

Structural characteristics of STEM education research in China: A content analysis of CNKI-CSSCI (2011–2024)

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Abstract: This study employs content analysis to examine the overall landscape and developmental trajectory of research on STEM talent cultivation in China, drawing on 41 CSSCI-indexed journal articles retrieved from the China National Knowledge Infrastructure (CNKI) database between 2011 and 2024. The findings indicate that the field is characterized by an exogenous, policy-driven impetus: research activity is closely synchronized with national policy releases but lacks endogenous momentum. Research themes are overly concentrated on curriculum design and the adoption of international practices, while implementation aspects—such as teacher development, assessment mechanisms, and industry-education collaboration—receive limited attention. The research ecosystem faces structural challenges, including regional imbalances, segmentation across educational stages, and a narrow range of research subjects. Most studies remain confined to theoretical elaboration, with a notable scarcity of empirical and longitudinal research. Overall, STEM education research in China is at a critical juncture and needs to shift from a “policy-responsive” mode to a “problem-driven” approach. There is an urgent need to strengthen top-level design, cross-sector collaboration mechanisms, and evidence-based research orientations to narrow the gap between theoretical frameworks and practical implementation, thereby better responding to the strategic demands of national innovation talent cultivation.

Keywords: content analysis; industry-education integration; policy-driven; STEM education; structural challenges; talent cultivation

1. Introduction

1.1. Research background

STEM education, as a paradigm of interdisciplinary integration, has been a central concern in global educational reform and the cultivation of innovative talent since it was advocated by the U.S. National Science Foundation in the 1990s [1]. Its development indicates that STEM literacy is not only a crucial indicator of national innovation capacity but has also driven policy diffusion and practical transformation from Europe and the United States to Asia [2,3].

Recent empirical research has increasingly focused on the effectiveness mechanisms of technology-mediated learning environments. Zourmpakis et al. [4] in their study of gamified learning centered on the “water cycle,” demonstrated that, compared with traditional inquiry-based instruction, adaptive gamified environments significantly improved elementary students’ science learning outcomes and helped eliminate initial gender gaps in performance. Uğraş et al. [5], drawing on the

TPACK framework, argued that the structural design of teacher professional development programs—particularly stepwise training models—is a critical determinant of the effectiveness of integrating emerging technologies such as ChatGPT into instruction. In early childhood education, Louka and Papadakis [6] investigated the impact of the ScratchJr programming environment on computational thinking and found that informal learning experiences—such as direct perception of physical phenomena—significantly influence the understanding of abstract concepts, highlighting the epistemological significance of learners’ prior experiences in the construction of STEM concepts.

In China, STEM education was incorporated into the national talent development strategy framework in 2017 [7]. However, a significant gap remains between policy objectives and practical realities. Structural challenges are primarily reflected in two aspects. First, there is a systemic mismatch between talent supply and industrial demand, particularly in strategically emerging fields such as artificial intelligence and intelligent manufacturing, where graduates’ competency profiles struggle to meet industry needs for high-level applied talent [8]. Second, the traditional discipline-based training model has difficulty effectively fostering interdisciplinary thinking and the capacity to solve complex problems collaboratively [9]. These challenges point to two fundamental issues facing the development of STEM education in China: the reorientation of talent cultivation goals and the corresponding restructuring of cultivation mechanisms.

1.2. Research purpose and methods

Against this backdrop, examining research on STEM talent cultivation in China has both theoretical and practical significance for clarifying the current state of the field, identifying research gaps, and establishing future directions. Although existing studies have accumulated over the years, most remain confined to policy interpretation or summaries of regional practice and lack macro-level empirical analysis of overall thematic structures and evolutionary trajectories [10]. To address this gap, this study employs content analysis, using the China National Knowledge Infrastructure (CNKI) as the data source and focusing on articles published in CSSCI-indexed journals. Compared with other journals or academic-commercial periodicals, CSSCI journals undergo more rigorous peer review and have greater academic impact, making them an appropriate indicator of the quality of social science research in China.

This study codes, categorizes, and quantitatively analyzes the selected literature with the following objectives:

1. To delineate research trends by examining changes in annual publication volume, thereby revealing fluctuations in academic attention and stage-specific characteristics.
2. To summarize research themes, specifically the distribution of major topics such as curriculum design, teacher development, industry–university–research collaboration, and evaluation mechanisms.
3. To explore developmental trajectories by analyzing the evolutionary paths of

research themes and their interactive relationships with national policies and economic demands.

4. To incorporate an international comparative perspective by integrating recent empirical findings from Western countries on policy implementation, teacher professional development, evaluation systems, and educational equity.

In summary, this study aims to present objectively the overall landscape and inherent logic of STEM talent cultivation research in China, providing an empirical foundation for policymakers, researchers, and practitioners, and promoting the development of the STEM education system toward greater systematization, evidence-based practice, and stronger industry–university–research synergy.

