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Integrating STEM Approach in K-12 Science Education Teaching Practice: A Systematic Literature Review

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Abstract

The integration of science, technology, engineering, and mathematics (STEM) in K-12 education is widely recognized as a critical means to ensure future prosperity, security, and a skilled workforce in these fields. This integrated STEM approach entails teaching these four STEM disciplines in a cohesive manner. However, several barriers have arisen, including the lack of a clear consensus on the key features of implementing integrated STEM education effectively. There remains uncertainty about which science subjects should be integrated with the other three disciplines and at what level within K-12 science education this integration should occur. Therefore, this study aims to establish a well-defined framework for teaching science through an integrated STEM approach (ISTEMA) and identify the types of integrated STEM disciplines employed in various educational settings through a systematic literature review. Secondary data, including scholarly journal articles and book chapters, were collected through searches in databases such as the Educational Resource Information Center (ERIC) and Web of Science. Data analysis was conducted using within-case and cross-case analysis methods. The findings of the study revealed that the framework of teaching science ISTEMA generally consists of six elements: inquiry-based, engineering-based, technology-based, problem-based, teamwork-based, and robotic-based learning. This approach primarily focuses on primary and lower secondary education. Engineering and technology content is predominantly integrated into the science subject. In primary education, science and engineering and science and technology are extensively used, while in lower and upper secondary education, science, engineering, and mathematics, science, technology, and engineering, or STEM are commonly employed.

Keywords: Actual teaching practices, integrated STEM approach, K-12 science education, systematic review

INTRODUCTION

The acronym STEM, representing Science, Technology, Engineering, and Mathematics, has become a widely used term, particularly in political and policymaking contexts. Its primary purpose is to address the increasing demand for a workforce skilled in these fields (De Vries, 2018). The President's Council of Advisors on Science and Technology (PCAST) has underscored the significance of K-12 education in STEM fields to ensure the future prosperity and security of the United States. This investment is considered a fundamental element, as it connects K-12 learners to the physical world through technological presentation and mediation (Oliveira et al., 2019).

The demand for a skilled STEM workforce is not limited to the United States; it's a global concern. For instance, Cambodia has set the goal of transitioning from labor-intensive industries to skills-driven industries by 2025, to achieve high-middle-income status by 2030 and high-income status by 2050, as outlined in the Industrial Development Policy (IDP) for 2015-2025. This transition involves the development of modern technology and knowledge-based industries. Similarly, the Africa Agenda 2063 underscores the importance of well-educated and skilled citizens supported by science,

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technology, and innovation to create a knowledgeable society where no child misses school due to poverty. In December 2018, the United States National Science and Technology Council (NSTC) issued the Federal STEM Strategic Plan titled "Charting a Course for Success: America's Strategy for STEM Education." This plan envisions a future where all Americans have lifelong access to high-quality STEM education, and the United States leads globally in STEM literacy, innovation, and employment.

Through these international goals, STEM education plays a crucial role, and the integrated STEM approach is recognized as an effective methodology for implementing a curriculum that integrates STEM disciplines in a holistic manner.

Purpose and Research Question

This study conducted a systematic literature review to identify key features and trends in K-12 integrated STEM education, examine the degree of interdisciplinary integration, and determine the prevalence of STEM integration across educational levels. Three main research questions were formulated to steer the investigation.

1. What comprised the fundamental essence of the integrated STEM approach as applied in K-12 science education?
2. What were the prevalent content areas and the various modes of integration between Science, Technology, Engineering, and Mathematics within the integrated STEM approach?
3. At which educational levels within the K-12 system was the integrated STEM approach predominantly employed, and what distinct types of STEM integration were evident at each of these educational levels?

LITERATURE REVIEW

Definition of Key Term

Before diving into an explanation of the integrated STEM approach, it's crucial to clarify several key terms that are frequently used in this field. These terms include *STEM integration*, *integrated STEM education*, *interdisciplinary approach*, and *transdisciplinary approach*. This section will provide detailed theoretical definitions for these terms.

