEM project.

Table 2. Characteristics table for the integration principle. A numerical superscript indicates that the marked article contributed unique information not found in the other referenced articles.

1.1	**At least two disciplines**	[7,36,42,48,50,63,65–68]
1.2	**Specific and shared learning goals** - Identify which discipline you are using, for what, and how - Retain the unique perspectives and thinking styles of each discipline	[7,33,66,71]
1.3	**At least two disciplines should have similar importance** - The presence and combination of the disciplines involved should be constantly revised to ensure they have similar presence	[43]
1.4	**Integration of content, procedures, and competences** - [1] Allow the learner to realise which content and skills are needed	[11,32,61,66,67,69], [71] [1], [72–74]
1.5	**Content integration** - Connected nature of the disciplines - Support of one discipline content to understand other - The decisions made during the project should be based on the combination of the content of different disciplines - [1] Content coherent with the curriculum	[7,17,27,28,48], [60] [1], [68,70], [71] [1]
1.6	**Context integration** - Disciplines to give context - Connections via problems - Context options: client or science problem to understand the context - Social context to give purpose to the project	[7,11,17,28,36,42,43,48,60,64]
1.7	**Explicit integration:** students do not integrate spontaneously the concepts of different disciplines - Use different representations (concept mapping, diagrams, etc.) - Strong teacher facilitator	[7,27,36,48,60]
1.8	**What/how integrate** - More integration is not necessarily better - Use also non-STEM disciplines (social context, arts, etc.) - Use of cross-cutting concepts	[7,70]
1.9	**Learner has the autonomy** to decide the disciplinary knowledge to use every time	[64]

3.3.2. Starting Point: Real-World Problems

There is a significant consensus emphasising that STEM projects should start from a real-world problem. While some authors view the real-world context as an independent principle apart from the "central problem" principle [36,50,63], the strong connection between the use of problems and real-world context leads us to consolidate both principles into one (Table 3). In addition, these problems are characterised by several properties, such as involving several disciplines (complex), not having a simple solution (extended), having several paths and solutions (open and ill-structured), being connected to the learners' lived experiences, and appearing in a variety of real contexts (persistent). Furthermore, the presentation of the problem should activate existing ideas and mental models in the learners. Although not all authors mention them, certain characteristics could further enhance the richness of these problems, such as integrating ethical–moral analysis to bring the project closer to real-world contexts. Another noteworthy point mentioned by some authors is that students should identify the details of the problem on their own to be able to develop the knowledge necessary to solve the problem and apply it.

Table 3. Characteristics table for real-world problem principle. A numerical superscript indicates that the marked article contributed unique information not found in the other referenced articles.

2.1	**Real-world problems** - [1] Open-ended: more than one possible solution - [2] Ill-structured: lack a clear path to the solution - [3] Complex: requires concepts and skills from several disciplines - [4] Extended: cannot be solved in a simple search for solution - [5] Connected to the students' lived experiences - [6] Present at the beginning to activate existing mental models - [7] Persistent: it occurs in multiple contexts; it does not exist only in textbooks	[11,17,36,42,43,50,60,61,63,66,73,74] - [1] [7,27,28,48,61,64,67–69,71] - [2] [7,27,28,48,61,64,68–71] - [3] [32,61,67,68,71] - [4] [67,68] - [5] [27] - [6] [7] - [7] [68]
2.2	**Social, moral, cultural, and ethical aspects**	[27,43,60,61]
2.3	**Cognitive conflict:** Students need to realise their mental model is insufficient or that they need new knowledge	[67]
2.4	**Higher-order learning and thinking process**	[63,74]
2.5	**Students as agents of change**	[27,28]
2.6	**Engineering design process/problem/tasks** - [1] Good option for integration (more difficult to integrate with life sciences) - Guide students through problem-solving and inquiry processes - [2] Use of a client to define problem constraints	[17,27,28,36,42,50], [60] [1,2], [61,64,66,68,72,74]
2.7	**Not only engineering design problem** - Design is a shared feature of STEM disciplines (science experiments, mathematical models, technology tools, etc.) - Depends on the goals (task, challenge, general issue, etc.)	[11,32,33,66,68]
2.8	**Students must determine the required standards, norms, and design descriptions** on their own to synthesise the knowledge and apply it	[36]
2.9	**The problem entry** can be carried out by any discipline, depending on the goals and orientation defined - Interdisciplinary: project-focused - Disciplinary: subject-focused (context with other disciplines)	[11]