2. Literature review

2.1. Theoretical foundations and core debates in STEM education

The theoretical foundations of STEM education are primarily rooted in constructivism and situated learning theory. Constructivism posits that learners actively construct knowledge by solving authentic, complex problems [11], providing an epistemological basis for project-based learning. Situated learning theory emphasizes the inseparability of learning from communities of practice [12], suggesting that STEM instruction must be embedded in authentic technological and engineering practice contexts.

The field is characterized by several persistent core debates in its theoretical development. The first concerns the depth and mode of integration. Existing research often remains at the multidisciplinary level, where disciplines are merely juxtaposed without achieving substantive integration. Ideally, interdisciplinary or transdisciplinary integration should dissolve disciplinary boundaries during the problem-solving process [13]. Louka and Papadakis's [6] study on computational thinking in early childhood provides empirical evidence: instructional designs combining “plugged” and “unplugged” activities produced different effects across conceptual dimensions. The experimental group performed better on concepts such as “representation,” “algorithms,” and “hardware–software interaction,” while the control group showed advantages on the concept of “debugging.” This indicates that strategies for interdisciplinary integration require differentiated designs based on learning objectives and conceptual attributes.

The second debate concerns equity and inclusivity. Achievement and participation gaps for women, ethnic minorities, and economically disadvantaged groups in STEM fields have been shown to stem from systemic factors including resource allocation, social culture, implicit bias, and curriculum design [14]. Zourmpakis et al.'s [4] study on gamified learning environments demonstrated that adaptive, technology-mediated instruction not only improved overall learning performance for both male and female students but also eliminated the initial disadvantages female students experienced in traditional inquiry-based environments, highlighting the potential of technology-mediated environments to mitigate gender gaps.

2.2. Implementation and evolution of STEM education policies in Western countries

The developmental trajectory of STEM education policies in Western countries, led by the United States, exhibits a distinct “crisis–response” model. After the National Science Foundation (NSF) promoted integrated education in the 1990s, the 2007 report *Rising Above the Gathering Storm* marked a turning point, framing student performance in mathematics and science as a threat to national economic security and innovation standing [15]. Subsequent policy developments—from the America COMPETES Act to STEM 2026—shifted the focus from scaling up access to deepening quality and emphasizing equity. Recent policies highlight immersive and gamified learning while striving to remove participation barriers for disadvantaged groups [16,17]. The report *Advancing Equity in K-12 STEM Education* by the National Academies of Sciences, Engineering, and Medicine proposes five equity frameworks and advocates “equity audits” to identify structural inequalities and guide resource allocation and institutional reform [18].

The European STEM Alliance aims to enhance the quality of science, technology, engineering, and mathematics (STEM) education. Its core mission is twofold: to promote policies and practices that drive economic growth, and to improve access to opportunities for all citizens [19]. A team from the Hellenic Open University, under the EU Horizon program, developed a multi-level impact analysis framework that integrates policy mapping, cross-country comparison, and stakeholder consultation. This framework systematically links challenges and causes with actions and indicators, categorizing them into four domains—policy governance, institutional conditions, educator capacity, and the collaboration ecosystem—and provides adaptable policy-evaluation tools for European countries [20].

Australia places particular emphasis on gender equity. The Australian Academy of Science and the Australian Academy of Technology and Engineering jointly released the *Women in STEM Decadal Plan* in 2019, which seeks to enhance women's participation and advancement in STEM through multi-level measures such as entrepreneurship grants, professional networks, and role-model initiatives [21]. Engineers Australia concurrently released the *National STEM Strategy 2019-2023*, integrating the development of female engineers into national strategic action.

2.3. International experiences in teacher capacity building

Teacher professional development is a critical component of STEM education quality. The NSF-funded “BETTER in STEM” program [22], which focused on student-centered undergraduate instruction, ran for five years. Through mechanisms such as summer workshops, peer observations, and student-data analysis, it developed an equity teaching framework with 31 indicators across four dimensions, resulting in an 80% increase in participating teachers' self-efficacy [23]. Australia has established a life-cycle model for science teacher professional development, differentiating stages such as novice, proficient, highly accomplished, and lead, with corresponding support measures for each stage. The Science ASSIST project

provides practical science activities and expert consultation to strengthen teachers' practical skills [21,24,25].

The “teaching school” model promoted by the University of Michigan, inspired by the concept of teaching hospitals, constructs an intergenerational team structure spanning pre-service training to teachers' first three years; it was implemented in school districts serving predominantly ethnic minority students. Through project-based and localized learning, this model has significantly improved students' standardized-test performance and their sense of belonging in STEM fields [26]. Uğraş et al. [5] designed a four-week ChatGPT-based teacher-training program grounded in the TPACK framework and found that positive trainee perceptions influenced student learning outcomes; this effect exceeded variations due to teacher demographics and motivation.

From an organizational and human-capital perspective, Dong et al. [27] argue that China's STEM teacher shortage results from both “systemic shortages”—caused by the inertia of subject-based education—and “structural shortages”—stemming from unclear human-capital structures. In the context of AI reshaping educational elements, they recommend promoting STEM-education ecosystem evaluations, constructing teacher-competency models, and developing digital resources and human–AI dual-teacher collaboration models to address systemic teacher-development challenges.

