STEM Education in China: A five years review report

Abstract: Recently, with the rapid development of STEM education, a large number of related studies have emerged. To understand the latest research status and trend of STEM education, the author used the literature analysis method to sort out and analyze the high-quality STEM education articles in recent five years, and the results show that: Domestic STEM education studies mainly focus on the following four aspects: STEM education concept, STEM education development path, STEM education design, and empirical research on STEM education, research on STEM education has gradually shifted from conceptual research to practical research, such as paying attention to STEM teachers' development, curriculum design, teaching model construction, etc. The advantage of previous research is that scholars have constructed many models to promote the development of STEM education practice, which provides support for promoting the localization of STEM education in China, but the development path of STEM education proposed by predecessors lacks top-down specific practices, there is less research on STEM textbook development and evaluation model, the scope of STEM education empirical research is narrow, and the research perspective is not broad enough. The review and analysis of STEM education in the past five years, helps readers and researchers to understand the current situation and frontier development direction of STEM education, identify the hot spots and reform trends of STEM education research, and promote further development of STEM education. Draw some enlightenment from it: future research needs to further promote practices, give specific development paths and top-down reform strategies based on existing research; increase empirical research on STEM education, provide a basis for educators to carry out STEM education practice, and promote sustainable development of STEM education.
Keywords: STEM education; Practice; Present situation; Curriculum; Teacher

1. INTRODUCTION

STEM education is a combination of Science, Technology, Engineering, and Mathematics. Since the National Science Foundation first proposed the idea of STEM education in the 1980s, it has become popular all over the world as a "global science and technology education strategy in the era of the knowledge economy" [1], now it has become an important part of cultivating future talents and responding to social challenges in the field of education in countries all over the world, including China [2]. A large number of scholars have devoted themselves to STEM education research, trying to contribute to promoting the development of STEM education and cultivating high-quality talents. Up to now, there have been a large number of literature on STEM research. Predecessors have reviewed STEM education before 2018, to explore the current situation and development trend of STEM education research after 2018, this paper reviews and combs the relevant research on STEM education in recent five years. This research can not only provide direction for the implementation and improvement of STEM education but also help researchers understand the cutting-edge content and future development direction of STEM education, to continue to deepen development, which is of great significance to the development of STEM education in China.

2. METHOD

2.1 Data Source

This paper adopts the method of literary analysis and takes the literature in the database of China Knowledge Network (CNKI) as the data source. CNKI is the most authoritative document retrieval tool for national academic journals. It covers a wealth of literature and materials, including various disciplines, and has great academic influence. Therefore, this database is selected to ensure the persuasiveness and reliability of the research.

2.2 Data Collection

To understand the cutting-edge content of STEM education research, the author takes "STEM education" as the search term, "subject" as the search item, and arranges it in descending order according to the publication time. The time range is limited to "2018-2022", and the source category is limited to "SCI source journals, Core journal of Peking University, CSSCI". A total of 422 results are retrieved, excluding the literature unrelated to the content of this research, book reviews, and interview articles, finally, 274 qualified literature remained.

2.3 Data Collation

Read the literature closely by taking notes, and the research aspects, research views, and research methods mentioned therein are recorded and coded. Finally, make statistics and summarize the above codes.

3. RESULTS

After sorting out and analyzing all the literature, it is found that the domestic research on STEM education in recent five years mainly focuses on the following four aspects: STEM education concept, STEM education development path, STEM education design, and empirical research on STEM education.

3.1 STEM Education Concept

Qin analyzed the turn of STEM education from the perspective of deep learning and pointed out that we should introduce big concepts to strengthen knowledge connection, and also pay attention to teachers' professional development, to overcome the superficial problems of STEM education [3]. Li and Lv understood STEM education from the perspective of scientific-practical philosophy and believed that the essence of STEM education is to let students intervene in the world and discover the world so that students can obtain authentic learning experiences, and break through the practical dilemma of utilitarian tendency and replication expansion of STEM education [4]. Based on scientific rationalism, Huang and Pei believed that STEM education has a three-tier system framework: belief level-the state of consciousness of STEM education, cognition level-the knowledge structure of STEM education, and method level-the thinking tool of STEM education [5]. Teng and others differentiated STEM education and STEAM education and concluded that STEM education and STEAM education have both similarities and differences in four aspects: theoretical basis, activity type, subject content, and curriculum carrier [6]. Yang and others analyzed the connotation and structural framework of STEM literacy and believed that the connotation definition of STEM literacy should not only clarify the subject category but also emphasize the characteristics of comprehensive ability [7].

