The development direction and challenges of STEM integration: a systematic literature review

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ABSTRACT

The development of society has put forward higher requirements for K-12 talent cultivation. However, some situations are not optimistic, such as students' low interest in mathematics, science and other disciplines, and the subject setting cannot match the needs of talent cultivation. Numerous studies confirmed that in the context of curriculum integration, further integration of science, technology, engineering, and mathematics (STEM) curriculum, learning methods and other aspects is needed, but there are still few summaries of the development direction and approaches of STEM in the context of STEM integration. This paper focuses on STEM integration, to clarify the development direction and approaches of STEM integration in the context of education reform, and then systematically summarize the development and existing problems of STEM integration education with a systematic literature review (SLR) method, 62 articles from 2013-2023 were finally selected from Web of Science (WoS). This study reveals the development of STEM curriculum, STEM pedagogy and models in STEM integration, attaches importance to the concept of interdisciplinary integration, advocates curriculum integration and improves students' 21st century skills by integrating. In addition, there needs to be more research focusing on the internal impacts of learning outcomes, STEM literacy, and student STEM identity.

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1. INTRODUCTION

Since the 21st century, the development of technology and advances in information technology have led to considerable interest in science, technology, engineering, and mathematics (STEM) education in countries around the world, there are increasing calls for the teaching of STEM within interdisciplinary settings, as a way of engaging students in authentic tasks and innovation [1], but more in terms of the development of separate STEM disciplines [2], like science, physics, and mathematics, but in recent years, the development of artificial intelligence (AI), big data, cloud computing, the internet of things (IoT) and other emerging industries have gradually recognized the importance of STEM integration in the context of talent training, and the development of society has brought about an increase in demand for comprehensive, complex talent [3], and STEM education has been shown to be effective in enhancing students' complex problem solving skills and has also been shown to be beneficial for career development [4]. Across the field of education, there has been an explosion of scholarly and educator research on STEM education [2]. Higher education has been exploring

STEM education models to find a way to restructure curriculum instruction, elementary schools are also trying to modify their curriculum to bring students' learning closer to real-world scenarios.

The earliest argument about STEM education was actually a perceived threat to national security in the United States from the Soviet Union, and in satellite related areas, the U.S. proposed a major effort to develop science and technology to meet the challenge posed by the Soviet Union, then the concept of STEM was proposed. Some scholars point out that the acronym "STEM" stands for a purposeful integration of individual disciplines as used in solving real-world problems [5], [6]. After nearly 40 years of development, in the last two decades, the U.S. has continued to reform its STEM model by proposing a framework for STEM education based on the STEM concepts, clarifying the consensus understanding of STEM integration, provided the first integrated STEM curriculum resources covering K-12 levels, mapping STEM curriculum roadmap, and providing a STEM implementation at the classroom level curriculum routes to support the systematic transformation of STEM integration approaches. At the same time, data-driven STEM learning and evaluation are used to develop effective STEM curriculum programs and a professional development (PD) framework for STEM teachers, to promote reform of STEM integration curriculum implementation and teaching methods, and train students to use STEM knowledge to solve real-world problems [7], to improve innovation, critical thinking, problem-solving skills, and develop 21st century skills [8].

Worldwide, in addition to the United States, other countries or regions are also doing different reforms in the STEM field. For example, in China, government and education policy makers include STEM education in national and long-term education development goals [9], [10], and recently in 2023, UNESCO has established the international institute for STEM education (UNESCO IISTEM) in China, which is also the tenth category 1st center established by UNESCO in the world and bears the heavy responsibility for the global development of STEM education [11], shows that attaching importance to the development of STEM education, accelerating the training of scientific and technological innovation talents, helping citizens acquire skills and literacy to adapt to future social. For an instance, in the action plan of education informatization 2.0, the ministry of education (MoE) stressed that AI and computer programming courses should become compulsory in primary and secondary school education and need to be included in academic level examination [12]; in the UK, a STEM strategy group has been set up, including the government, with representatives from various levels, including ministers and civil servants, as well as representatives from various disciplinary associations and academic societies [13]; in Germany, STEM education has been mentioned many times in government reports, and it is clear to strengthen STEM education in all stages of German education and develop STEM education in schools [14]; in Japan, the government requires STEM education at the elementary and secondary school levels to focus relatively on the cultivation of STEM research-oriented talents, increase students' interest and enthusiasm in STEM-related subjects, and strengthen STEM elite education at the high school level [15]. In Malaysia, recognizing that enrollment in STEM majors is a concern, the MoE and the ministry of science, technology, and innovation (MOSTI) launched the STEM strategic plan to increase student enrollment in STEM majors to build a STEM literacy society, a high-quality and sufficient workforce [16], [17]. More countries and regions have realized the importance of STEM education for talent training and national development.

In fact, since the emergence of the STEM concept, there have been various definitions of STEM education in academic. Up to now, no consensus has been reached, but many scholars and institutions hold the view of STEM integration [18]. They believe that the essence of STEM education is to discover the intrinsic connections between subject knowledge, and that the most important concept is integration (integrated STEM or STEM integration). This is why, as of now, the further integration of the STEM narrative in different countries and regions has resulted in the emergence of STEAM (add A, art), STEMM (add M, medicine), applied mathematics, science, engineering and entrepreneurship (AMSEE), STIM ("I" means informatics), STREM (add R, reading), GEMS (focus on girls STEM), BEMS (focus on boys STEM) [19]. This also reflects the different understanding and needs of STEM in different countries. Therefore, different needs of STEM are adjusted according to their own situations under the general framework. However, in view of these extensions, STEM is still in the context of integration in general.