2.4. Evaluation systems and equity outcomes

The “Learning by Making” randomized controlled trial implemented by WestEd in rural California high schools, supported by the U.S. Department of Education's Investing in Innovation Fund, aimed to address early learning gaps among rural students through computational thinking and authentic STEM applications. Quantitative results did not show a significant impact of the intervention on academic achievement, but qualitative findings identified key factors for enhancing STEM equity in rural and high-needs schools: localized learning, real-world application contexts, and teachers' collaborative development of instructional capacity within professional learning communities all contributed to increased student engagement and teacher self-efficacy [28].

El-Hamamsy et al. [29] conducted a large-scale empirical study (N = 1,384 students; 83 teachers) on primary-school computer-science curriculum reform using hierarchical regression and structural equation modeling. Results showed that exposure to computer science education helped reduce learning gaps between high- and low-achieving students and between genders. Teachers' positive perceptions of professional development significantly influenced student learning, while teacher demographic characteristics and motivation showed no significant effect, indicating that teacher-training effects can transcend individual differences.

Zourmpakis et al. [4] evaluated the effectiveness of adaptive gamified environments from a gender perspective and found significant improvement for both male and female students in the experimental group; the initial disadvantage for female students disappeared after the intervention. Moreover, female students in the

experimental group performed significantly better than those in the control group, demonstrating the compensatory effects of technology-mediated environments for disadvantaged groups.

Louka and Papadakis's [6] study further revealed complex interactions between instructional design and students' informal learning experiences. The ScratchJr intervention group performed better on concepts such as “representation” and “algorithms,” while the control group using unplugged activities performed better on the concept of “debugging,” possibly due to assessment items drawing on students' life experiences (e.g., a seesaw). This suggests that STEM education evaluation must consider the interplay between learners' prior experiences and pedagogical characteristics to avoid single indicators masking heterogeneous effects of instructional design.

2.5. Evolution and current challenges of STEM education in China

The development of STEM education in China began with academic introductions in the early 21st century, while its elevation to a strategic issue at the national level stemmed from the endogenous demands of innovation-driven development and economic transformation. The release of the China STEM Education White Paper in 2017 marked its integration from a marginal educational experiment into the core of the national innovative talent cultivation system [7]. Thereafter, policies such as “Mass Entrepreneurship and Innovation,” the 13th Five-Year Plan for Educational Informatization, the Educational Informatization 2.0 Action Plan, and the Strengthening Basic Disciplines Plan further provided institutional legitimacy and resource support [30].

However, the literature indicates that current practice still faces multiple structural challenges, including superficial curriculum integration [31], systemic deficiencies in teacher capacity [32], mismatched evaluation mechanisms, and regional imbalances in resource allocation [33]. The Yu and Yang [34] further identify a significant “knowing–doing gap” in Chinese STEM education: courses labeled as STEM in higher education are often mere rebrandings of traditional science and engineering disciplines, while in basic education, limitations in teachers, equipment, and assessment make substantive interdisciplinary curricula difficult to implement, often taking the form of “craft classes” or “competition coaching.”

These phenomena suggest that Chinese STEM education is at a critical stage of transition from “scale expansion” to “quality enhancement,” with the core challenge shifting from conceptual introduction to the systematic resolution of multi-level implementation barriers. International experience indicates that effective STEM education reform requires shifting to problem-driven research paradigms [4], establishing closed-loop mechanisms for teacher training [5], connecting informal learning experiences with formal curricula [6], and incorporating equity as a core evaluation component [18]. This imperative underscores the theoretical and practical urgency of examining the current state of STEM education research in China.

3. Research design

3.1. Content analysis method

This study employs content analysis. This methodology combines quantitative statistics with qualitative interpretation, converting qualitative information from texts into quantifiable data through systematic categorization, coding, and quantitative processing to reveal underlying structures, implicit contexts, and developmental trajectories [35]. Content analysis differs from simple word-frequency counts by emphasizing inference of textual meaning within a theoretical framework and by deducing qualitative changes from quantitative variations, with the aim of understanding the contextual background and intrinsic implications of texts.

There are three reasons for selecting this method. First, content analysis is systematic and objective: by establishing clear category definitions and coding rules in advance and by conducting coder reliability tests, it reduces researcher bias and enhances the replicability of analytical procedures and the credibility of results [36]. Second, content analysis is non-intrusive: the documentary data exist prior to the study and are not affected by the research process, ensuring the stability and auditability of data sources. Third, this method is suitable for longitudinal trend analysis and can effectively present the temporal evolution of research themes, which aligns with this study's objective of exploring the developmental trajectory of STEM education research in China from 2011 to 2024.

3.2. Data sources and screening process

To ensure academic representativeness and authority, this study limits its analytical scope to journal articles indexed by the Chinese Social Sciences Citation Index (CSSCI) in the China National Knowledge Infrastructure (CNKI) database. CSSCI is a widely recognized journal-evaluation index in Chinese social sciences, and using this filter helps ensure the academic impact and rigor of the sample.