From the above analysis, it can be found that some scholars analyzed STEM education from different perspectives, some scholars discussed the relationship between STEM education and other concepts, and some scholars pay attention to STEM literacy.

3.2 STEM Education Development Path

As for the overall development path of STEM education, many scholars have proposed to establish a STEM education teacher training system and build a teacher professional growth path; Promote the integrated construction of disciplines, majors, and courses; Establish and improve the STEM education reform system and mechanism; Expand the education alliance and build a healthy STEM community and enterprise alliance; establish an evidence-based teaching evaluation system, etc. [8-10]. Some scholars also put forward development paths for a specific aspect, including STEM teacher development and SSTEM education implementation paths at all stages.

3.2.1 STEM Teacher Development

The effective implementation of STEM education depends on the quality of STEM teachers. In recent five years, many scholars in China have studied the development path of STEM teachers. Huang’s research team believed that the cultivation of STEM teachers' literacy in primary and secondary schools should start with teacher training, take the form of small-scale offline centralized training, and take scientific literacy, mathematical literacy, engineering practice, etc. as the training content, they believed that the process of centralized training should be expert guidance + theoretical learning, workshop experience + hands-on exploration, on-site observation + contact practice, independent design + in-depth experience, sharing and communication + reflection and improvement, project cooperation + follow-up [11]. Luo believed that the ways to promote the professional development of STEM teachers included strengthening top-level design, innovating STEM teacher cultivation mode, paying attention to practice, establishing STEM teacher access standards, etc. [12]. Mao and others believed that the professional development of leading teachers can be cultivated from three paths, which are suitable for teachers with different ability levels. Teachers can choose different paths to learn according to their conditions, Path 1: observation and imitation - practical experience - transformation and innovation; Path 2: discipline practice - concept promoting change - qualitative change and innovation; Path 3: observation and learning - collaborative innovation - practical improvement [13]. Dong believed that the development path of STEM teachers' information literacy includes: teacher training, observation and cooperation, and personal practice [14]. Miao and others distilled the optimal path of STEM teacher professional development into the following three aspects: establishing competency-based training ideas, sorting out effective STEM teaching methods and integrating them into training programs, and establishing a professional standard evaluation system [15]. Song and Guan advocated that teachers should be the main body of curriculum development through the reform of school institutions and support systems, the establishment of an interdisciplinary learning community to promote teachers to change their learning modes, and the use of technological innovation training to promote teachers' sustainable and independent development [16].

It can be found that for the research on STEM teacher development, scholars have proposed optimization paths from different angles, but they all mentioned teacher training and practice improvement.

3.3 Implementation Path of STEM Education at All Stages

3.3.1 STEM Education Development in Childhood Stages

As the initial stage of implementing STEM education, STEM education for preprimary children is receiving increasing attention [17]. Gao and others stressed that teachers should create a good supportive environment for children, pay attention to the strategic nature of language guidance, and integrate rich subject knowledge and experience into learning activities in a project-based way to promote the improvement of children's STEM literacy [18-22]. Wei and others advocated that families, schools, and society should provide learning resources for children and coordinate the diversified STEM education resources of "home-school-community" [22-23].