So, this study aimed at identifying the dimensions of STEM integration, reveals somes development situations and challenges to explore it is directions. There has been a lot of debate regarding the discussion on STEM integration and practices. Therefore, the corresponding research questions are: i) what aspects of research related to STEM integration? and ii) what does STEM integartion situations in those main aspects?

2. METHOD

This review was conducted using the systematic review method. According to Mengist's *et al*. [20] research, using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) method includes the following two main phases: screening and inclusion. This review utilizes the PRISMA guidelines, in order to be included in this review, for higher reliability and validity, studies needed to be peer-reviewed and finish published in Web of Science (WoS). Eligible articles also need to be published in English with K-12 education. And the search has limited the research to journal articles between 2013 to 2023. To maximize the replicability of our search strategy, we choose to only include research published in WoS journals. In the first phase, following this process, and related research studies were searched by using various combinations of the keywords ‘STEM’, ‘STEM education’, ‘STEM integration’, ‘integrative STEM’, ‘STEM integrated’, among these records we found 394 articles, and after 309 unrelated were removed, we were left with 85 articles might be related to current study for further screening.

In the second phase, duplicates were excluded, and the articles were reviewed to determine whether the studies were suitable for the current study, by examining the abstract, against certain criteria. These criteria were: i) being related with STEM; ii) including the process of K-12 in school; and iii) being peer-reviewed articles. Finally, after manual screening, 62 research studies were included. The articles selected were read by researchers and their aims, procedures and results were presented. These articles selected depending on some common characteristics, such as, how do teachers carry out STEM courses in the classroom, the integrated approach of STEM courses, the learning methods of students, the outcomes of STEM learning. Figure 1 shows these 3 selection processes and results.

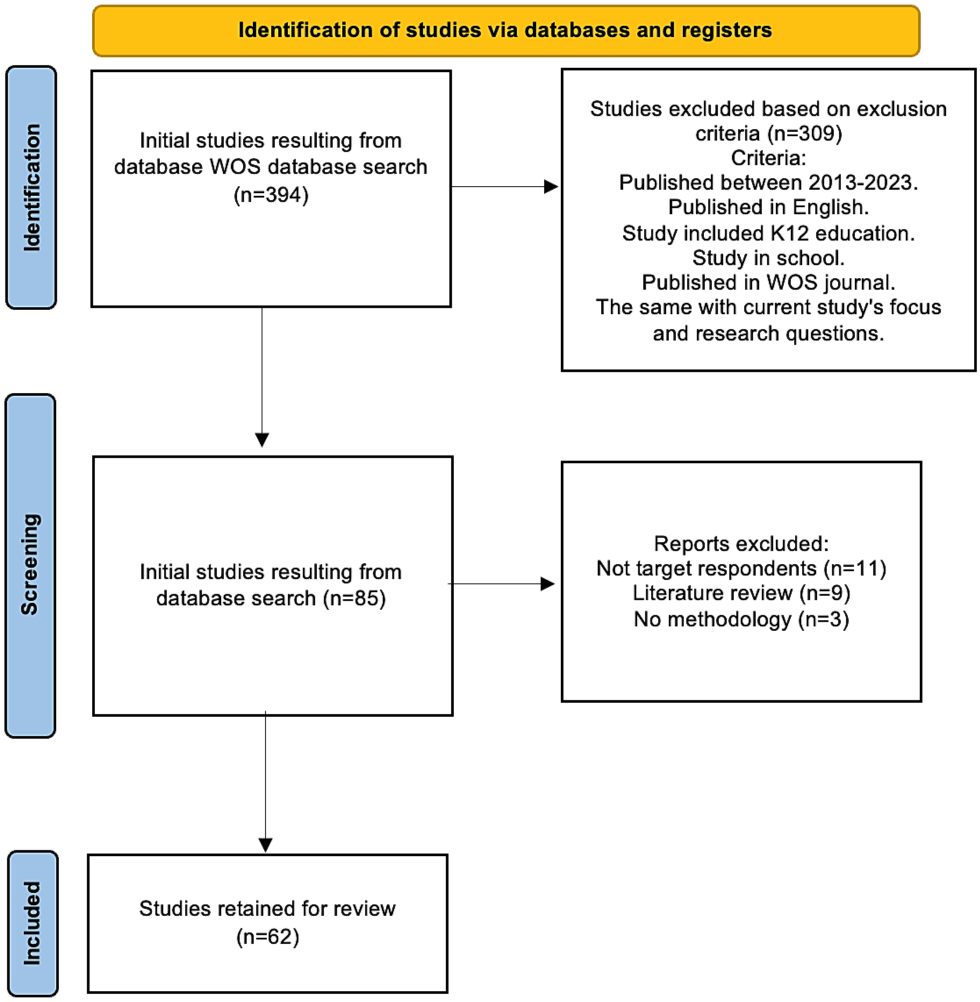

Figure 1. PRISMA flow chart identification of studies via databases

3. RESULTS AND DISCUSSION

3.1. Results

When analyzing the publication years of the 62 retained articles, an interesting phenomenon emerged, even though STEM education was proposed almost 40 years ago, there has been a noticeable increase in research interest in this area recently. Out of the chosen articles, 38 were published in the past three years. The surge in publications that has occurred recently suggests that STEM education has become much more prominent worldwide and that its significance in the current educational environment is being acknowledged.