The search timeframe was January 1, 2011, to December 31, 2024. The year 2011 is taken as the starting point because 2010 marked the beginning of Chinese scholars' attention to STEM education.

To avoid interference from the medical term "stem cells," a combined Chinese and English search approach was adopted rather than using "STEM" as a direct keyword. Chinese search terms were "科學、科技、工程、數學" and "科學、技術、工程、數學"; English search terms were "Science, Technology, Engineering, Mathematics" and "Science, Technology, Engineering, Math." The search fields were limited to Subject,

The literature screening proceeded in three stages. The first stage yielded an initial set of 193 articles, forming the original database. In the second stage, two trained researchers independently reviewed titles, abstracts, and keywords. Articles were required to explicitly contain the search terms and to have STEM education as the main topic. Exclusions included articles with only marginal mentions of STEM, non-academic content, lack of abstract/keywords/references, and duplicates. After comparison and discussion, 127 articles were excluded, leaving 66. In the third stage, a full-text review was conducted. Inclusion criteria were that the article's research theme

focused on STEM education, the content addressed STEM education research in China, and the article was a research paper. Exclusions included articles that only introduced foreign curricula, focused on maker or programming education without integrating core STEM concepts, were unavailable in full text, or were of low quality. After this stage, 25 articles were excluded, resulting in a final sample of 41 articles (21.24% of the initial yield).

For duplicate publications, if the same study appeared in different forms, the journal-article version was prioritized; if published in multiple journals, the earliest or most complete version was retained. No such duplicates were found during screening.

3.3. Category construction and coding process

The analytical category framework was constructed using a combined deductive and inductive approach: key dimensions (e.g., policy, curriculum, teachers) were drawn from the literature review, while emerging themes were incorporated based on preliminary analysis of a subset of sample articles.

Four core categories were established. Category 1 comprised basic bibliographic information, including publication year, journal name, first author's institution, and institution location. Category 2 was research theme, divided into eight subcategories: policy research; curriculum and instructional design; teacher development; evaluation systems; industry–university–research collaboration; international comparison; theoretical foundation research; and others. Category 3 was research method, distinguishing empirical research (questionnaire survey, case study, experimental/quasi-experimental study, interview study, mixed methods) from non-empirical research (theoretical discussion, literature review, commentary/opinion). Category 4 covered research subjects and focus, including educational stage, type of research subject, student grade level, and subject area.

For coding and reliability testing, the training materials covered category definitions, coding rules, and tool operation, and included practice exercises. Four articles (approximately 10%) were randomly selected for pilot coding. Two coders independently coded these articles, then compared results and discussed and revised ambiguous or divergent definitions. The pilot coding results were not included in the formal analysis. After confirming the stability of the category framework, the two coders independently coded the 41 articles, recording results in an Excel coding sheet and resolving ambiguities through discussion. After coding, 10 articles (approximately 24%) were randomly selected for reliability testing. Cohen's kappa coefficient was used to measure consistency for each category. Results were: publication year $\kappa = 1.00$, journal name $\kappa = 1.00$, first author's institution $\kappa = 1.00$, research theme $\kappa = 0.86$, research method $\kappa = 0.89$, research subjects and focus $\kappa = 0.84$. All values exceeded 0.80, indicating a high level of reliability.

3.4. Limitations of the research sample

This study limits literature sources to CSSCI-indexed journal articles in CNKI for three main reasons: first, the author's institution does not have subscriptions to international databases such as Scopus or Web of Science; second, access to platforms

such as ERIC and Google Scholar is restricted under mainland Chinese regulations; third, given constraints of time and resources, CNKI provides stable search and full-text access sufficient for the study’s needs. Although the scope is restricted to CNKI-CSSCI journals, the included articles still reflect mainstream research directions and standards in Chinese academia.

Using a single data source may introduce the following biases. First, STEM education research by Chinese scholars published in international journals is not included, which may create a “localization bias” and underestimate Chinese participation in global scholarly dialogue. Second, policy-driven characteristics may be exaggerated because CSSCI journals tend to be more responsive to national policies; including more international outlets might moderate the observed policy-driven features. Third, geographic concentration findings may be reinforced, since CSSCI publication patterns exhibit institutional clustering, with top normal universities having significantly greater publication opportunities than many local institutions.

4. Analysis and discussion

4.1. Basic characteristics of the sample

4.1.1. Annual distribution

The annual distribution of sample articles (2011–2024) shows that STEM education research in China exhibits distinct policy-dependent characteristics. Fluctuations in research activity are highly correlated with the timing of major national policy announcements. Between 2011 and 2015, related research appeared sporadically (6 articles, 14.63%); beginning in 2016, research output increased significantly (35 articles, 85.37%), producing two peaks in 2016–2017 (12 articles, 29.27%) and in 2021 (7 articles, 17.07%). These peaks correspond to the release of key policies such as the 13th Five-Year Plan for Educational Informatization, the China STEM Education White Paper, and the Compulsory Education Curriculum Plan (2022 Edition). After 2022, the number of studies declined markedly (4 articles, 9.76%), suggesting that, after the stimulus of policy initiatives waned, the field has not yet developed a sustained, practice-driven research momentum (see **Figure 1** and **Table 1**).