Satchwell et al. (2002a) defined *integrated STEM education* as the amalgamation of theory and practice from science and mathematics with technology and engineering education. This type of education often incorporates project- and problem-based teaching methods (Barron et al., 1998; Blumenfeld et al., 1991; Hmelo-Silver, 2004). Similarly, Selcen Guzey et al. (2017) articulated that integrated STEM education involves employing engineering design and practice as vehicles for teaching science and mathematics. It can be achieved through various approaches, including project-based, problem-based, inquiry-based, or theme-based methods (Apedoe et al., 2008). *STEM integration*, on the other hand, is an educational approach that equips students with critical thinking skills, aiming to mold them into fully dynamic citizens (Chesky & Wolfmeyer, 2015). Essentially, STEM integration entails utilizing knowledge and skills from multiple disciplines to address complex real-world phenomena or situations (Honey et al., 2014, p. 52). This approach amalgamates various disciplines into a more cohesive and interdisciplinary learning and skill development process (Science et al., 2018; Wei & Chen, 2020). *An interdisciplinary approach* is a teaching and learning technique that commences with a real-world problem or issue and prioritizes interdisciplinary content and skills, such as critical thinking and problem-solving, over subject-specific content and skills (Wang et al., 2011). Satchwell et al. (2002b) described interdisciplinary instruction as taking place within one domain while implicitly connecting to other disciplines. It's an approach that combines elements of two or more disciplines, thus creating explicit connections between relevant fields (Klein, 2008; Miler, 1981). In contrast, *the transdisciplinary approach* centers on real problems or issues without being confined to the content of a single discipline. It integrates core ideas from different disciplines (Klein, 2008). Miller (1981) aptly characterized transdisciplinary approaches as conceptual frameworks that transcend narrow disciplinary worldviews, encompassing various aspects of the other fields that are handled separately by individual specialized disciplines.

Although previous researchers used different terms, they often refer to the same concept, theory, aim, and instructional practices. For example, Bryan & Guzey (2020) found that STEM integration is fundamentally equivalent to integrated STEM education. Therefore, in this study, the integrated STEM approach is used, and it represents a teaching and learning method that utilizes the knowledge, skills, and values of STEM subjects to address real-world problems (Ng & Adnan, 2018). It encompasses a range of constructivist and transformative approaches, including problem-based learning, project-based learning, robotics activities, science exhibitions, and gaming competitions, which are commonly implemented in classrooms (Wei & Chen, 2020; Ayieko et al., 2017).

The Importance of the Integrated STEM Approach

Numerous empirical studies have provided compelling evidence regarding the substantial benefits of implementing an integrated STEM approach. These advantages encompass the development of essential skills, including critical thinking, problem-solving, collaboration, teamwork, and, notably, 21st-century skills (Mustafa et al., 2016; Polydoros, 2021). Furthermore, it positively influences students' academic achievements, interests, motivation, and overall attitudes toward STEM subjects in higher education (Toma & Greca, 2018; Polydoros, 2021).

Challenges

Indeed, despite the recognized importance and effectiveness of the integrated STEM approach, its implementation faces numerous challenges. These challenges encompass teachers lacking the essential content and pedagogical content knowledge in STEM disciplines, the inadequacy of learning and teaching materials, and the complexity and time-consuming of developing curricula and lessons that encompass all STEM disciplines (Nadelson and Seifert, 2017; Toma & Greca, 2018; Tawbush et al., 2020). Additionally, there exists inconsistency in the terminology and usage of this teaching approach among researchers, and a consensus on its core operational features. For instance, Ziaeefard et al. (2017) referred to this approach as co-robotics pedagogy, Bernstein et al. (2021) as problem-based learning in interdisciplinary integration of engineering, science, and computational thinking, Century et al. (2020) identified it as a problem-based transdisciplinary module, and Schellinger et al. (2022) denoted it as integrated science and engineering units, all with the common aim of teaching STEM disciplines in an integrated manner. Hence, it is crucial to formulate a clear and standardized operational framework for this teaching approach that can serve as a guiding tool for instructors, curriculum developers, and STEM practitioners.

Although Thibaut et al. (2018) defined five elements of the integrated STEM approach, their focus was predominantly on secondary education. Furthermore, their review exclusively encompassed studies that integrated at least three STEM disciplines, thereby excluding those that integrated only two STEM disciplines, as well as studies conducted in primary education or lower secondary levels. Another concern is the ambiguity surrounding the extent and manner in which science subjects have been integrated with other STEM disciplines. Wei & Chen (2020) underscored that the highest level of STEM integration, which involves the integration of two or more disciplines into real-world problems or systemic issues, offers students the opportunity to personalize their learning experiences. Hence, it is imperative to conduct a comprehensive review of previous studies focusing on the operational implementation of the integrated STEM approach at various levels within K-12 science education.