The primary debate related to these principle centres on the nature of the problem, where two perspectives emerge based on the explanations found in the articles: engineering design-based problems or non-engineering design problems. These perspectives highlight two key points in the analysis: the widespread agreement in defining problems as design problems and the ongoing discussion regarding the nature of the design problem (engineering versus non-engineering). While a specific tableanalyses design principles (result Section 3.3.3), authors defending the use of engineering design problems claim that it creates the opportunity to integrate and guide the students through the problem-solving process. Conversely, the other perspective suggests that design is not exclusive to engineering and that the nature of the problem may vary based on the goals of the STEM project. Thus, under the latter perspective, any discipline could serve as the starting point for the problem.

After discussing and defining some general characteristics about the problems as the starting point of the STEM projects, the next coherent question would be related to the types of problems we could use. Only five articles present various problem approaches and types, and they are all different from each other (Table 4). Although this discrepancy makes the understanding of the topic more complex, it also illustrates the opportunity to think about the problems as diverse entities adaptable to the project's objectives. The explanations of each type of problem in Table 4 are taken from the review articles themselves. In two cases, the papers' authors only mention the types of problems in their article introductions, and we have not been able to retrieve more information about their meaning.

Table 4. Problem approaches and types.

- **Project-based:** final product with specifications and teacher guidance - **Problem-based:** no final product; focus on students solving a problem on their own with almost no teacher guidance - **Problem-centred:** a more open project that is in between the previous ones; transferring knowledge to a realistic context.	[7]
- **Problem-based:** mayor technology issue - **Project-based:** design-specific engineering task - **Inquiry-based:** understand and debunk misconceptions	[36]
- **Problem to solve** - **Challenge to overcome** - **Product to produce** (physically or using other representations)	[68]
- **Diagnosis** - **Strategic performance** - **Situated cases/policies** - **Design problems**	[71]
- For engineering design: - **Problem-centric:** presentation of a big problem to find solutions - **Solution-centric:** revise and optimise a product - **User-centric:** very specific problem to solve	[73]

Based on the information retrieved about the problem approaches and types, we can also observe that while Thibaut, Ceuppens et al. [7] make a classification based more on the teaching and learning approach, the rest of the authors in Table 4 talk about the type of problem itself. This is why the classification of the Thibaut, Ceuppens et al. [7] approach could be complementary to the other typologies, combining the teaching and learning approach with the formulation of the problem to be solved.

3.3.3. Design

The design principle appears in the vast majority of the analysed articles, particularly concerning engineering design, placing engineering as the central axis of integrated STEM education projects. Thus, we have decided to integrate the "centrality of engineering" principle with the "design" principle. However, design does not only appear in an engineering context; it appears in the rest of the STEM disciplines too [66]. Even so, many authors argue that using an engineering design context creates the ideal scenario for integrating the other disciplines as it facilitates the relationship between knowledge and discipline-specific procedures between them (Table 5). Knowing that, one of the issues we found with the engineering design idea is the vast variety of names for the design process we can find in the literature.

Table 5. Characteristics table for the design (engineering design) principle. A numerical superscript indicates that the marked article contributed unique information not found in the other referenced articles.

3.1	**Design on an engineering context** - Using engineering design allows the integration of the other disciplines, filling the gaps between content knowledge, procedures, and their applications	[7,27,28,31,36,42,48,50,60,61,64,66,68,77]
3.2	**Specific problems** - Consider constraints, risks, criteria, etc.	[7,11,27,48,50,60,64,68,74]
3.3	**Variety of names**	
	Engineering Design Process	[17,27,28,33,61,65,68]
	Engineering Design Challenge	[60,72]
	Engineering Design	[74]
	Engineering-Based Problem	[73]
	Design-Based Learning	[7,32,48]
	Design-Based Project	[50]
	Design Thinking	[11]
	Design-Based Thinking	[61]
	Design Process	[64]
	Problem-Based Learning	[69]
	Technology practices	[43]
3.4	**Activities** (Iterative process) - Define/identify the problem/problem scoping (goals, variables, and constraints) - Development plans/solutions (pros and cons) - [1] System thinking - [2] Modelling/Prototyping - Implementation and analysis (testing) - Assessment - Modification/Redesign/Optimisation - Reconstruct - [3] Outcomes communication	[7,11,17,27,33], [36] [2], [42,43,48], [50] [2], [60] [3], [61] [1,2,3], [64] [2], [65] [2,3], [66], [69] [2,3], [72,73], [74] [3]
3.5	**Informed design decisions** - Evidence-based decisions based on other disciplines	[36,61,64,66]
3.6	No specific explanation	[28,66,71,77]