3.3.2 STEM Education Development in Primary and Secondary Schools Stages

Zhou believed that the implementation of STEM education should be promoted in the basic education stage from the following aspects: integrating STEM education into subject courses, integrating engineering and technology education into science and mathematics education, and holistic designing STEM education in and out of subjects [24]. Tian put forward suggestions for STEM education in primary and secondary schools, such as strengthening interdisciplinary learning and cooperation, strengthening the construction of compound teaching staff, strengthening the research and practice of localization, and strengthening the development and cooperation of resources, to accelerate the research and practice of STEM education in China [25]. Wang believed that the development of STEM education in the basic education stage can be promoted from the aspects of building a STEM education experimental system, building a STEM education think tank platform, establishing a STEM educator training system, promoting STEM education academic research, and using information technology to empower STEM education. He pointed out that it is these practical measures that promote the successful implementation of Shaanxi universal STEM education [26].

3.3.3 STEM Education Development in Colleges and Universities

There is not much research on STEM education in colleges and universities in China. Bai believed that there is still a prominent problem of insufficient talent innovation ability in China's high-level engineering industry characteristic colleges and universities. To change this situation, colleges and universities should pay attention to cultivating students' cross-border integration ability in professional teaching, promote the integration of disciplines, majors and courses, implement project-based teaching, establish an evidence-based teaching evaluation system, establish and improve the STEM education reform system and mechanism [27].

It can be seen that most scholars have proposed the development path of STEM education from the perspective of teachers, curriculum, multi-party cooperation, and evaluation system.

3.3 STEM Education Design

The development of STEM education should not only focus on the overall construction of the STEM ecosystem but also implement the design and exploration of curriculum, teaching, teaching materials, and evaluation models.

3.3.1 STEM Ecosystem Construction

As an interdisciplinary integrated education model, STEM education cannot simply rely on a certain type of teachers or curriculum, but needs a perfect ecosystem to comprehensively ensure the development of SSTEM education [28]. A few scholars have studied the construction of a STEM ecosystem based on the experience of the United States. Gao and others believed that a suitable framework for STEM ecosystem construction should include six elements: hardware facilities, policy funds, teachers, curriculum resources, method practice, and achievement transformation. Perfect hardware and software facilities maintain the normal operation of the system. Policy funds provide an external guarantee for the STEM ecosystem, and teachers are the internal driving force to promote the operation of the STEM ecosystem, Curriculum resources are the scientific support of the STEM ecosystem, and method practice is the premise to promote the benign development of STEM ecosystem, form a dynamic system to ensure the cultivation of students' multidisciplinary ability [28]. Chen believed that an A-STEM learning ecosystem covering all elements and links should focus on school education and the direct social cooperation immediately close to school education. Among them, the producer is the exporter of learning resources, the consumer is the absorber of learning resources, and the decomposer is the analyst of learning resources. The construction strategy should be carried out by strengthening teacher empowerment, establishing partnerships, and accelerating top-level design [29].

3.3.2 Curriculum Design

STEM curriculum is a key element to promote the implementation of STEM education in schools [30]. Improving the quality of STEM education is inseparable from the innovative design of the STEM curriculum [31]. In the past five years, many scholars have tried to develop a STEM curriculum or construct a STEM curriculum system. Ye and others advocated that big concepts should be integrated into the construction of a STEM curriculum system, emphasizing curriculum integration, including technology and curriculum integration, STEM education and science curriculum integration, etc. At the same time, large concepts should be investigated and analyzed in many links of classroom teaching, to ensure that the curriculum can move forward in the direction of "big concepts" and the effective path of student development [32-36]. Many scholars have built STEM curriculum models of integrated design thinking, such as the "O-A-P-S" STEM curriculum design model of integrated design thinking proposed by Wu's team [37], the deep integration model of design thinking constructed by Wang [38], and Chen constructed a STEM integrated curriculum framework of technology education based on design thinking [39]. They all affirmed the importance of design thinking and explained its application to specific cases.