RESEARCH METHOD

The current study employed a systematic literature review to critically analyze, identify, synthesize, evaluate, and summarize findings from relevant previous studies related to the utilization of the integrated STEM approach in science education within the K-12 context (Gopalakrishnan & Ganeshkumar, 2013). The search covered the Educational Resource Information Center (ERIC) and Web of Science databases, using five different combinations of search key terms: "STEM Approach" (n=136), "STEM Integration Approach (n=80), "Integrated STEM Approach (n=50), "Interdisciplinary STEM Approach" (n=33), and "Transdisciplinary STEM Approach" (n=7) plus "+ Science Education + K-12 Education" respectively. This extensive search resulted in a total of 306 empirical studies. Duplicate search results were excluded, leaving 186 articles for further consideration. Subsequently, the researcher applied four primary criteria to inspect and filter the results. Firstly, all selected studies had to be published in peer-reviewed journals or book chapters written in English within the past ten years, from 2012 to 2022. Conference papers, theses, or dissertations were excluded. Secondly, the articles needed to focus on the integration of science disciplines with other STEM fields regardless of the number of integrated disciplines. Articles not integrating the science discipline were excluded, such as those solely concentrating on the interdisciplinary integration of engineering and mathematics and so on. Thirdly, the articles were required to provide a clear description of the actual teaching and learning practices associated with teaching science using the integrated STEM approach. Lastly, all selected studies had to describe the integrated STEM approach's actual teaching and learning practices within science subjects at the K-12 education level. Following these criteria, 25 empirical studies remained. For dataset analysis, the researcher applied an analysis framework based on the research focus. Data analysis employed a within-case and cross-case analysis method (Miles and Huberman, 2014). Initially, within-case analysis was used to examine, categorize, synthesize, and summarize the selected articles in a table featuring three categories: (1) the type of research focuses on discipline integration, (2) the K-12 education level, and (3) the characteristics of actual teaching practices. Subsequently, a cross-case analysis was conducted. The actual teaching practices extracted from all articles were restructured, grouping similar elements into six categories. Through this process a common essence of the integrated STEM approach in science education was formulated, comprising six elements. Finally, descriptive statistics were then applied to elucidate the types of discipline integration and K-12 education levels.

RESULTS AND DISCUSSION

Instructional Practices of Integrated STEM Approach in Science Education

The instructional practices of the integrated STEM approach in science education have been extracted from all the empirical studies in this systematic literature review. Similar content, elements, and characteristics of each actual teaching practice have been categorized into six instructional practice categories: inquiry, engineering design, problem focus, technology, teamwork, and robotics (see Appendix 1). A summary of the different instructional categories found in each article is presented in Table 1. The detailed descriptive characteristics of each instructional practice within each category are discussed in greater detail below.

Inquiry: The initial category within the instructional practices of the integrated STEM approach pertains to the utilization of inquiry-based learning. The inquiry-based learning approach entails students engaging in exploration, investigation, observation, and experimental activities to formulate scientific answers to key questions. The role of the teacher is to guide and lead students to answer questions (Pedaste et al., 2015). Inquiry-based learning is employed to enhance students' scientific knowledge, skills, and critical thinking. This approach was originally designed for science education, but it is not limited to application in other disciplines such as mathematics and technology (Satchwell et al., 2002b).

As a result of the review of papers, the fundamental characteristics of inquiry-based learning have emerged in several aspects. Firstly, students initiate their learning journey by acquiring introductory concepts related to each designed lesson. During this learning phase, students are exposed to concepts associated with inquiry activities, science, robotics, and programming (Ching et al., 2019). For instance, in various science lessons, teachers introduce fundamental concepts such as mass, force, friction, displacement, velocity, speed, acceleration, and momentum at the outset of the lesson. Teachers also explain the breadboard, its structure or function, and its circuits. Moreover, as an example in biology subjects, teachers introduce the concepts of genetics and modified organisms, as well as the use of box plots for data analysis (Hutchins et al., 2020; Rahman, 2021; Yin et al., 2020). Secondly, questioning plays a pivotal role in inquiry-based learning as it encourages students to stimulate their scientific knowledge on a given topic and lesson (Stump et al., 2016). It also guides students to think in ways that connect the content to engineering design challenges (Crotty et al., 2017), the concept of co-robotics, and clients' needs (Johnston et al., 2019; Ziaeefard et al., 2017). Thirdly, observation, investigation, exploration, experimentation, and data searching are vital steps. Students commence by observing the specifics of lesson activities or performances through videos or actual practices organized by teachers to predict or form hypotheses regarding possible answers to the problem settings (Hutchins, Biswas, Zhang, et al., 2020; Rahman, 2021). Subsequently, students conduct research to explore the nature of each STEM discipline and existing data or previous information (Crotty et al., 2017; Peel et al., 2021; Schellinger et al., 2022) and investigate real-world problems, the nature of science, and society issues (Century et al., 2020; Chung & Li, 2021; Peel et al., 2021). Additionally, students perform experiments or engage in hands-on activities to address key questions. Examples several studies illustrate that students conduct various science experiments, inquiry lessons, and hands-on activities to explore the conceptual aspects of science and other STEM disciplines (Aranda, Guzey, et al., 2020; Aranda, Lie, et al., 2020; Chiang et al., 2022). Finally, data analysis and results presentation are conducted. In these steps, students apply mathematical concepts and tools such as simple calculations, data tables, graphs, bar charts, and box plots to analyze, measure, and display results (Luo et al., 2020; Peel et al., 2021; Siverling et al., 2021).