After analysing the activities used in the articles to describe the design processes, it becomes apparent that, despite the different names given to the design process, they share considerable similarities. Consequently, based on the activities the authors outlined when describing the engineering design process, we have derived the following sequence of activities: definition of the problem, including the specification of criteria and constraints; researching and developing solutions and evaluating their pros and cons; prototyping or modelling; testing; assessing; optimising; reconstructing; and communicating. Notably, from those activities, prototyping and modelling are mentioned only in six papers [36,50,61,64,65,69], and communicating the results appears only five times [60,61,65,69,74]. Additionally, English's article [61] includes a new idea based on system thinking, which is defined as the ability to understand a problem as a system of interacting elements. Thus, highlighting the system thinking concept enhances the importance of the context and the impact of our design decisions. Lastly, there are four papers that do not develop on the design principle despite mentioning it in their framework explanations.

3.3.4. Inquiry

The concept of inquiry is prevalent in most of the articles reviewed for this study. However, six of them omit an explicit explanation of its meaning, while another two present it as a skill to be developed (Table 6). When authors do develop what inquiry means in the integrated STEM education context, we found differences in whether they attach inquiry only to the field of science or not. Nevertheless, they all present inquiry as a way of acquiring new knowledge to then apply it to the problem-solving process (or to the engineering design).

Table 6. Characteristics table for the inquiry principle.

4.1	**Hands-on activities**	[7]						
4.2	**Hands-on and minds-on activities** - Manual activities should be helped by decision-making reasoning	[42,72]						
4.3	**Activities**	[42]	[74]	[7]	[36]	[32]	[48]	[69]
	Observe		X		X	X		X
	Raise Questions	X	X			X	X	X
	Seek information/assess existing ideas		X	X		X	X	X
	Make predictions/Hypothesise	X		X			X	X
	Plan or design research	*	X	X		X	X	X
	Collect data	*	X	X	X	X	X	X
	Analyse and interpret results	*	X		X	X		X
	Propose explanations and predictions	*	X			X		X
	Evaluate results	*	X		X			X
	Optimise			X			X	
	Communicate results		X		X	X		X
	* Those characteristics are defined by the authors using only the *Investigate* term.							
4.4	**Creating researchable questions** - Initiates knowledge building - Questions current knowledge and identify the needs	[7,31,43,48,67,74]						
4.5	**Inquiry in science** - An inquiry is a scientific procedure - Helpful for the engineering design process	[42,66,68,74]						
4.6	**Inquiry not exclusively in science** - Creates high-order connections	[7,63]						
	As the "need to know" process - To improve the efficacy of engineering practices ("need to do") using science, technology, and mathematics	[28,33,36,64,68]						
4.7	**Appropriate amount of guidance** - It is challenging for the students - Pure discovery learning without guidance is ineffective - Teachers help pupils discover flaws in their reasoning/research design	[7,32]						
4.8	No specific explanation	[17,66,70,71,73]						
4.9	Inquiry as a skill to be developed but not as a teaching–learning strategy	[11,61]						

Different authors define specific inquiry activities in their studies, and these vary from one group to another. While common activities such as posing questions, gathering information, planning the research, and collecting data are frequently mentioned, other activities are more the subject of discussion. The clearest example is optimisation, which appears in only two articles. On the contrary, questioning is of major importance for some researchers, as it allows learners to start creating and constructing knowledge. In contrast to the activities proposed so far, Chu et al. [31] present the inquiry within the framework of the 5E activities: engage, explore, explain, elaborate, and evaluate. Likewise, although English [61] describes inquiry as a skill to be developed, she introduces the concept of philosophical inquiry, which involves critically examining the inquiry process itself, uncovering hidden assumptions, considering alternative courses of action, and reflecting on the conclusions drawn.