3.3.3 Construction of Teaching Mode

A large number of scholars have constructed STEM teaching modes, including STEM education mode based on advanced learning, STEM engineering design teaching mode oriented to the cultivation of computational thinking, evidence-based STEM teaching mode, "scaffolding+" STEM teaching mode, STEM gamification learning mode, STEM teaching mode specially constructed for secondary vocational schools, STEM teaching mode focusing on the analysis of engineering problem solving, etc. There is also teaching design research based on STEM concepts and taking specific teaching content as an example. Li and others believed that the scientific STEM education model should adhere to the idea of scope and sequence learning, and follow the construction process of "scope and sequence goal design → scope and sequence dimension extraction → achievement level division → academic expectation performance → evaluation and strategy support", formulate ability goals from shallow to deep based on students' a priori level, visually represent the development process and key obstacles of students' problem solving from the starting point to the end of advanced, it also emphasizes the construction of students' cognitive schema to provide effective evidence for the process evaluation of students' problem solving [40]. Gu and others believed that the STEM teaching mode of secondary vocational schools based on the 5E teaching mode and combined with the engineering design process can lay the foundation for the development of STEM education in secondary vocational schools [41]. Wang conducted 6E teaching exploration and believed that letting students experience a series of processes including participation, exploration, interpretation, engineering, deepening and evaluation can stimulate students' initiative and participation, cultivate their ability to solve problems in real situations, and promote the integration of knowledge between different disciplines [42]. Li and Gu believed that the construction of AI-STEM innovation integration mode requires taking design thinking as an action point, creating personalized and flexible activity organizations with the help of AI technology situations, and paying attention to two points in application: the goal of activity design should enlighten students' innovation consciousness and pay attention to the obstacles to the scope and sequence of students' innovation; teachers should appropriately increase guidance or assistance links, and do not rely too much on artificial intelligence technology [43]. After the construction of the teaching model, scholars have applied it in the school classroom to verify feasibility and effectiveness of the teaching model.

3.3.4 Textbook Development

In the past five years, only one scholar has explored the development of textbooks under the STEM idea. This scholar believed that under the STEM education idea, the development of primary school science textbooks should be based on the core qualities of Chinese students' development and the "primary school science curriculum standards for compulsory education" initiated by the Ministry of education in 2017. It is suggested that education publishers should build a STEM education support system to provide educational services matching primary school science textbooks, including building a systematic online and offline teacher training curriculum system, building a STEM education resource platform, and implementing school enterprise linkage [44].

3.3.5 Evaluation Model Construction

Sustainable development of STEM education cannot be achieved without a mature and feasible evaluation tool, and only by continuous evaluation can it be constantly revised and improved. In recent years, some scholars have tried to develop a mature and suitable the development of STEM evaluation model in China. Li's team believed that mature STEM education and teaching quality evaluation tools should include four primary indicators and 22 secondary indicators of classroom environment, curriculum structure, teaching content, and student performance. It should not only comprehensively consider the essential characteristics of STEM, existing STEM education evaluation tools, and indicator dimensions, but also directly focus on classroom teaching, and can comprehensively evaluate all aspects of STEM education [45]. Shou and others believed that the high-level thinking evaluation model for STEM learning should include nine evaluation indicators: problem-solving, metacognition and reflection, creative thinking, critical thinking, decision-making thinking, self-monitoring, migration and application, scientific methods, and self-regulation, with their approximate weights of 19.55%, 5.18%, 15.90%, 13.47%, 25.69%, 3.42%, 7.73%, 5.39%, and 3.67% respectively. The evaluation tool can be used to evaluate the STEM teaching goal of *developing students' high-level thinking* [46].

3.4 Empirical Research on STEM Education

Lian, Jian, and others pay attention to STEM education under knowledge construction and used the experimental method to explore whether the influence mechanism of STEM learning motivation in the crowdsourcing knowledge construction environment can promote the development of students' motivation and whether STEM learning under the knowledge construction environment can have a positive impact on students' learning behavior, learning efficiency, work performance, and other knowledge construction activities, the results were positive [47-48]. Liu investigated the impact of the college entrance examination reform on the STEM academic performance of Tsinghua undergraduates, the empirical research results showed that the STEM course performance of students after the college entrance examination reform is higher than that before the reform [49]. Wu's team carried out an exploratory experiment of applying R language and 3D printing to higher mathematics teaching in combination with STEM education ideas and verified the positive feedback effect of computer-aided tools and STEM education practice activities on the cultivation of interdisciplinary practical innovation ability and the improvement of learning interest of college students [50]. Zhang's team used experimental methods to explore the impact of design-based interdisciplinary STEM teaching on pupils' interdisciplinary learning attitudes, and the results showed that this teaching can improve students' interdisciplinary learning attitudes [51].