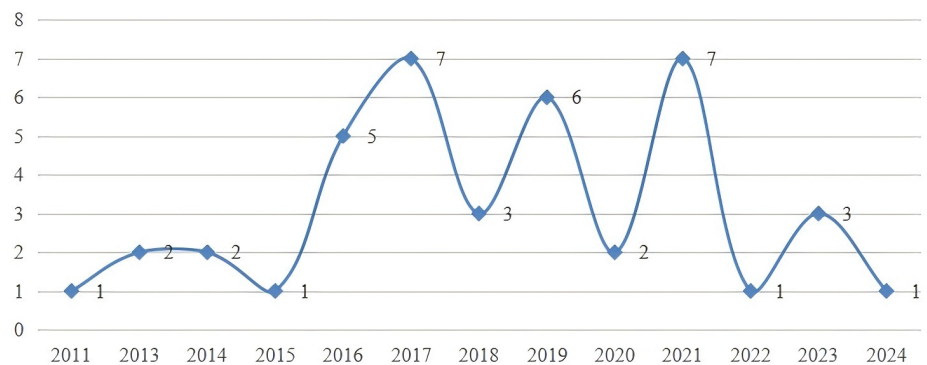


Figure 1. Annual distribution of sample papers from 2011 to 2024.

Table 1. Annual distribution of sample articles (2011–2024).

Year	Number	Percentage (%)	Key policy events
2011	1	2.44%	-
2012	0	0.00%	-
2013	2	4.88%	-
2014	2	4.88%	-
2015	1	2.44%	Launch of “Mass Entrepreneurship and Innovation”
2016	5	12.20%	Release of the 13th Five-Year Plan for Educational Informatization (proposed exploring STEM models)
2017	7	17.07%	Release of the China STEM Education White Paper; integration of STEM into the Compulsory Education Primary School Science Curriculum Standards
2018	3	7.32%	Release of the Education Informatization 2.0 Action Plan
2019	6	14.63%	
2020	2	4.88%	
2021	7	17.07%	
2022	1	2.44%	Promulgation of the Compulsory Education Curriculum Plan and Curriculum Standards (2022 Edition) (interdisciplinary thematic learning)
2023	3	7.32%	Release of the Opinions on Strengthening Science Education in Primary and Secondary Schools in the New Era
2024	1	2.44%	-

Unlike the “crisis-response” model underlying STEM education in the United States, early research in China largely constituted an academic response to national strategies rather than arising from intrinsic disciplinary needs or from educational practice. This policy-driven model presents a critical challenge for the field as it transitions from “responding to policy” to “responding to problems.”

4.1.2. Institutional distribution

Regarding the geographical distribution of first authors' institutions, the sample shows a high degree of spatial concentration. Beijing (11 articles, 26.83%), Shanghai (7 articles, 17.07%), and Wuhan (5 articles, 12.20%) together account for 56.10% of the total, while articles from provincial capitals or municipalities directly under the central government constitute 37 articles (90.24%) (see **Table 2**). In terms of institutional type, normal (teacher-training) universities account for 80.49% (33 articles), with Beijing Normal University, East China Normal University, and Central China Normal University as primary contributors; comprehensive universities (12.20%), polytechnic universities (4.88%), and research institutions (2.44%) have limited participation. This pattern indicates that Chinese STEM education research is largely positioned within the “education” domain rather than within “science/technology” or “engineering,” with normal universities as the main force. Consequently, research perspectives tend to be confined to curriculum, instruction, and teacher development, while perspectives such as the practical demands of talent cultivation from polytechnic universities or explorations of cutting-edge technology education from research institutions are relatively absent. This reflects that such research has not yet entered the purview of

professional education research institutions.

Table 2. Distribution of first authors' institutional locations (sorted by number of publications).

City	Province	Region	Number	Percentage (%)
Beijing	Capital, Municipality	North China	11	26.83%
Shanghai	Municipality	East China	7	17.07%
Wuhan	Provincial Capital, Hubei	Central China	5	12.20%
Zhengzhou	Provincial Capital, Henan	Central China	3	7.32%
Hangzhou	Provincial Capital, Zhejiang	East China	2	4.88%
Nanjing	Provincial Capital, Jiangsu	East China	2	4.88%
Nanchang	Provincial Capital, Jiangxi	Central China	2	4.88%
Chongqing	Municipality	Southwest China	2	4.88%
Tianjin	Municipality	North China	1	2.44%
Changchun	Provincial Capital, Jilin	Northeast China	1	2.44%
Quanzhou	Fujian, Second-tier City	East China	1	2.44%
Guilin	Guangxi, Third-tier City	South China	1	2.44%
Jingzhou	Hubei, Third-tier City	Central China	1	2.44%
Zhaoqing	Guangdong, Third-tier City	South China	1	2.44%
Guangzhou	Provincial Capital, Guangdong	South China	1	2.44%

Regarding journal sources, the sample is dispersed across 24 journals, indicating that a stable publishing platform has not yet formed. The journals with the highest numbers of articles are predominantly core journals in educational technology (see **Table 3**), such as China Educational Technology, Open Education Research, and Educational Technology Research, which together account for 34.15%. Although this publishing channel aligns with the interdisciplinary and technology-integrated nature of STEM education, it may weaken important perspectives such as the disciplinary logic of science education, the practice-oriented nature of engineering education, and the institutional analysis of policy implementation.