Lastly, although only two articles mention it, the necessity for teachers to provide appropriate guidance throughout the inquiry process should be stressed, as pure open inquiry presents significant challenges for students.

3.3.5. Teamwork

Students working in teams is a consistent principle occurring across the review articles. However, there are ten articles in which no further explanation is given, and four others merely highlight the presumed advantages of teamwork, such as encouraging active participation and commitment (Table 7). On the other hand, although several terms are used to refer to teamwork (collaboration, cooperation, community of practice, and teamwork) and their meaning may differ, only Thibaut, Ceuppens et al. [7] make a comparison between collaboration and cooperation, favouring the use of the latter for integrated STEM education. Moreover, when discussing communities of practice, studies also include the out-of-school context, which links the classroom and the real world by involving experts or stakeholders, e.g., from local communities. Such an approach might be challenging for the teachers because they make contact with experts, and they need to be open to inviting them into the classroom [42]. Finally, three articles present some teamwork strategies and ideas to implement with students.

Table 7. Characteristics table for the teamwork principle.

5.1	**Terminology referring to teamwork** - Collaboration - Cooperation - Community of practice - Work in teams/teamwork	- [7,11,17,28,31,32,50,61,65,69,71,73,74] - [7,36,43,48,67,68] - [42,72] - [60,74]
5.2	**Difference between collaborative and cooperative work** - Collaboration: students create their own teams and there is no training - Cooperation: there is teacher intervention and students assess their team performance	[7]
5.3	**Out of school collaboration** - Community of practice can go further than the school context, working with STEM professionals, for example	[11,42,70,72]
5.4	**Strategies** - Provide rewards for successful interdependence - Shared resources - Tasks that are too difficult to be carried out individually - Positive interdependence between groups - Rubric, diary, and commitment reports for the group assessment - Attribution of roles within the group - Focus group discussions	[7,31,43,48,71]
5.5	**Advantages** - Active participation of all team members - Stimulates students' thinking and learning motivation - Higher cognitive engagement - Students share ideas and make decisions by discussing them	[48,67,68,71,72]
5.6	*No specific explanation:* Some just mention teamwork as a 21st century skill to be addressed	[17,28,32,36,50,60,61,65,69,73,74]

3.3.6. Student-Centred

Integrated STEM education should follow a student-centred pedagogy where the student is the protagonist of the learning process by participating actively, learning by doing, and being aware of the whole process [7,27,31,36,50,60,65,71]. According to some authors, learners should have the autonomy to make their own questions, decide the disciplinary knowledge to use in the design process and how to use it, and construct their solution to the problem with minimal teacher modification [42,64,65,68,70,71]. In addition, they should also be involved in determining the success criteria for the problem solution and the assessment process [68,70]. Teachers are the guides of the students' learning process through the adaptation of the learning pace, by taking the students' interests into consideration, and by enhancing cooperation and participation [11,71].

3.3.7. Mathematical Thinking

Mathematics integration has been described as an issue in STEM education due to the complexity of aligning the development of new mathematics knowledge with the other disciplines. We found 11 articles that gave special attention to the mathematics discipline. Creating a relationship between mathematics content and mathematical thinking in the context of real-world problems can help students to understand both the problem and the mathematics better [42,61,63]. That way, some authors describe mathematics as a special point of attention during the design of STEM projects [60,72]. In fact, mathematical modelling can be used to enhance the integration of mathematics, as it is linked to the engineering design process' stages [61,63,66]. In addition, mathematics is of major importance in the evaluation of the design or solution to the proposed problem through data analysis [28,33,61,68–70]. However, using mathematics just as a tool can cause the development of new mathematical knowledge through the integrated STEM project to be scarce [60]. We must also bear in mind that the integration can be complex since, on the one hand, not all the mathematical content worked on in secondary school can be applied to engineering design processes, and on the other hand, these students may not have sufficient cognitive development to do so [42,68].

3.3.8. Twenty-First Century Skills

From the articles reviewed, only two present 21st century skills as a principle for STEM [7,27]. They describe those skills as knowledge construction, collaboration, real-world problem solving, communication, use of information, creativity, critical thinking, and innovation, among others. However, in the rest of the papers, authors present those competences as learning outcomes to achieve using integrated STEM education, creating the framework around the development of these competences [11,17,28,32,63,67,71].