In order to guarantee the excellence and inclusivity of every article, a thorough rubric was employed, evaluating seven specific criteria: objectives, review of the literature, framework, participants, methods, results and conclusions, and significance [21]. The research was condensed and amalgamated into 6 distinct groups, shows in Table 1. The initial category, comprising 12 studies, centers on STEM curriculum and investigates the incorporation of diverse disciplines within the framework of curriculum integration. It examines how each subject contributes to the STEM learning process and analyzes strategies for interdisciplinary learning. The second and third center around pedagogical techniques in STEM education and learning projects that are backed by methodologies such as problem-based learning (PBL), engineering-design learning (EDL), and game-based learning (GBL), these methods effectively enhance students' research skills. The fourth category consists of 15 research on STEM models, with a focus on student-centered learning activities such as project-based learning (PjBL) and innovative learning models. The fifth category, comprising of 4 research, underscores the crucial role of teachers in the incorporation and advancement of STEM curriculum, emphasizing their important contributions to the instructional process. The last category comprises four studies that examine assessment systems in interdisciplinary STEM integration, evaluating the efficacy of various evaluation approaches. This study especially examines the STEM curriculum, STEM pedagogy, and STEM models to investigate the directions and ways for development in these three areas of STEM integration.

Based on findings, we can categorize the modules and processes that are part of STEM integration in the K-12 stage. The framework is composed of 6 components: teacher, project, pedagogy, model, curriculum, and evaluation, with K-12 students being the focal point from the students' perspective. From an educational perspective, these modules precisely constitute a closed loop of teaching and learning, as depicted in Figure 2. This essay will explore the concepts of STEM curriculum, STEM pedagogy and STEM model.

Table 1. Results of initial search

Category	Objective	Database	Quantity
1	STEM curriculum (SC)	WoS	12
2	STEM pedagogy (SP)	WoS	22
3	STEM project (SPj)	WoS	14
4	STEM model (SM)	WoS	15
5	STEM teacher (ST)	WoS	4
6	STEM evaluation (SE)	WoS	4

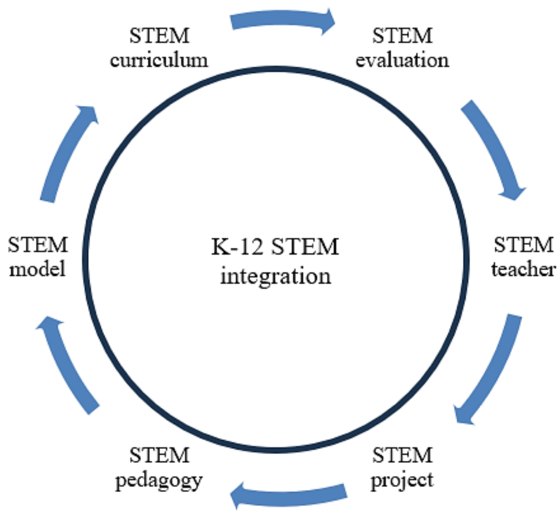

Figure 2. Framework of K-12 STEM integration

3.1.1. STEM integration articles related to STEM curriculum

Although there is still lack of accepted definitions of STEM integration, crossing disciplinary boundaries is the main feature of STEM integration [21]. We try to understand STEM integration from different perspectives, from its composition structure, there are several important dimensions in STEM field, among which curriculum integration is the most important. The information that can be obtained from Table 2 is that, 12 studies discussed the STEM curriculum, 5 of them also discussed STEM evaluation, projects or teacher. This part discusses teaching exploration and practice of integrating curriculum design iteration into STEM curriculum. The development direction of STEM curriculum must be interdisciplinary, and the process of integrating curriculum design into curriculum development is constantly iterated and improved, some papers provide a conceptual framework for STEM integration activities and guidelines, and some give suggestions on how to design courses without losing the integrity of the discipline, and some talk about trying to integrate the content of different disciplines, different design methods, different learning methods, so as to achieve the improvement of students' knowledge skills, 21st century skills, emotional attitudes, and other aspects [22]. And there are also research contributes to conceptualizing how interdisciplinary processes that enable synergistic interweaving of disciplines and how curriculum processes can be effectively framed and enacted [23].

Table 2. Articles related to STEM curriculum

Author	Main objectives	Brief description
Ring-Whalen *et al.* [24]	SC	To investigate the conceptions of integrated STEM curriculum held by in-service science teachers.
Aldemir *et al.* [25]		Integration of neural engineering curriculum in high school to support STEM learning.
Aranda *et al.* [26]		In engineering design and science courses, teachers and students integrate STEM curriculum.
Fornsaglio *et al.* [27]		STEM curriculum generated student grouping strategies to assess their impact on student understanding of science concepts, learning perceptions, and attitudes toward science.
Bedada and Machaba [28]		The teaching effect of integrating GeoGebra into STEM curriculum to learn mathematical knowledge.
Guzey and Li [29]		The impact of student behavioral engagement and career eliculation on Achievement in STEM curriculum.
Garner *et al.* [30]	SC and SPj	STEAM curriculum that integrates art and socio-emotional learning content enhance students' interest.
Reynante *et al.* [31]	SC	By analyzing the K-12 STEM learning standards document, identified eight interdisciplinary thematic STEM curriculum.
Zhang *et al.* [32]	SC	STEM teacher experiences and challenges in implementing the invention education curriculum.
Petrosino *et al.* [33]	SC and SE	Differences in implementation and evaluation of engineering integration curriculum in junior high school.
Park and Cho [34]	SC and ST	STEAM curriculum integrating history and STEM integration, to analysis students' historical identity.
Ryan *et al.* [35]	SC	Integrate science and engineering curriculum through their core ideas and practices dimensions.
Tytler *et al.* [23]		Analyzes interdisciplinary STEM curriculum, reveals the design characteristics of collaborative interweaving of STEM subjects.
Juškevičienė *et al.* [22]	SC and SPj	The combination of maker lab and physics in STEAM education provides a comprehensive STEM curriculum.
Chiang *et al.* [9]	SC and SE	Investigate the effect of an integrated STEM curriculum on children's attitudes and engineering design skills.