Table 3. Distribution of sample article journal sources (only journals with more than three publications are shown).

Journal name	Number of publications	Percentage (%)
China Educational Technology	5	12.20%
Open Education Research	5	12.20%
Educational Technology Research	4	9.76%
Foreign Education Research	3	7.32%

Note: Four journals published two articles each, and 16 journals published one article each.

Within China's disciplinary classification system, STEM education does not have an independent position and is primarily published in educational technology journals. Although this channel aligns with STEM education's emphasis on interdisciplinarity and technological integration, it may also diminish perspectives such as the disciplinary logic of science education, the practice-oriented nature of engineering education, and the institutional analysis of policy implementation. The dispersion of sample articles across numerous journals indicates that the field has not yet formed a stable academic community or dialogue platform.

From a spatial-distribution perspective, research output is notably concentrated in regions and institutions with dense higher-education resources, confirming the basic premise of resource dependence theory [37]. However, this structure also leads to the

near absence of voices from the central and western regions, which is disproportionate to the population size and educational needs of these areas, thereby limiting the diversity of research perspectives and the representativeness of practice.

4.2. Distribution of research themes

4.2.1. Thematic structure

Regarding research themes, curriculum and instruction account for the highest proportion. “Curriculum/Textbook Analysis and Comparison” (11 instances, 16.18%) and “Teaching Models/Curriculum Design and Development” (10 instances, 14.71%) together constitute 30.88% of occurrences (see **Table 4**), indicating that research focuses on the practical aspects of STEM curriculum and instruction. “Introduction and Implications of International Experiences” (9 instances, 13.24%) reflects strong attention to foreign experiences, suggesting the field remains in a stage of introduction and adaptation.

Table 4. Distribution of research themes in sample articles.

Research theme	Occurrences	Percentage(%)
Curriculum/Textbook Analysis and Comparison	11	16.18%
Teaching Models/Curriculum Design and Development	10	14.71%
Introduction and Implications of International Experiences	9	13.24%
Student Learning Outcomes/Attitudes Research	8	11.76%
Exploration of STEM/STEAM Education Concepts	7	10.29%
Teacher Development and Training	6	8.82%
Policy Analysis and Comparison	5	7.35%
Connotation and Structure of STEM Literacy	4	5.88%
Research on Interdisciplinary Integration Models	4	5.88%
Research Trends/Bibliometric Analysis	2	2.94%
Research Purpose Not Explicitly Stated	2	2.94%

Note: Occurrences and percentages are based on 41 sample articles; a single article may involve multiple research themes, so the total exceeds 41.

In empirical and theoretical directions, “Student Learning Outcomes/Attitudes Research” (8 instances, 11.76%) and “Exploration of STEM Education Concepts” (7 instances, 10.29%) each account for about one-tenth, meaning empirical research and theoretical discussion proceed in parallel. “Teacher Development and Training” (6 instances, 8.82%) and “Policy Analysis and Comparison” (5 instances, 7.35%) have received some attention, but their proportions remain lower than those of curriculum-design themes.

Although “Connotation and Structure of STEM Literacy” (4 articles, 5.88%) and “Research on Interdisciplinary Integration Models” (4 articles, 5.88%) have relatively low proportions, they represent emerging directions in recent years and may indicate that research is extending from macro-level curriculum design toward literacy construction and integration mechanisms.

Structurally, curriculum/instruction themes and international-experience themes together account for over seventy percent, while supporting and foundational themes such as teacher development, policy, literacy construction, and interdisciplinary integration collectively account for less than thirty percent. This suggests that current

research primarily follows the main lines of “how to design curriculum” and “how other countries do it,” with limited investment in implementation aspects such as “who will teach,” “how policies will be coordinated,” and “how interdisciplinary integration can truly be achieved.”

This thematic structure indicates that Chinese STEM education research remains in a stage of conceptual introduction and theoretical construction, with research focus concentrated on front-end design and relatively insufficient attention to implementation. While the precedence of theoretical and curricular research is common when introducing emerging educational concepts, inadequate attention to critical dimensions such as teacher development, evaluation, and industry–university collaboration may create a structural risk of disconnect between program design and practical context.

4.2.2. Methodological characteristics

The data show that non-empirical research constitutes the majority. Literature analysis (17 occurrences, 24.64%), qualitative analysis (16 occurrences, 23.19%), and practical design (8 occurrences, 11.59%) together account for over half of occurrences. If the six articles (8.70%) with unspecified research methods are added, this proportion increases further.