Engineering Design: The second category of instructional practice of the integrated STEM approach involves the application of the engineering design method. Previous studies have shed light on various facets of engineering design. Firstly, the design challenge or engineering design challenge that addresses and aligns with the demands of the current industrial revolution and modern society. This initial step aimed to identify, formulate, and define the engineering problem. In preparing for the design challenge, students were acquainted with the client's requirements and provided with a list of design constraints, evaluated counterexamples or suboptimal designs, and completed two smaller sub-challenges centered on the core concepts of engineering design (Aranda, Lie, et al., 2020; Guzey & Jung, 2021). For example, Wieselmann et al. (2021) denoted that at the outset of an engineering-focused lesson, students were introduced to a fictional client seeking their assistance in designing a laser security system to safeguard valuable assets in a museum exhibit. Similarly, Dasgupta et al. (2019) reported that on the first day of the lesson, students were presented with a significant design challenge: designing a low-cost, energy-efficient home in Indianapolis for the design principal. Secondly, the engineering design process, which includes design planning, actual design work, testing, and redesigning. During the design planning phase, students consider crucial factors such as design methodology, required materials available at their schools, time constraints, costs, and testing methods (Aranda, Guzey, et al., 2020; Chung & Li, 2021). This phase then transitions to the actual design stage. However, prior to that, students engage in various science-focused lessons and participate in and complete several science experiments and inquiry lessons. Subsequently, students apply their scientific knowledge to address the design challenges by initiating the design, testing, evaluating, and making improvements to their solutions (Aranda, Lie, et al., 2020; Wieselmann et al., 2021). Finally, it involves the creation of a report detailing the design process. Students are required to write or prepare a brief report discussing their designs using evidence-based reasoning and present it to the entire class (Crotty et al., 2017; Guzey & Jung, 2021). Throughout these processes, teachers are expected to provide support, share ideas, and justify decisions (Aranda, Lie, et al., 2020).

Technology: The third common essence focuses on the utilization of technology. Technology-based methods are employed to enhance computational thinking (CT) practices, encompassing abstraction, decomposition, algorithmic thinking, and pattern generalization (Bernstein et al., 2021; Century et al., 2020; Yin et al., 2020). For instance, Peel et al. (2021) showcased the use of the game "Lightbot" to enhance students' CT by engaging them in different levels of the game. Additionally, technological devices such as computers, projectors, and internet capabilities have been integrated into teaching and learning in integrated STEM education. This integration involves activities such as watching program tutorials, videos and practicing programming robots (Ching et al., 2019; Petrosino et al., 2016). Firstly, it involves the use of software for data collection, design, solving design challenges, and hardware control (Dasgupta et al., 2019; Yin et al., 2020). The use of software enabled students to engage in procedural construction actions, making the learning of physics and programming more enjoyable and intuitive (Dasgupta et al., 2019; Yin et al., 2020). For instance, Dasgupta et al. (2019) guided students in addressing energy consumption design challenges using energy 3D software, while Petrosino et al. (2016) utilized software to measure the accuracy of trial runs for various helmet designs. Secondly, it encompasses modeling, simulation, and visualization design solutions. For instance, students developed, applied, tested, and refined a measurement distance "step-size" by modeling the motion scenario and fine-tuning their "step-size" using the ViMAP application (Dickes et al., 2020). Another example from Hutchins, Biswas, Zhang, et al. (2020) revealed that students employed variables and expressions instead of hard-coding values into their models, and they figured out how to use conditionals to model stopping conditions. Finally, students documented the results of running their models, simulations, and visualizations, noting both positive and negative outcomes (Hutchins, Biswas, Maróti, et al., 2020; Jeong & Kim, 2015).