3.3.9. Assessment

Assessment is a concept that appears as one of the activities in both inquiry and design. Rather, this principle focuses on the assessment of the students' work and learning process during an integrated STEM education project. The papers' authors, referring to the principle, understand assessment as a part of the instruction process that should be related to the learning objectives of the project and adapted to the individual learning process [7,36,64,67,68,70,71]. That means that the assessment should not focus on the final product only but should also take into account the work performed during the whole project, such as disciplinary practices, cross-cutting concepts, and disciplinary content ideas for the problem-solving process [50,70].

This assessment can be performed both by the teachers and by the students [68,70]. Regarding the former, teachers should focus on the learning objectives and intended outcomes to be able to formulate a suitable and meaningful assessment for their students [36]. Likewise, they should specify to the students what is expected from them in terms of quality performance or product [50]. When the students are in charge of the assessment, it can be either self-assessment or peer assessment [68,70]. Some studies focus on students' metacognitive thinking and reasoning, stating that students need to evaluate and reflect on their learning process and results to continuously adjust strategies to achieve the objectives while learning from failure [67,71]. Thus, for the pupils to be aware of their progress, they should identify what they already know and what they need to know [71].

Within the assessment principle, there are two types of assessment that can be used in class: summative and formative. The first is used to understand the students' mastery of the goals and allows the teachers to analyse what occurred within the classroom [7,67,68]. Conversely, formative assessment provides guidance and feedback to students and teachers to monitor the learning process and to support further learning [7,67,68,70]. Formative assessment is especially useful since it allows teachers to recognise their students' problems, resources, and strengths and adapt the sequence and the approach based on that. That means that this type of evaluation should be carried out regularly [68].

Following the explanations of Fang et al. [64], Reaves et al. [70], and Thibaut, Ceuppens et al. [7], scoring rubrics are a useful tool for the assessment process. Additionally, Reaves et al. [70] and Hu and Guo [67] propose different strategies for summative assessment such as a paper–pen test (focused on steps and procedures using multiple choice, essay, or combination questions), performative assessment by reflecting on the steps of the problem-solving process, and computer interactive assessment.

3.3.10. Hands-On

There is only one paper presenting hands-on as a principle, describing it as the use of experiential and manipulative learning activities allowing students to observe the role of innovation [7]. Additionally, although the other authors do not describe it as a main characteristic, some papers mention hands-on activities as an important part to learn from experiences or to create prototypes and experiments through the project [17,36,42,50,74]. It is worth highlighting that in two studies they claim that hands-on activities should always be matched with minds-on experiences [42,72].

3.3.11. Modelling

Models are simplified representations of phenomena or systems, and some of the selected articles present them as a useful tool for STEM education [66]. In fact, Hallström and Ankiewicz [66] argue that models could be used to create links between the STEM disciplines since the concept of a model appears in every discipline. For example, this review's results highlight the emergence of modelling at various points, such as in the table on design principles (Table 5) related to engineering design and the principle of "mathematical modelling" [31,36,48,63,66]. Models can also be used to register the learning progress by critically thinking about the previous model and adapting it using new knowledge acquired during the STEM project [7,43,61,66]. Finally, there is an article that presents modelling as a teaching strategy that can be used at the same level as problem-based learning, engineering design process, or argumentation, explaining that the decision of which teaching strategy to use as the core is based on the objective we are pursuing with the project [32].

3.3.12. STEM Careers

One of the goals of STEM education is the promotion of STEM professions, which requires students to be exposed to detailed information about STEM careers [27,60]. According to the articles reviewed, it can be performed in two ways: engaging students in authentic STEM works or activities [42] and connecting students with professionals [28,65]. The latter method is particularly significant for under-represented groups in STEM, as exposure to role models positively influences students' perceptions of these careers [27]. Gale et al. [65] explain that creating connections between STEM professionals and students is not obligatory for a successful integrated STEM education project, although it can help students to see the reality of STEM work.