The studies on STEM curriculum reveals a diverse array of approaches and focus areas, several examined the integration of various disciplines within STEM education. Ring-Whalen *et al.* [24] explored in-service science teachers' conceptions of integrated STEM curriculum, while Aldemir *et al.* [25] investigated the integration of neural engineering curriculum in high schools, and Aranda *et al*. [26] focused on integrating STEM in engineering design and science courses, other studies assessed the impact of innovative teaching strategies and tools. Fornsaglio *et al.* [27] evaluated the impact of student grouping strategies on science learning, Bedada and Machaba [28] analyzed the use of GeoGebra for teaching mathematical concepts, and Tytler *et al.* [23] examined the collaborative design of interdisciplinary STEM curricula. The role of student engagement and attitudes was highlighted by Guzey and Li [29], who studied the effects of engagement and career-focused activities on STEM achievement, and Chiang *et al*. [9], who assessed the impact of STEM curricula on children's attitudes and engineering skills. Furthermore, studies by Garner *et al*. [30] and Juškevičienė *et al.* [22] focused on integrating art and socio-emotional learning into STEM (STEAM) and combining maker labs with physics, respectively. Additionally, Reynante *et al.* [31] identified interdisciplinary themes within K-12 STEM standards, while Zhang *et al.* [32] detailed teachers' experiences with invention education curricula. Petrosino *et al.* [33] compared implementation methods for engineering curricula in junior high schools, and Park and Cho [34] explored integrating history with STEM to enhance students' historical identity. These studies collectively highlight the evolving landscape and multifaceted nature of STEM curriculum integration, emphasizing interdisciplinary approaches, innovative methods, and the critical roles of teachers and student engagement.

The results indicate that the integration aspect of the STEM curriculum exhibits a wide range of variations. Within the framework of multidisciplinary and multi-disciplinary integration, STEM disciplines expand beyond STEM to include STEAM, STEM+N, where N encompasses not just humanities and social sciences. It also integrates disciplines such as medical engineering, laboratory fabrication in physics, and history within the STEAM framework. Based on the integration of STEM principles, we have developed a conceptual framework for the STEM integration curriculum. This framework, referred to as the dimensions of STEM integration curriculum, is illustrated in Figure 3.

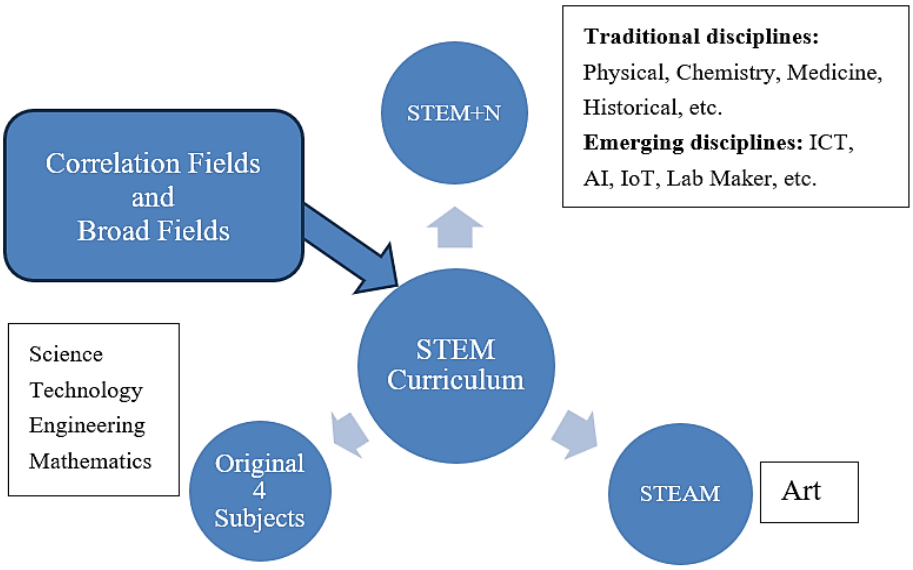

Figure 3. Subject dimensions of STEM intergration curriculum

3.1.2. STEM integration articles related to STEM pedagogy

Leung [36] identified STEM pedagogy as a pedagogical system in which different STEM components impact with each other under the learning environment. Learning approaches which STEM pedagogy focus on in Table 3 reveals that out of the 62 journal papers, the highest proportion, consisting of 22 studies, focuses on STEM pedagogy. Among researchers primarily examine learning methods such as PBL (PrBL or PjBL), EDL, inquiry-based learning (IBL), and GBL. These methods are closely related to educational research and emphasize the integration of STEM pedagogy based on STEM curriculum. The reviewed studies on STEM curriculum integration reveal various pedagogical approaches and their impacts on student learning and engagement. Several studies focused on EDL. In [37]–[41] examined EDL's role in integrating STEM disciplines, improving student learning outcomes, and assessing STEM mastery. Lie *et al.* [42] emphasized the importance of design within EDL. Siverling *et al.* [43] further explored combining EDL with EBR. PjBL was another common focus, with Wieselmann *et al.* [44], Lynch *et al.* [45], Lee *et al.* [46], and Belland *et al.* [47] investigating its effects on student engagement, cognitive development, and interest in STEM careers. Navy and Kaya [48] looked at PrBL's application in primary schools, and other pedagogical approaches included design learning (DL) by Karahan *et al.* [49], active learning (AL) by Gonzales *et al.* [50], and game-based learning (GBL) by Moore *et al.* [51]. Additionally, Chung and Li [52] integrated issues-based art education (IBAE) to emphasize inquiry and real-world learning, while Cruz-Sandoval *et al.* [53] used competency-based learning (CBL) to emphasizes knowledge, attitudes, and skills to make informed decisions and meet professional challenges effectively. These studies collectively highlight the effectiveness of diverse methodologies in enhancing STEM pedagogy integration and improving student learning outcomes.