Problem Focus: The fourth category centers on the utilization of a problem-focused, where students are actively engaged with real-world problems. Two distinct approaches have been explored in previous research: *Problem-Based Learning* and *Project-Based Learning*. These two approaches are adopted to facilitate student-centered learning processes and tackle real-world issues (Asghar et al., 2012b; Jeong & Kim, 2015). While the fundamental concept of these two approaches is similar, some variations have been observed in previous studies. *Problem-based learning* has been identified as instructional practices in integrated STEM education, encompassing various aspects. Firstly, the process begins with establishing the problem scenario at the outset of the lesson, following the presentation of a problematic situation by the teachers (Jeong & Kim, 2015; Johnston et al., 2019). Secondly, defining and constructing a solution involves students expressing a range of creative ideas and engaging in problem analysis. Students employ scientific knowledge and reasoning by researching previous cases and drawing from past experiences documented in other studies, adapting concepts and principles to facilitate problem-solving (Chiang et al., 2022; Johnston et al., 2019). Thirdly, a phase of demonstrating, testing, and redesigning the solution is undertaken through simulation, visualization, and modeling of the results of students' design solutions (Century et al., 2020; Jeong & Kim, 2015; Johnston et al., 2019; Siverling et al., 2021). Finally, there is a concluding phase where students reflect on what has been achieved or highlighted in the outcome of the solution (Jeong & Kim, 2015). In contrast, in *Project-Based Learning*, students develop predetermined projects to demonstrate problem-solving. By the conclusion of the lesson, final products are generated as the outputs of a series of activities within the lesson (Century et al., 2020). However, Project-Based Learning encompasses similar aspects to Problem-Based Learning, such as problem-scoping, identification, and construction of solutions, testing and redesigning of solutions, and presenting final products (Guzey & Jung, 2021; Peel et al., 2021).

Teamwork: The fifth category focuses on promoting group work and collaboration among students, which is a fundamental aspect of student-centered pedagogy aimed at enhancing students' communication skills, fostering group discussions, and encouraging teamwork (Aranda, Lie, et al., 2020; Siverling et al., 2021). Previous literature has highlighted two main approaches in this category: *collaborative learning* and *cooperative learning*. Although there isn't a clear distinction between these two approaches, the nature of the designed learning activities are different. *Collaborative-based learning* is defined as students working together in group activities within the context of inquiry and problem-based learning. For example, Aranda, Lie, et al. (2020); Gale et al. (2020); Petrosino et al. (2016); Siverling et al. (2021) noted that students engage in collaborative group work to discuss, plan, conduct experiments, and reflect on solutions to defined problems. On the other hand, *cooperative-based learning*, is identified as teamwork specifically designed for projects. For instance, Guzey and Jung (2021) and Johnston et al. (2019) described situations where students collaborated as teams to plan, design prototypes, build, test, evaluate, redesign, and present their solutions in response to client demands. Additionally, Chantong et al. (2020) mentioned that students were organized into groups based on the required activities.

Robotic: The sixth category of instructional practices in the integrated STEM approach, known as the robotic approach, encompasses several key aspects. This approach involves introducing students to the world of robotics and guiding them through the process of robot design and programming. Here's a summary of the key components within this category: *Introduction to Robotic Design* - Students begin by familiarizing themselves with robot activities. This can be facilitated through teacher presentations or using tutorial programs. Students engage in robot activities, which may include completing worksheets and practicing robot programming (Ching et al., 2019; Rahman, 2021). *Robotic Design Process:* This step initiates with students asking questions about robotics, showing their curiosity and interest in the field (Ziaeefard et al., 2017). To answer these questions, students delve into various inquiry activities related to scientific principles, robotics, and programming. They may also research different robot designs to gain a deeper understanding (Bernstein et al., 2021; Ching et al., 2019; Ziaeefard et al., 2017). In addition to this, students learn fundamental concepts such as mass, force, friction, displacement, velocity, speed, acceleration, and momentum. They also acquire basic skills in controlling robots, such as making them move forward or backward, measuring errors, and collecting data (Luo et al., 2020; Rahman, 2021). Discussions about the nature of robots and how to control them are also a part of this phase (Luo et al., 2020; Rahman, 2021). *Programming and Testing:* Students are introduced to programming, where they create the necessary code to control robots. This includes programming robots to perform specific tasks, move in various directions, and execute predefined actions (Ching et al., 2019; Rahman, 2021). *Testing and Validation:* In this stage, students test their robot designs. They engage in troubleshooting and debugging to ensure their robots function as intended. Students may also perform tasks and participate in challenges to validate their robot designs (Ching et al., 2019; Rahman, 2021). For instance, Rahman (2021) mentioned a challenge where LEGO robot vehicles were placed at different locations on a sliding surface, requiring the robots to navigate from higher to lower positions along the sliding path. *Solution Explanation:* Finally, students are expected to explain the solutions they've developed to address the challenges posed by their robot designs (Ziaeefard et al., 2017). This robotic approach allows students to explore robotics, from the basics of design and programming to practical testing and problem-solving, fostering a hands-on and engaging learning experience within the integrated STEM framework.