The proportion of empirical research is relatively low. Survey methods (4 occurrences, 5.80%), observation (4 occurrences, 5.80%), and interviews (4 occurrences, 5.80%) together account for less than twenty percent. Among these, only one study (1.45%), Zhang et al. [38], employed quasi-experimental methods capable of examining causal relationships. Most other studies remain at the level of conceptual elaboration, theoretical synthesis, literature review, and qualitative interpretation.

This methodological pattern reveals a research orientation characterized by “more design, less validation.” Most studies on curriculum design remain at the level of conceptual elaboration and framework construction, lacking longitudinal data and empirical testing of implementation effects. For example, although Xie and Li [39] proposed a comprehensive STEM curriculum reform concept with a full exposition, they did not provide empirical data on student learning outcomes after implementation, making it difficult to judge the practical utility of their proposal. Overall, research output shows characteristics of “emphasizing design over empirical validation” and “abundant ideas but limited verification,” with many results remaining at the stage of blueprint development and therefore difficult to transform into replicable and scalable effective practices. This creates a significant gap between theoretical exploration and practical validation [40].

4.3. Educational stages targeted by research

Regarding the distribution of educational stages, basic education constitutes the majority. Articles explicitly targeting primary and secondary schools total 12 (29.27% of the sample). Preschool education (3 articles, 7.32%) and higher education (3 articles, 7.32%) account for small proportions, while vocational education shows no related research, and “unspecified” accounts for 23 articles (56.10%). Research focus clearly leans toward basic education, with relatively insufficient attention to

higher education and vocational education, which are directly linked to industrial talent output. The “unspecified” category mostly includes articles focusing on overall STEM concepts, cross-country comparisons, curriculum design, or teacher development without specifying an educational stage.

Regarding the type of research subject, “students” (including learning attitudes and STEM literacy) (12 articles, 29.27%) and “curriculum/textbooks” (including STEM curriculum design and textbook comparison) (14 articles, 34.15%) together account for over half, followed by “country/policy/education system” (8 articles, 19.51%). Only 4 articles (9.76%) target “teachers” (including PCK and professional development), and 3 articles (7.32%) target “schools/educational institutions.”

This distribution reveals several structural characteristics. First, there is a “top-heavy” pattern across educational stages: research is highly concentrated in basic education, especially the primary stage, while higher education and vocational education are nearly absent. These latter stages are critical links in the talent-cultivation system connecting professional competence with industrial needs. Second, there is a “focus on objects over people”: research on “object” dimensions such as curriculum design, textbook development, and policy analysis dominates, while “human” and “system” dimensions such as teacher development and institutional support have not received commensurate attention. Together, these characteristics reflect a significant misalignment between research focal points (basic education, curriculum design, overall STEM concepts) and the critical links for practical implementation (higher education, teacher training, subject-specific instruction).

4.4. Current status of systematic development

Although a small number of studies in the sample (5 articles) advocate constructing an integrated STEM education ecosystem involving multiple stakeholders such as schools, communities, government, and enterprises, the overall research landscape largely remains at the stage of vision articulation and principle exploration. Compared with international efforts that propose top-level institutional designs, such as STEM 2026 in the United States [15] or the MINT Action Plan in Germany, related research in China has not yet developed a similarly operational framework. The advocated “STEM ecosystem” therefore often remains a vague vision, difficult to translate into concrete pathways for cross-sectoral collaboration. This results in insufficient integration of STEM education research and practice when aligning with national innovation strategies [31].

4.5. Identification and discussion of structural deficiencies

Synthesizing the above analysis, the structural deficiencies identified in this study are as follows.

First, the high concentration of regional distribution (East China, North China, and Central China together account for 85.38%; regions such as South China, Southwest, Northeast, and Northwest—collectively home to over 40% of the population—contribute less than 15% of output) (see **Table 2**). This not only confirms the basic proposition of resource dependence theory [37] but also stands in stark

contrast to the equity frameworks emphasized in Western countries in recent years. For example, the U.S. report *Advancing Equity in K-12 STEM Education* explicitly lists “reducing gaps between groups” and “expanding opportunity and access” as core objectives [18], and advocates equity audits to identify structural inequalities. In contrast, the spatial distribution of Chinese STEM education research reproduces regional imbalances in educational resource allocation. The practical needs of vast inland and rural areas are nearly absent from the mainstream academic perspective. This “spatial blind spot” in knowledge production means that policy formulation lacks an empirical basis tailored to local conditions, diverging from international experiences of enhancing equity in rural and high-needs schools through localized learning [28].

Second, the “top-heavy” distribution across educational stages (basic education 29.27%, higher education only 7.32%, vocational education zero) highlights a structural disconnect between research perspectives and the talent-cultivation pipeline. International experience shows that effective STEM education reform needs to span K–12 through higher education and closely align with industrial needs [27, 29]. The BETTER in STEM program in the U.S. focuses on teacher development in higher education [22], while Australia's Women in STEM Decadal Plan concerns the entire pathway for women in STEM from education to employment [21]. Both demonstrate that systematic research on higher and vocational education is indispensable for talent cultivation. The absence of research in these stages in China means that the interest and foundational literacy cultivated in students during primary and secondary school may be difficult to translate into professional competence and industry integration, creating a structural break in the talent-cultivation chain. This deficiency also echoes the teacher-shortage dilemma, characterized by both “systemic shortages” and “structural shortages” [27].