With the help of the foreign STEM classroom evaluation scale, Chen's team studied the STEM characteristics of the high-quality science courses in primary schools characterized by STEM. The results showed that the participation of middle school students in the high-quality STEM courses was very high, and paying attention to scientific practice, taking into account the core concepts of the discipline and interdisciplinary concepts [52]. Song and others interviewed primary school science teachers with STEM teaching experience, and using the research method of grounded theory, they obtained a qualitative understanding of primary school science teachers on the characteristics of STEM teaching. In the understanding of the STEM teaching concept, teachers believed that STEM teaching is suitable for all students and can effectively cultivate students' core learning ability in the 21st century; in the process of STEM teaching implementation, teachers believed that STEM teaching theme should focus on a practical problem or project, and determine the specific STEM teaching process according to the teaching theme; in the choice of STEM teaching evaluation, teachers believed that the traditional paper and pencil test can no longer be used as the main evaluation method; in terms of the support and hindrance of STEM teaching, teachers believed that teachers' teaching beliefs and continuous needs for professional development are important factors that affect their acceptance of STEM teaching ideas and willingness to participate in STEM teaching practice [53]. Peng and Zhu interviewed STEM teachers to find out how teachers understand the essence of STEM education and found that teachers' understanding of the essence of STEM education presents two orientations: "teaching orientation" and "subject orientation" [54]. Many scholars also pay attention to the current situation of students' STEM learning, including the current situation of students' emotions in STEM classroom, the current situation of students' STEM learning attitude, the current situation of students' STEM learning effectiveness, the current situation of students' STEM professional interest, and the current situation of STEM education equity. The results show that middle school students STEM learning attitude is generally positive. STEM teaching has positive effects on students' learning attitude, discipline learning, and high-level ability, but middle school students' STEM vocational interest is not high as a whole. Male students, urban students, and students whose parents have higher professional reputations and better family economic conditions have a greater probability of obtaining STEM education opportunities [55-58].

It can be found that the empirical research on STEM education in the last five years probably includes two parts. One part is the impact research, mainly the impact of STEM education on students, and the other part is the current situation research, mainly including the STEM characteristics of primary school science courses, teachers' understanding of STEM education, and students' STEM learning status.

4. DISCUSSION

The author analyzed the current situation of STEM education research in China in the past five years. Scholars' research focused on the following four aspects: STEM education concept, STEM education development path, STEM education design, and empirical research on STEM education.

There is less research on the STEM education concept, and there are less than ten relevant pieces of research literature in the past five years. Its categories include analyzing STEM education from different perspectives, exploring the relationship between STEM education and other concepts, and analyzing the connotation of STEM literacy. Zhang mentioned in his literature review that international STEM education journals pay attention to the research on the connotation of STEM education, he pointed out that previous scholars' understanding of STEM education includes three aspects: STEM education should point to solving practical problems in the real world, STEM education should point to the effective integration of coherent systems of various disciplines, and STEM education should be committed to promoting diversity and inclusiveness [59]. However, this study found that only one scholar has paid attention to the connotation of STEM education in recent five years, which shows that this aspect is no longer a research hotspot. However, future research can deepen the connotation and concept research of STEM education, to provide theoretical support for the practice development of STEM education.