Table 1: Overview of the actual teaching practice categories present in each paper.

No	Authors, Year	Inquiry	Engineering	Technology	Problem-Based	Teamwork	Robotic Based
1	Aranda, Guzey, et al., 2020	√				√	
2	Aranda et al., 2020	√	√				
3	Bernstein et al., 2021	√	√	√			
4	Century et al., 2020	√		√	√		
5	Chantong, et al, 2020		√	√		√	
6	Chiang et al., 2022	√			√		
7	Ching et al., 2019	√	√		√		√
8	Chung & Li, 2021	√	√				
9	Crotty et al., 2017	√	√				
10	Dasgupta et al., 2019		√				
11	Dickes et al., 2020	√		√			
12	Gale et al., 2020	√	√	√		√	
13	Guzey & Jung, 2021		√	√	√	√	
14	Hutchins et al., 2020		√	√	√		
15	Jeong & Kim, 2015	√		√	√		
16	Johnston et al., 2019	√			√	√	
17	Luo et al., 2020	√				√	√
18	Peel et al., 2021	√			√		
19	Petrosino et al., 2016,	√	√	√		√	
20	Rahman, 2021	√	√				√
21	Schellinger et al., 2022	√	√				
22	Siverling et al., 2021	√	√	√	√	√	
23	Wieselmann et al., 2021	√	√		√		
24	Yin et al., 2020	√	√	√			
25	Ziaeefard et al., 2017	√	√	√	√		√
		21	17	12	11	8	4

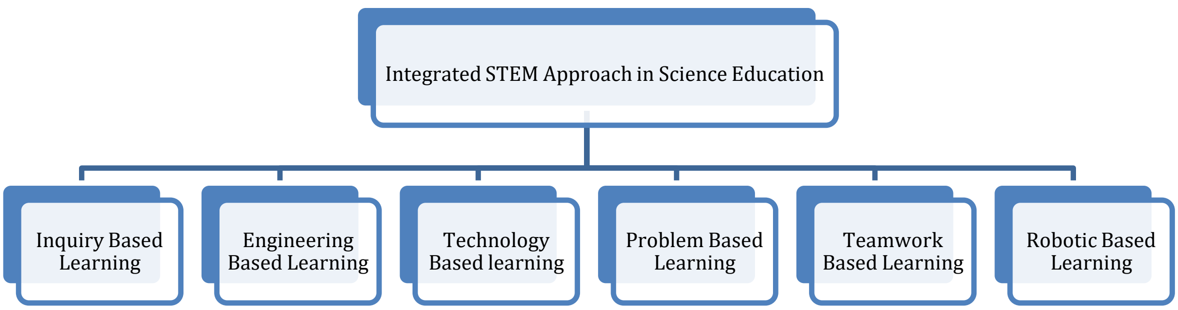

Figure1: Framework for Integrated STEM Approach in Science Education

STEM Disciplines Integration Types

To address research question two, which focuses on the dominant content and the type of discipline integration within K12 STEM education. As shown in Table 2, among the 25 empirical studies, the results revealed the following other distribution among the seven types of integration: the integration of science and engineering (SE) has seven studies, science, technology, engineering and Mathematics (STEM) had five studies, science, technology, and engineering (STE), science, engineering and mathematics (SEM) and science and technology (ST) consists of four studies respectively, and science technology (STM) had one study. These findings suggest that the most prevalent type of integration between science to other disciplines was SE integration, followed by STEM, STE, SEM, and ST Integration. However, STM and SM Integrations were less common and were not found in the reviewed studies.

The integration of engineering into science education can take different forms. It can involve using engineering as a context within science classes, or it can entail teaching engineering content as a part of science lessons (Moore et al., 2014). Additionally, engineering design challenges apply core scientific and mathematical concepts to solve real-world challenges, offering a practical application of these principles in society (Bryan & Guzey, 2020). Another form of integration involves incorporating engineering and technology into science and mathematics education. Bryan & Guzey (2020) noted that engineering and technology can serve as tools or methods in teaching science and mathematics. In this approach, students use engineering and technology design to apply their scientific and mathematical knowledge and skills to solve design problems. Furthermore, technology is often employed as a tool by scientists and mathematicians to address problems and mathematics ("A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas," 2012). The level of integration can vary, encompassing disciplinary, multidisciplinary, interdisciplinary, or transdisciplinary approaches (Wei & Chen, 2020).