3.3.13. Technological Literacy

Regarding the role of technology in STEM, Kelley and Knowles [42] present a discussion on different perspectives to understand technology: on the one hand, there is the instrumental perspective where technology is seen as a tool for learning, and on the other hand, there is the humanities perspective that focuses more on the purpose of technology. Sujarwanto et al. [72] agree with the first perspective, presenting technology as a tangible form of scientific products and engineering processes as well as a tool to create new knowledge. Similarly, Gale et al. [65] focus on advanced manufacturing technology as one of the leading ideas in integrated STEM project design, while Hallström and Ankiewicz [66] present computational design as a useful tool when it comes to technology.

3.3.14. STEM Practices

There are two articles that mention STEM practices as a principle for integrated STEM education [27,28]. Following their explanations, those STEM practices are based on learning by allowing students to design, evaluate several possible solutions, collect data, analyse, visualise, and create explanations based on evidence. They also highlight the need to scaffold students to help them connect the different disciplines to the main engineering design challenge. Although Reaves et al. [70] do not present STEM practices as a principle, they also give special importance to the disciplinary practices related to inquiry and design to use them as took for the problem-solving process.

4. Discussion

In this study, we have presented a systematic literature review analysing integrated STEM education frameworks and principles to compare the different perspectives in the literature. One of the obstacles that authors claim in the STEM education literature is the absence of a unified integrated STEM education framework, which makes it difficult to understand its basis [26,27,30,32]. With our analysis focused on exploring the similarities and differences present in the literature, we aim to contribute to the establishment of such a unified framework.

4.1. Towards a Consensus of Integrated STEM Education Principles

Regarding the first research question, we have identified 16 different principles in the reviewed articles, which further confirms the diversity of perspectives in the literature. However, the appearance frequency varies a lot between the different principles. Based on that, we could conclude there is some consensus on the need for "integration", "real-world problem context", "design", "inquiry", and "teamwork" in integrated STEM education. That aligns with the results from the systematic literature review Thibaut, Ceuppens et al. [7] carried out, where, based on a socio-constructivism approach, they extracted the same five key principles for integrated STEM education as the most frequent ones in our study.

Additionally, although we identified 16 principles, some can be linked due to their similarities. As explained in the Section 3, most articles contextualise the problems in a real-world context, so we thought there was no need to analyse and discuss the principles "problem-based" and "real-world context" separately. Likewise, engineering plays an essential role in most integrated STEM education frameworks, and on the secondary school level, it is mainly related to the concept of design. Thus, we also decided to combine both of them into the design principle.

In addition, although the "hands-on" principle is a separate one for some researchers, it also appears in the explanations about "inquiry" and "design". Therefore, we believe that "inquiry" and "design" encompass the characteristics presented in the "hands-on" principle and that its presentation as a separate principle does not add extra information. Similarly, the explanations given in the principle of "STEM practices" and the "modelling" principle are in line with the steps described in the design and inquiry principles. Moreover, integrated STEM education fits within the general approach of current education framed in socio-constructivism, where the focus on competence development is essential. It is for that reason that the principles of "student-centred learning" and "21st century skills" are directly related to the general vision of education and do not necessarily have to be specific to integrated STEM education.

Thus, we believe that "integration", "real-world problem context", "design", "inquiry", and "teamwork" encapsulate the principles of "21st century skills", "student-centered", "hands-on", "modelling", and "STEM practices" since their characteristics are similar.

On the contrary, other principles add new information that cannot be framed in those first five principles. First, explicitly being aware of the assessment process and how to apply it to a STEM project is a valuable principle that does not appear in the previous ones. In addition, most articles in this study are focused on the science and engineering disciplines, analysing the characteristics of inquiry and design. However, only ten articles highlight the need to integrate "mathematical thinking" and pay attention to the role of mathematics, while only three articles talk about "technology literacy". That, on the one hand, reflects an issue already studied in the literature regarding the importance asymmetry between the disciplines [26–28]. On the other hand, having those principles makes explicit the need to pay attention to how to integrate those two disciplines into STEM projects and possibilities to do so.

Finally, one of the objectives of bringing integrated STEM education into the classroom is to increase students' interest in STEM jobs [2–4]. For this reason, creating a link between the classroom and the reality of the work world through role models and examples from real companies or activities can play an essential role in achieving that objective. This approach not only brings authenticity to the learning experience but also makes STEM careers more tangible and appealing to students. Therefore, keeping in mind a principle such as STEM careers can be interesting and adds a novel point to some of the analysed frameworks, since only four studies mentioned this principle.