STEM Pedagogy can be categorized into two aspects based on learning styles: student-centered learning and teacher-centered learning, shows in Figure 4. In the present STEM classroom environment, the previous teacher-centered method is rapidly being superseded by the student-centered learning model. Researchers and scholars have employed many STEM learning styles, such as PjBL, PrBL, project-oriented problem-based learning (POPBL), IBL, DL, and AL. Among them, PBL (including PjBL and PrBL), POPBL, IBL, and DL are the most widely utilized.

Table 3. Articles related to STEM pedagogy

Author	Main objectives	Brief description
Guzey *et al.* [38]	SP (EDL)	To assess the impact of EDL basic science courses on student learning outcomes and attitudes.
Guzey *et al.* [39]		The impact of EDL basic science courses on the learning and achievement of the K12 student population.
Johnston *et al.* [40]		Using engineering to integrate science and mathematics in the STEM integration unit of EDL to help students in engineering practice.
Mathis *et al.* [41]		Students use science and math concepts in integrated STEM unit on the foundations of EDL, demonstrating that EDL pedagogy curriculum assesses students' STEM mastery.
Lie *et al.* [42]		Design concepts of students participating in STEM unit of EDL foundation, clear the importance of design in integration process.
Siverling *et al.* [43]		In STEM integration unit, students integrate all STEM disciplines while demonstrating designs, supporting engineering design fundamentals as a curriculum pedagogy.
Wieselmann *et al.* [44]	SP (PjBL)	Analyze different STEM PBL curriculum units at K12 stage and explore the learning effects of integrating PBL into STEM at different stages.
Lynch *et al.* [45]		Improve STEM skills through PjBL, technology integration, and robust STEM courses.
Lee *et al.* [46]		To confirm the influence of STEM PBL pedagogy on students 'emotional engagement in mathematics.
Belland *et al.* [47]	SP (PrBL)	Increase student cognitive engagement and introduce interesting STEM careers by integrating STEM PBL into the mathematics curriculum.
Navy and Kaya [48]		Explore the application of STEM PBL pedagogy developed by teachers integrating STEM subjects in primary schools.
Karahan *et al.* [49]	SP (DL)	Explore the influence of STEM integrated media DL pedagogy on students' attitudes towards science and technology courses.
Gonzales *et al.* [50]	SP (AL)	Explore the possibility of STEM integration courses and providing STEM opportunities for students through the implementation of STEM AL.
Moore *et al.* [51]	SM and SP (PjBL)	Implementation of a STEM+C model integrating pictures and engineering design in early childhood classrooms.
Li *et al.* [54]		A STEAM model that addresses the problem of insufficient STEM teachers and STEM integration through collaboration and PjBL.
Way *et al.* [55]		A three-level STEM Model helps teachers and students build STEM skills, design processes, and integrated STEM programs.
McHugh *et al.* [56]		The impact of the STEM MISP model on students' science knowledge, problem-solving skills, and math attitudes.
Chung and Li [52]	SP (IBAE)	Integrate IBAE into STEM emphasizes inquiry, real world learning, and critical thinking through IBAE pedagogy.
Cruz-Sandoval *et al.* [53]	SP (CBL)	CBL pedagogy to enhance integration of knowledge, attitudes, and skills, enabling individuals to make informed decisions and meet professional challenges effectively.
Baker and Galanti [57]	SM and SP (EDL)	MEAs serve as a STEM model to help mathematics teachers build a vision of STEM integration.
Siverling *et al.* [43]	SP (EDL and EBR)	Eexplore the use of EBR in EDL STEM integration units.