The results also indicate that STEM discipline integration does not necessarily require the inclusion of all STEM disciplines; it typically involves the integration of at least two of these disciplines. Furthermore, the findings highlight the prevalence of science and engineering integration in the reviewed empirical studies. Overall, the extent of integration may differ, with some studies adopting a more disciplinary approach, while others employ multidisciplinary, interdisciplinary, or transdisciplinary approaches to STEM integration. The choice of integration approach depends on specific educational goals and the nature of the content being taught.

Table 2: Overview of science subject integrated with other STEM disciplines and level of education by each study.

Authors	Discipline Integration Types							K-12 Education Level			
	STEM	STE	SEM	ST	STM	SE	SM	Pre-Pri	Pri	Low-Se	Up-Se
Aranda, Guzey, et al., 2020						√			√		
Aranda et al., 2020						√			√		
Bernstein et al., 2021		√								√	
Century et al., 2020				√					√		
Chantong, et al, 2020			√							√	
Chiang et al., 2022	√								√		
Ching et al., 2019	√								√		
Chung & Li, 2021			√								√
Crotty et al., 2017			√						√	√	
Dasgupta et al., 2019		√								√	
Dickes et al., 2020					√				√		

Authors	Discipline Integration Types							K-12 Education Level			
	STEM	STE	SEM	ST	STM	SE	SM	Pre-Pri	Pri	Low-Se	Up-Se
Gale et al., 2020	√									√	
Guzey & Jung, 2021						√				√	
Hutchins et al., 2020						√				√	
Jeong & Kim, 2015	√									√	
Johnston et al., 2019			√							√	
Luo et al., 2020				√					√		
Peel et al., 2021				√							√
Petrosino et al., 2016,		√								√	
Rahman, 2021				√					√		
Schellinger et al., 2022						√			√		
Siverling et al., 2021						√			√		
Wieselmann et al., 2021						√			√		
Yin et al., 2020		√									√
Ziaeefard et al., 2017	√									√	√
	5	4	4	4	1	7	0	0	12	11	4

Note: *Pre-Pri= Pre-Primary Education; Pri = Primary Education; Low-se = Lower Secondary Education; Up-Se = Upper Secondary Education)*

Additional findings related to the dominant content within STEM disciplines reveal that engineering and technology were in high proportion integrated with science, whereas mathematics had a lower prevalence as denoted in Table 3. These findings underscore that engineering emerged as the dominant content area with a stronger connection and integration with science subjects, followed by technology. In contrast, mathematics integration with science was less prevalent. The integration of engineering into science education aims to inspire K-12 students to explore engineering design, comprehend the interrelationships between science and engineering, and apply their scientific knowledge and skills to address engineering challenges within their science curriculum (Selcen Guzey et al., 2017).

Table 3: STEM disciplines breakdown in articles

STEM Disciplines	# Article (%), N=25
Science (S)	25 (100%)
Technology (T)	14 (56%)
Engineering (E)	20 (80%)
Mathematic (M)	10 (40%)

STEM Integration in K12 Science Education

In response to research question three, which examines the main focus of integrated STEM education at different K12 educational, and the types of STEM integration observed at each level, the following findings emerge: As denoted in Table 4, a total of 12 studies were conducted at the primary education level, whereas 11 studies were conducted at the lower secondary education four studies took place at the upper secondary education and two studies were conducted at two different levels of education. Crotty et al. (2017), focused on primary and lower-secondary schools, while Ziaeefard et al. (2017), targeted lower-secondary and upper-secondary schools.

These results indicate that the primary and lower secondary education levels received the most attention from previous researchers in terms of integrated STEM education. Conversely, studies at the upper secondary education were less common. It is noteworthy that no studies were conducted in pre-primary education. The implementation of integrated STEM education at the early childhood education level presents various challenges, including students' limited reading, writing, and observational abilities, developmental disparities among students, and the cognitive limitations of young children (Bagiati et al., 2015; Jamil et al., 2018; Park et al., 2017).

Another finding was about the type of STEM discipline integration by educational level: primary education: STEM discipline integration types observed included SE (5 studies), ST (3 studies), and STEM, STM, and SEM (1 study each). Lower secondary education: STEM discipline integration types included STEM (3 studies), STE (2 studies), and SE (2 studies). Upper secondary education: STEM discipline integration types comprised STEM, STE, SEM, and ST (1 study each).

These findings indicate that at the primary education, the integration of two STEM disciplines, SE and ST, was predominant. In contrast, lower and upper secondary education levels tended to focus on the integration of three or four STEM disciplines, including STEM, STE, STM, and SEM. It is noteworthy that at the primary education level, integrating three or four disciplines appeared challenging due to the young age of students and their limited knowledge about the natural world and various aspects of STEM fields. Conversely, implementing three or four content integrations seemed more suitable for lower and upper secondary education levels.