There are a lot of studies on the development path of STEM education, which is consistent with Gong's point that the study on the development path is the focus of domestic STEM education research [60]. Scholars put forward suggestions from the aspects of STEM teacher training, curriculum practice construction, multi-party cooperation, and evaluation system. It can be seen that scholars reach a consensus on the development path of STEM education. Among them, the STEM teacher development path is a hot topic, and scholars have emphasized teacher training and practice improvement. This is consistent with the hot spot of STEM teacher professional development research mentioned by Zhang and others in their review, she also pointed out that most scholars in her research only put forward the relevant literacy that teachers should have under the STEM education idea, and did not put forward some available education and training models [61]. However, this study found that in the recent five years, minority scholars have proposed teacher training models, providing STEM teachers with specific and feasible training paths. It can be seen that the practical research on STEM education in China has developed rapidly in the past five years. Many scholars try to promote STEM education practice from the perspective of teacher training and emphasize multi-party collaboration, which has injected vitality into STEM education and provided specific development measures and directions. In the future, Chinese scholars can vigorously promote STEM education practice from a broader perspective under the background of the national development of STEM education, and provide power for cultivating high-quality talents.

In the aspect of STEM education design, including STEM ecosystem construction, curriculum design, teaching mode construction, textbook development, evaluation model construction, and there are a large number of studies on this aspect, especially curriculum design, teaching mode construction, which is consistent with the results that Wei and others mentioned in their review articles that curriculum design, curriculum system construction, model construction were research hotspots [59-62], it can be seen that in recent years, scholars have paid special attention to the development of STEM education practice and tried to implement the STEM Education described in the article, but there are few studies on the construction of evaluation model. Gong and Zhan also pointed out in their review article that there are few evaluation studies on students' STEM learning results in China [60], which coincides with the conclusion that there are few studies on the construction of evaluation models in this paper.

In the empirical research of STEM education, most scholars use the methods of interview and experiment, the research content mainly includes impact research and current situation research. It can be seen that scholars pay more attention to the current situation and the impact effect of STEM education. The perspective of empirical research has not been opened, and the scope of research is not wide enough. Chinese scholars can refer to foreign research results on STEM empirical education, learn foreign research methods and perspectives, and expand the empirical research on

STEM education.

From the above summary and analysis, it can be found that in the past five years, the research on STEM education has been extensive, and has gradually shifted from conceptual research to practical research, paying attention to the development of STEM teachers, curriculum design, teaching model construction, etc., which is consistent with the number of applied research gradually exceeding basic theoretical research pointed out by Zhang and others in their review articles [63]. There are also some shortcomings in previous studies. In terms of the development path of STEM education, most scholars just shouted slogans and put forward suggestions, but did not propose how to implement them from top to bottom, lacking systematic arrangement and design. In the aspect of STEM education design, there is very little research on textbook development and evaluation model. In terms of STEM education empirical research, scholars' research perspective is not broad enough, the research scope is narrow, and the number is small. It is also necessary to continue to deepen STEM education empirical research.

5. CONCLUSION

The author collated and analyzed the relevant research on STEM education in recent five years, and draw the following conclusions:

(1) The research on STEM education in recent five years includes the following four aspects: STEM education concept, STEM education development path, STEM education design, and empirical research on STEM education.

(2) There is less research on the STEM education concept, which is not a hot topic that scholars pay attention to. In the aspect of STEM education development path, scholars put forward suggestions from the aspects of STEM teacher training, curriculum practice construction, multi-party cooperation, and evaluation system, among which STEM teacher development path is a hot topic. There are many research achievements in STEM educational design, including STEM ecosystem construction, curriculum design, teaching mode construction, textbook development, and evaluation model construction. Among them, curriculum design and teaching mode construction are research hotspots. In the aspect of STEM education empirical research, including impact research and current situation research. The relevant research on STEM education has gradually shifted from conceptual research to practical research, paying attention to the development of STEM teachers, curriculum design, teaching model construction, and so on.

(3) Reviewing the STEM education research in the past five years, it is found that there are deficiencies. The development path of STEM education proposed by predecessors lacks specific implementation practices from top to bottom, there is less research on STEM textbook development and evaluation model, the scope of STEM education empirical research is narrow, and the research perspective is not broad enough.

Therefore, future research needs to further promote practices, give specific development paths and top-down reform strategies based on existing research; increase empirical research on STEM education, provide a basis for educators to carry out STEM education practice, and promote sustainable development of STEM education.

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