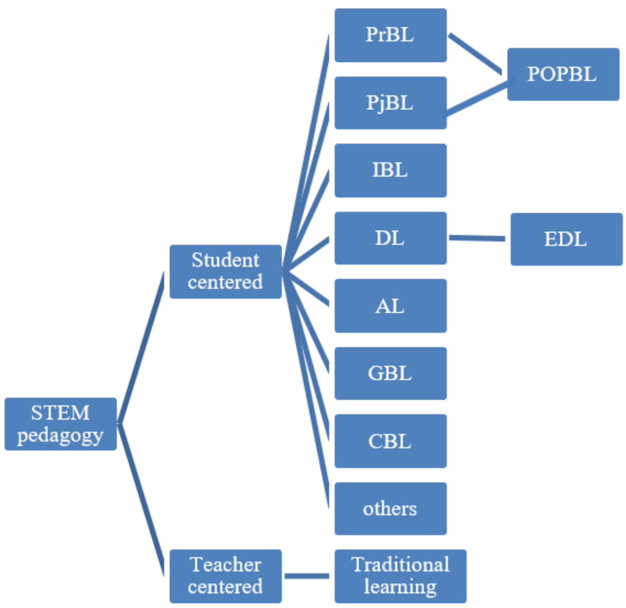

Figure 4. Dimensions of STEM pedagogy

3.1.3. STEM integration articles related to STEM model

The reviewed studies on STEM models explore diverse approaches and their impacts. Gencer *et al.* [58] and Eğitimi *et al.* [59] focus on theoretical integration strategies and the shift towards innovative, integrated models. Gale *et al*. [60] delve into key components and specific implementation cases within STEM models, including the INSPIRES curriculum, which emphasizes biology and technology education. Waterman *et al.* [61] and Araya *et al.* [62] integrate computational thinking and machine learning into STEM courses, bolstering data analysis and modeling skills. Quigley *et al.* [63] and Ortiz-Revilla *et al.* [64] examine problem-based instruction models and their impact on civic education. Tijaro-Rojas *et al.* [65] adopt a systematic and integrative sequence approach in physics education. Baker and Galanti [57] utilize mathematical modeling activities (MEAs) to foster STEM integration in mathematics education. Way *et al.* [55] and Lu *et al.* [66] introduce multi-level STEM models and project-based learning (PjBL) strategies to nurture STEM skills and creativity. McHugh *et al.* [56] evaluate the impact of the STEM MISP model on science knowledge and problem-solving skills. Moore *et al.* [51] and Li *et al.* [54] address teacher shortages and early childhood education through collaborative STEAM models and integrated STEM+C approaches. Collectively [51], [54], these studies highlight the diverse strategies and significant benefits of various STEM models in improving educational outcomes.

Table 4 indicates that among the 62 journal papers, 15 studies discuss the STEM model, 5 of which also discuss STEM pedagogy, and 1 discusses STEM teacher. This part discussed the progress of STEM curriculum integration under different models, which been designed and verified by scholars. In summary, STEM model mainly focuses on three types of STEM integration: curriculum integration, learning mode and teaching mode. Like Waterman *et al.* [61] designed the strategy of integrating computational thinking into core elementary STEM subject areas was intended to cultivate computational thinking practices in support of science learning. Within the context of a year-long professional learning program in Australia, Way *et al.* [55] developed an innovative tri-level approach to skill-building for teachers and their students.

Table 4. Articles related to STEM integration model

Author	Main objectives	Brief description
Williams *et al.* [1]	SM	To explore STEM models in INSPIRES curriculum and majors on the pedagogy of biology and technology education.
Gencer *et al.* [58]		Explores integrated STEM model from the theoretical level and emphasizes the integration strategy of STEM education.
Eğitimi *et al.* [59]		STEM model promotes the transition from departmental teaching to an integrated model that promotes innovation.
Gale *et al*. [60]		Key components and specific implementation cases of STEM model.
Waterman *et al*. [61]		Computational thinking is integrated into STEM courses, and students' ability of data analysis activities is explored through three kinds of STEM integration models.
Araya *et al.* [62]		STEM models of computational thinking, modeling capabilities, and machine learning activities are integrated into STEM education.
Quigley *et al.* [63]		STEM models of problem-based instruction, disciplinary integration, and problem-solving skills.
Ortiz-Revilla *et al.* [64]		STEM model analyzes the goals of comprehensive STEM education and discusses its impact on civic education.
Tijaro-Rojas *et al.* [65]		A STEM model's systematic and integrative sequence approach (SISA) applied in physics.
Lu *et al.* [66]	SM and SP	An integrated STEM curriculum model, through PjBL strategies, cultivates creativity.
McHugh *et al.* [56]	(PjBL)	The impact of the STEM MISP model on students' science knowledge, problem-solving skills, and math attitudes.
Li *et al.* [54]		A STEAM model that addresses the problem of insufficient STEM teachers and STEM integration through collaboration and PjBL.
Moore *et al.* [51]		Put engineering as the basis of STEM, the views and suggestions of STEM integration in early education were summarized through GBL.
Baker and Galanti [57]	SM and SP (EDL)	MEAs serve as a STEM model to help mathematics teachers build a vision of STEM integration.
Way *et al*. [55]	SM and ST	A three-level STEM Model helps teachers and students build STEM skills, design processes, and integrated STEM programs.

In addition, researchers focused on and designed STEM integration-oriented projects based on STEM curriculum and pedagogies, there are the innovation implementation framework activities for visual innovation, PD program using the INSPIRES educative curriculum, conceptual model of STEAM, innovative STEAM education model supported by cooperative teaching [67], SISA [65], MiSP [68]. In this review, the STEM model considered to be an intermediate process between STEM pedagogy and STEM curriculum, and STEM

Model built through student-centered pedagogy is supported [46]. Student-centered model design is also the development trend of STEM integration [69].

3.2. Discussion

The discussion on STEM integration has attracted wide attention, there are 62 literatures, among which 15 discuss STEM curriculum, 14 discuss STEM projects, and 22 discuss STEM pedagogy. Besides, there are 4 studies on STEM teachers, 14 papers on STEM models and 4 papers on STEM evaluation. Some of them contain multiple discussions, so the overlaps are counted in the final results. From the results, it can be seen that STEM integration is emphasized in K-12 education. The 62 literatures screened support that STEM integration cultivate students' real-world problem-solving ability and 21st century skills. The construction of the STEM integrated curriculum, the pedagogy they followed, the model design of project learning, IBL, EDL, PBL are all commonly used learning methods and others learning methods like GBL and CBL in the educational field at present, they all value student-centered learning [51]. A large number of courses, project cases and appropriate learning methods are widely carried out in K-12 schools and have been widely recognized [70].