Table 4: Overview of STEM contents integration by level of education

Discipline integration	Primary N=12	Lower Secondary N=11	Upper Secondary N=4
Science, Technology, Engineering and Mathematic	2	3	1
Science, Technology and Engineering	0	3	1
Science Technology and Mathematic	1	0	0
Science, Engineering and Mathematic	1	3	1
Science and Technology	3	0	1
Science and Engineering	5	2	0
Science and Mathematics	0	0	0

CONCLUSIONS

Based on the findings of the systematic literature review, a framework for instructional practices of integrated STEM approaches in K-12 science education has been formulated. This framework encompasses six fundamental elements that have been derived from the common aspects found in actual teaching practices of integrated STEM approaches in science education. These six elements include inquiry, engineering, problem, technology, teamwork, and robotic-based learning. An overview of this framework can be seen in Figure 1.

Additionally, the study revealed that engineering and technology disciplines were the dominant content areas integrated with science within K-12 science education. Among various types of STEM integration, the two-discipline integration of SE was identified as the most prevalent. Furthermore, the study observed that the application of integrated STEM approaches was more frequently encountered at the primary and lower secondary education levels, whereas it was less common at the upper secondary and pre-primary levels. Specifically, at the primary education level, two-discipline integrations such as SE and ST were extensively employed. Conversely, lower and upper secondary education appeared to emphasize the integration of three or four STEM disciplines, including SEM, STE, and STEM.

The study suggests that in primary education, students should be introduced to a variety of knowledge and skills associated with the nature of science and its connections to real-world problems, which serve as fundamental concepts within STEM disciplines. This approach helps students become acquainted with the integration of content areas. Subsequently, as students progress to lower and upper secondary education and beyond, they can effectively engage in more complex integrations involving three or four STEM disciplines. It is advisable to commence with a simpler integration of two STEM disciplines (SE, ST, or SM) at the primary education level due to students' limited knowledge and experiences. As students advance, educators can gradually introduce more intricate three or four-discipline integrations in subsequent educational levels.

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Appendix: Overview of the actual teaching practices from all papers arranged in 6 categories

No	Key Essence	Actual Instructional Practice (extracted from the papers)
1	**Inquiry**	- Introduce the concept of each lesson - Create questions - Observe and watch some activities and videos - Conduct research and investigate - Conduct experiments and hands-on activities - Collecting data, analysis, and interpret results
2	**Engineering**	- Introduce engineering design - Engineering design process - Critique a counterexample or a suboptimal design - Used art supplies and recycled available materials - Test and valid their designs - Competition challenges - Model-building, and challenge tasks - Produce a final report
3	**Problem focus**	- Problem analysis, scoping, and setting the design solution - Identifying problem-solving methods and solutions - Planning for their programming solutions - Search for the clues of the solution to deal with the problem - Develop and construct the solution - Explain and present the solution to solve the challenge - Test the solutions, and constructed prototypes - Modified the idea to enable problem-solving and verify a solution - Develop the project - Share solutions to build a prototype, test and evaluated their prototype
4	**Technology**	- Computational thinking practices - Students play different levels of the game, - Watch program tutorial and practicing programming - use of videos as an instructional tool - Use of devices such as computers and projectors and internet capabilities - Use of software for data collection - Using software to perform procedural construction actions - Solving the design challenge by 3D software - Worked on modelbuilding - Demonstration through simulations, visualizations, and modelling - Create a mineral detector that can detect conductivity - Create a simple project - Change parameters of simulation models - Document the results of running their models with different positive and negative
5	**Teamwork**	- Student-cantered pedagogies - Group discussion and reflection - Collaborative group work - Working as a group to learn, plan, build, test, and redesign their

No	Key Essence	Actual Instructional Practice (extracted from the papers)
		solution and present it to the client - Student teams designed prototypes, tested, evaluated, and re-designed water filters
6	**Robotic**	- Learned the basic controls such as making the robot move forward, backward - Students were provided some accessories of robotics kits which have free coding play such as making Dash push a ball using a towing bar, coding Dash to play Xylophone - Worked on the puzzles with the robotics kits - Design the robots and model them in 3D design software - Assemble their robots as the production result - Working collaboratively to design and assemble robot - Create codes to run their robots using mathematical and computational thinking - Write a program that allowed the robots to navigate - Programming their robots and testing their solution - Discussed what a robot was and how to control robots