4.2. Variability in Principles' Characteristics

Now, turning our attention to the characteristics further describing the principles, we have identified some discussions in the information registered. A first observation is the variety of terms relating to the same concept. This issue appears in the "problem type" results (Table 4), where all five articles expanding on the topic use different typologies, and even the same problem type name (i.e., problem-based) has different meanings. Hence, although having different types of problems widens the possibilities for STEM project designs, we need some sort of consensus on the problem types, their names, and definitions to be able to understand each other and expand on the details of each of the problems.

The same situation appears with the names given to the design process and approach (Table 5). We registered eleven different terms, and when examining the details, we did not find significant differences between them. With design being one of the central principles in integrated STEM education, there should be a clarification of the differences between those terms or a decision about which term would be the most appropriate to use.

The analysis also identified that while most articles focus mainly on science and engineering principles, mathematics and technology are less frequently integrated. This suggests a disciplinary imbalance that has already been highlighted several times in the literature on integrated STEM education, with science and engineering taking precedence over mathematics and technology [26–28]. This 'asymmetry' points to a potential area for further development in creating a more balanced and inclusive STEM education framework.

Another observation to be made is the lack of clarification on how the characteristics fit together and how they are translated into reality. The first example here is the understanding of the "integration" principle, where in addition to the debate around the number of disciplines needed, authors do not develop how to translate the characteristics of the integration principle into a real project. The literature on STEM education already shows the complexity level of the debate around the integration concept and the types of integration (i.e., multidisciplinary, interdisciplinary, or transdisciplinary integration) [45–47]. In this study, we encounter the same problem of a lack of explanation as to how to bring it to the design of a STEM project and the impact that decisions at the integration level have on the rest of the principles.

A second noteworthy example illustrating the obscurity of how to translate principles and characteristics to practice is related to the problem approaches and types (Table 4). Although the five papers discussing the topic give new perspectives on the "real-world problem" principle, they do not develop on the impact that using different problem types could have on the STEM project design. The problem formulation has a direct effect on which disciplines to integrate and the design and inquiry activities you need to use to solve it.

A third observation is the variety of opinions regarding the discipline ownership of inquiry and design. In other words, we found a discussion on whether or not inquiry is exclusively a science activity and whether or not design is exclusively an engineering activity. However, we did not detect any explanation of the impact that discussion could have on the STEM project design process and learning outcomes in students.

Fourth, those two principles ("design" and "inquiry") are also difficult to understand in terms of their role in integrated STEM education, as they are defined as separate principles, and it is not clear how they integrate with each other. This ambiguity raises questions about how they are put into practice in a teaching and learning sequence. Should the project follow the design principle activities? At what point is inquiry integrated there? Which design or inquiry activities should be used? Should all design and inquiry activities appear in one STEM project? How does it impact the initial problem definition and the acquired learning outcomes?

4.3. Limitations

Despite following the rules of systematic literature review to avoid bias, it remains possible that there are other relevant articles that were not included in the set due to the defined search terms and inclusion and exclusion criteria. Moreover, the terminology used has been biased based on the order of article reading. In fact, as we started defining the principles from the Thibaut, Ceuppens et al. [7] article, the most frequent ones followed their terminology. Likewise, although all results are based on the high consensus rate and discussions between researchers that reviewed the articles independently, grouping characteristics described by different authors based on their commonalities may have caused some detail to be lost in the process.

4.4. Future Research

Subsequent research may consider examining the relationship between the principles and elucidating the discussions identified in this review. Firstly, as explained in the Section 4.3, there might be articles that have useful information to complete our results and solve some of the problems identified. Thus, it would be very enriching to augment the research by adding more studies that integrate approaches that we have left out in this study, such as gender perspective, the inclusion of minority groups in the STEM sector, or teacher training studies [21,40]. Additionally, further research might investigate the impact that the design decisions or the desired teaching–learning outcomes could have on the interpretation and the interrelationship between the principles. Finally, since this study has only collected theoretical explanations, an analysis of real STEM projects could increase the information on the characteristics of the principles and help to bridge the gap between theory and practice.