The surge in publications related to STEM education, particularly evident in the last three years, underscores the growing recognition of STEM's importance in modern education. This proliferation of research reflects a global acknowledgment of the need to advance STEM education to meet the demands of an increasingly complex world. Through a meticulous evaluation employing a comprehensive rubric, this study has identified six distinct categories encapsulating the breadth of research in STEM education. The first category focuses on STEM curriculum integration, exploring the amalgamation of diverse disciplines to enhance interdisciplinary learning, studies within this category delve into strategies for integrating subjects such as science, engineering, and mathematics, shedding light on how each contributes to the overall STEM learning experience. Pedagogical techniques in STEM education constitute the second and third categories, with a focus on methodologies such as PBL, EDL, and GBL, by employing these methods, educators aim to enhance students' research skills and deepen their engagement with STEM pojects. The fourth category centers on STEM models, emphasizing student-centered learning activities like PBL and innovative teaching methods, these studies highlight the efficacy of student-centric approaches in cultivating critical thinking and problem-solving skills. The fifth category underscores the pivotal role of teachers in advancing STEM curriculum integration, The last category underscores the pivotal role of teachers in advancing STEM curriculum integration, studies within this category explore the contributions of educators to instructional processes and highlight the importance of PD in fostering effective STEM teaching practices. The last category investigates assessment systems in interdisciplinary STEM integration projects; by evaluating various evaluation approaches, researchers aim to gauge the effectiveness of these projects in fostering holistic learning outcomes.

Further analysis of the reviewed studies reveals a diverse array of pedagogical approaches and their impacts on student learning and engagement. From EDL to PBL and IBAE, these methodologies offer promising avenues for enhancing STEM curriculum integration and improving student outcomes. Additionally, the exploration of STEM models showcases a rich tapestry of strategies aimed at improving educational outcomes. From theoretical integration strategies to the incorporation of computational thinking and machine learning, these models offer valuable insights into enhancing data analysis, problem-solving, and critical thinking skills among students. In conclusion, the breadth and depth of research in STEM education underscore its significance in modern educational discourse. By embracing interdisciplinary approaches, innovative pedagogies, and leveraging the expertise of educators, stakeholders can continue to advance STEM education and equip students with the skills needed to thrive in an ever-evolving world.

3.2.1. STEM integration and STEM curriculum

When we discussing STEM integration, it is necessary to clarify the concept and development of curriculum integration, because in essence, STEM integration is a form of curriculum integration [71]. The other terms for curriculum integration are transdisciplinary curriculum and convergence curriculum. The idea of curriculum integration comes from the realization that practical problems in the real world are not solved by separate subjects in school education, and that in many cases, the skills people need are developed through an integrated curriculum [72]. For example, mathematical knowledge, chemistry knowledge, geography knowledge, and even art and music knowledge may be applied to solving physics problems. The discussion on curriculum integration has always been a very hot topic in the educational circle, but up to now, the academic circle's description of curriculum integration is still not conclusive [73].

The two terms often used in the literature to describe curriculum integration are 'multidisciplinary' and 'interdisciplinary', and most scholars distinguish between multidisciplinary and interdisciplinary integration by the pathways and degrees of integration. Integration pathways are broadly divided into two types, correlation fields curriculum and broad fields curriculum, depending on how they are organized [2]. The way courses are organized in correlation curriculum fields is currently popular because it preserves the identity of each subject and allows each subject to be run as an independent course [74]. However, the implementation of correlation fields poses a major challenge in that it requires a high level of curriculum and teacher-student collaboration. The correlation fields attach great importance on the level of curriculum integration, and the curriculum needs to be dynamic, and teachers need to ensure that there is a close relationship between the integrated curriculum and each independent course in the process of curriculum design and implementation [71]. In addition, major changes are needed to accommodate the harmonization of the integrated curriculum and other subjects, or they are abandoned due to incoherence. Such as in the integration of engineering courses, the knowledge of physics needs to be applied, and the knowledge of physics is closely connected with the knowledge of mathematics. In the process of solving this engineering problem, the knowledge of mathematics that needs to be applied does not match the knowledge of physics. In other words, students do not have the same level of mastery of mathematical knowledge and physical knowledge, which makes the integration course of solving engineering problems very difficult to carry out.

The counterpart of correlation curriculum fields is the integration of broad fields curriculum. The broad fields curriculum model [75], on the other hand, removes the boundaries between disciplines and integrates all disciplinary content into new areas of learning. The broad field curriculum model of STEM education no longer emphasizes the existence of physics, chemistry, and even science as separate disciplines, and instead integrates STEM content into a structured curriculum structure. The integration of broad areas of curriculum is generally achieved through activities or projects in the form of thematic activities or projects further achieve a coherent and organized structured curriculum structure [2]. For example, the teacher is given an intelligent track-seeking car project, and integrates the relevant knowledge of science, technology, engineering, mathematics, physics, computer and other courses into the project, and learns by completing the project. Therefore, the restriction between disciplines is broken, and students can experience learning in real situations through activities or projects, so that they can learn knowledge of various subjects unconsciously. But at the same time, it needs to be noted that the grasp of the balance between subjects puts forward higher requirements for teachers.

Some evidences indicate STEM integration was not provided a strict definition to avoid limiting creativity in an area that still requires research and practice [73]. Integrated STEM Education Framework talk about 'STEM integration' refers to the teaching of science or mathematics subject matter and practices through engineering practices and engineering design that integrate related technologies. The disciplines of STEM education are closely linked in an integration approach that prepares students to attempt to learn knowledge and skills that can be flexibly transferred to solve real-world problems [7], [76].

Traditionally, the most common and widespread curriculum model remains that of separate subjects [2], each subject is taught separately, but with little attention paid to how subjects relate to each other. For example, students are exposed to math and English from kindergarten level to science, physics, chemistry, and biology in middle and high school, and most of the curriculum is assessed through exams or curriculum tests that measure achievement. STEM, on the contrary, is more of an "integrated curriculum design" that integrates STEM and even more disciplines in a way that shows more clearly the functional relationships and deeper connections between the curricula. We tend to define STEM integration as a group of related but different disciplines that are formed into a single learning area. Topics from different fields are combined into new teaching tasks, so that each topic is no longer prominent in the new teaching tasks, and more comprehensive and broader project case courses are taken instead, like robot projects, intelligent aircraft projects, or intelligent track-seeking car projects, such courses are a combination of physics, mathematics, computer, art, music and a series of related subjects.

Interdisciplinary is an important core feature of STEM education. The disciplines in STEM education must be closely linked to foster students' mastery of knowledge and skills in an integration way and be able to make flexible transfer applications to solve real-world problems. In general, the division of knowledge by subject is helpful for scientific research, delving into the mysteries of natural phenomena and dividing knowledge into modules that are easy to teach, but does not reflect the authenticity and interest of our living world [77]. As a result, teaching in separate subjects has become a major disadvantage in today's highly developed world [75]. In response to this problem, there has been a trend to eliminate sub-disciplines and to integrate education, Maryland University engineering professor Leigh R. Abts uses "meta-discipline" to describe STEM, meaning that it is an integration knowledge domain representing science, technology, engineering, mathematics and other disciplines that exist in the real world and are indispensable and interconnected with each other [77], [78]. STEM interdisciplinary means that educators did not focus on a specific discipline or focus too much on disciplinary boundaries [1], but changed to specific problems, emphasizing the use of related knowledge from STEM disciplines to solve problems and achieve the educational goal of improving students' ability to solve real-world problems across disciplinary boundaries and from the perspective of integration application of multidisciplinary knowledge.

3.2.2. STEM pedagogy and STEM model

A mature comprehensive STEM curriculum needs to be supported by the coordination of teacher resources and other supports in different disciplines, this is a precondition which also becomes a relatively large challenges, just like the problems we mentioned before, in some common STEM models, often require several disciplines or even interdisciplinary and inter-school teams to carry out, especially some largescale projects [79]. The STEM model for K-12 have become broader, schools and society are trying to integrate more information technology into the K-12 in order to provide students with more opportunities, STEM programs, such as robotics projects, astronomy projects, art and humanities projects, and bioinformatics projects, involve not only K-12 but also whole education stage [80]. STEM curriculum in either direction may require different models like learning methods, different learning designs, and different teacher roles at different times. While research strongly argues for interdisciplinary, student-centered design, it is more important that any framework be flexible enough to accommodate other approaches [81].

On this basis, scholars have explored a series of methods suitable for practice. STEM education especially based on students centered pedagogies has the potential for increasing students' cognitive engagement while, at the same time, introducing interesting STEM careers. At present, PjBL, PBL, and EDL are the most commonly used learning methods, which have been proved to be helpful for students to improve their STEM level, develop skills and choose career paths in the 21st century [39], [48], [82]. Researchers also continue to gain experience in these designed programs that can make STEM education more interdisciplinary. In fact, the construction of these STEM curriculum and programs requires the support of many resources, including support from external social, from within the school, and from STEM discipline leaders [83], at the same time more important is the implementation of the subject teachers and students' support. These projects require constant iterations due to traditional beliefs about curriculum and assessment, time and space constraints, and challenges to changing curriculum structures. Therefore, it will be very difficult to carry out reform smoothly.

Historically, integrated curriculum advocacy has never prevailed against disciplinary interests [79], [84]. One may also ask, based on previous experience, whether the reform of interdisciplinary STEM integration will make a difference with regard to current needs. Perhaps, with the call for a reorientation of education, major changes in the way knowledge are acquired, teachers and students engaging in STEM, STEM integration will become an established phenomenon. Perhaps more importantly, STEM integration could be a constant source of motivation for educational discipline reform.

4. CONCLUSION

Overall, plenty of research proposed that STEM education should pay attention to interdisciplinary integration, not only the integration of the original four disciplines, but also the integration of STEM and other disciplines, at least the integration of one STEM discipline and one non-STEM discipline. However, no matter how the external integration of subject changes, the core of STEM education is to achieve flexible cross-integration among disciplines through interdisciplinary education, promote the development of various disciplines, and achieve personal ability improvement or physical innovation, this point has always been indisputable. STEM education emphasizes interdisciplinary crossing and integration and achieves the development of students' diverse abilities through the learning of knowledge structure and application mode among different disciplines. We can rely on the subject transfer idea of STEM education to realize the knowledge application between subjects through practice. Due to the need for scientific progress and development, various disciplines have gradually separated and formed their own relatively independent system. However, when facing real problems, students need to integrate multiple disciplines to apply real situation problems and form a more complete and coherent understanding of the world in the process of constant subject conversion.

This article summarizes some integration frameworks and the development paths and methods of STEM integration. In particular, this study reveals the development of STEM curriculum, STEM pedagogy and model in STEM integration, and pays attention to the concept of interdisciplinary integration, advocates curriculum integration, and improves students' abilities by integrating curriculum or learning methods. Additionally, it is important to note that research on the internal impact of learning outcomes, STEM literacy, and students' STEM identity remains insufficient, as well as limited research on how to explicitly integrate existing STEM subject curriculum standards to address real-world problems and improve 21st century skills. Considering the current real challenges, subsequent research needs to further explore the intrinsic connection between curriculum implementation methods and STEM outcomes to provide more data support for the development of STEM integration to better improve learning effects and cultivate talents for social development.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare there is no competing interests.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [ZL], upon reasonable request.

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