5. Conclusions

In conclusion, this systematic literature review is the first of its kind to analyse the similarities and differences between integrated STEM education frameworks presented in the literature. We have seen that some principles appear in most articles, which means that overall scholars are following the same big ideas. However, this study also shows there are a number of discussions to develop and decisions to be made to clarify that common framework that is so often requested in the literature.

The review shows that there is a consensus in most STEM studies, firstly, on the necessity of integration between science and engineering disciplines, although a certain 'integration asymmetry' is detected with respect to the disciplines of mathematics and technology. Secondly, there is an agreement that STEM projects should start from a problem in a real context. However, in this principle, there is debate about the nature of the problem, whether it should be an engineering design or a scientific–technical problem, the nature of which may vary according to the objectives of the STEM project. Likewise, there is a lack of consensus on the types of problems that could be used as starting points and the impact of that decision on the project design and learning outcomes.

There is also agreement in the studies reviewed regarding design and inquiry skills, with the aim of acquiring new knowledge to apply to the process of problem solving and design in engineering. However, when analysing the characteristics of these principles, we find a polysemy of meanings for the terms inquiry and design process. Here, there is an absence of conceptual clarification and consensus that makes it difficult to analyse practical proposals for STEM projects, as the activities included in the design and inquiry processes vary from one integrated STEM education study to another. Therefore, we see a need for clarification not in the principles but in the defining characteristics, as it is an important step in bringing STEM projects into the classroom and being able to verify which projects are examples of quality integrated STEM education projects and which are not. That problem also affects the "assessment" principle, since it is crucial to explain how to translate the theory of the principles into practice in real STEM projects to shed light into the assessment process of the students' learning process and outcomes.

Furthermore, this article does not attempt to define a new theoretical framework but rather presents the commonalities and main debates at the theoretical level in order to develop a basis and direct future research in the area.

Founded on the results obtained, the authors of this study conclude that progress has been made towards developing a consensus theoretical framework for integrated STEM education. As mentioned in the discussion, we have principles that focus more on the educational context in which integrated STEM education is to be developed: a student-centred teaching–learning process that seeks to develop 21st century skills. Starting from that premise, the results indicate five principles on which the literature is in broad agreement: "integration", "real-world problem", "design", "inquiry", and "teamwork". Hence, the consensus suggests that a STEM project should originate from a real-world problem that is composed of at least two disciplines that have specific and shared learning goals. These disciplines can either contribute content to the problem-solving process or enrich the context. Either way, it is crucial for students to be aware of how the disciplines are integrated.

The findings from the analysis underscore that the initial problem plays a key role in the integrated STEM education projects since the learning process will develop around it. Thus, according to the general agreement between the articles analysed, the problem should be open-ended, ill-structured, complex, and extended, and it needs to create a cognitive conflict in the students to foster the demand for the acquisition of new knowledge. To solve that problem, we need to develop design and inquiry activities while working in teams. Additionally, to the five principles depicted from the main consensus, most of this study's authors show that assessment is also essential for a quality integrated STEM education project. Thus, both students and teachers should be actively involved in an assessment process that is focused both on the learning process and on the result.

The analysis of the reviewed articles led as to take in mind the influence that the selected problem type can exert on the design of the STEM project. The choice of problem not only determines the disciplines involved in the process but also affects the development of design and inquiry principles. In other words, the formulation of the problem will help us to identify which design and inquiry activities are necessary to achieve the stated objectives. In any case, as explained in the discussion, further research is needed to determine the relationship between the principles of "real-world problem", "design", and "inquiry".

Finally, although this study developed in this article highlighted that there are the key points of the theoretical framework to be developed, the rest of the principles recorded ("mathematical thinking", "modelling", "STEM career", etc.) also enrich knowledge on the subject and help to create more complete STEM projects.

We hope that the presented study has served to highlight the principles of STEM education where there is currently sufficient consensus, which indicates clear progress within this educational area. We also hope that further contributions will be made to help resolve the inconsistencies and lack of clarity detected in the defining characteristics of the principles of STEM education.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/educsci14091028/s1, Table S1: Selected Articles' Characteristics Table. The Systematic Literature Review developed for this study is registered and publicly available in OSFregistries: https://osf.io/jqgep/ (accessed on 28 August 2024). There you can find the search strategy details, the PRISMA flowchart, and the list for the final article selection.

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