Third, the structural “emphasis on design over implementation” in research themes (curriculum and instructional design accounting for 30.88% versus teacher development 8.82%) is causally linked to the “knowing-doing gap” currently faced by STEM education in China. International experience indicates that teacher capacity building is a critical component of STEM education quality [5]. The insufficient attention in Chinese research to implementation aspects such as teacher development, evaluation, and industry–university collaboration makes it difficult to overcome practical bottlenecks, like: once the curriculum plan and theoretical framework are available, can teachers implement them effectively? How should outcomes be evaluated? How can schools and enterprises collaborate?

Fourth, the methodological characteristic of “more design, less validation” (literature analysis, unspecified methods, and general qualitative analysis together account for over half; quasi-/experimental research only 1.45%) is interrelated with the problem of disconnection between theoretical exploration and practical validation and contrasts with the recent empirical turn in Western STEM education research. The quasi-experimental design of Zourmpakis et al. [4] and the structural-equation-modeling analysis of El-Hamamsy et al. [29] demonstrate the irreplaceable role of high-evidence-strength methods in assessing instructional intervention effects and identifying equity impacts. The empirical deficit in Chinese

research methods makes it difficult to address core propositions demonstrated in international studies (e.g., Louka and Papadakis, [6]). The current research landscape not only fails to provide practitioners with scientifically validated, replicable, and scalable effective models, but also leaves policy formulation without reliable evidentiary support, constraining the transformation of STEM education from a “policy-responsive” to a “problem-driven” research paradigm [4].

In summary, the four structural deficiencies identified—regional imbalance, segmentation across educational stages, thematic skew, and empirical deficit—do not exist in isolation but collectively constitute the current predicament of STEM education research in China. The root of this predicament can be traced to the unique developmental path of STEM education in China: as a reform agenda driven top-down by national policies, its research ecosystem has been imbued from the outset with a strong “policy-responsive” character rather than arising from intrinsic disciplinary or practice-based needs. This path dependence has led to research resources being concentrated in themes and institutions with high policy sensitivity and clear publication thresholds. In contrast, implementation aspects such as teacher development, evaluation, and industry–university collaboration, as well as talent-output stages such as higher education and vocational education, have been marginalized due to the lack of strong policy impetus. Overcoming this structural predicament will require shifting from “responding to policy” to “responding to problems,” constructing a new ecosystem oriented by practical needs, involving diverse stakeholders, and supported by empirical methods.

5. Conclusion

5.1. Major Research Findings

This study draws four major conclusions:

First, research activity is characterized by an exogenous, policy-driven impetus and insufficient endogenous motivation. Since 2016, STEM education research in China has grown significantly, driven by policies such as “Mass Entrepreneurship and Innovation” and educational informatization. However, the number of studies declined after 2022, indicating that the field's momentum depends on external stimuli and has not yet developed a mature, problem-driven, evidence-based research paradigm. This limits the depth and sustainability of scholarly inquiry.

Second, research themes are imbalanced, revealing a disconnect between theoretical construction and practical validation. Research is overly concentrated on theoretical interpretation and macro-level curriculum frameworks, while rigorous empirical studies of teaching practice, learning outcomes, and curriculum implementation are lacking. The tendency to emphasize design over validation leaves most findings at the conceptual level, making them difficult to translate into implementable, replicable models and weakening the practical guiding role of academic research in educational transformation.

Third, the research ecosystem is closed and fragmented, failing to integrate key social actors. Research resources are highly concentrated in teacher-training (normal)

universities in cities such as Beijing, Shanghai, and Wuhan, reflecting urban–rural and regional resource disparities that produce homogenized perspectives and limit responsiveness to diverse regional needs. The research focus is heavily skewed toward basic education, while higher and vocational education are neglected, creating a discontinuity in the talent cultivation pipeline. University scholars are the primary research actors; enterprises and industry associations are largely absent, hindering the formation of a collaborative industry–university–research ecosystem.

Fourth, there is a lack of systematic top-level design and mechanism research, resulting in a disconnect from national strategic needs. Although some studies advocate an integrated STEM education ecosystem, unlike countries such as the United States and Japan that advance STEM through coordinated national strategies, relevant research in China largely remains at the stage of vision articulation. There is insufficient in-depth exploration of institutional barriers to cross-sector collaboration, incentive-compatibility mechanisms, resource sharing, and benefit distribution. This creates a strategic gap given the urgent need for high-quality, interdisciplinary innovative talent to support economic transformation and upgrading.

5.2. Recommendations

This study offers recommendations at the macro, meso, and micro levels:

Recommendations for government and policymakers: Formulate a national medium- and long-term STEM education development strategy and roadmap that clarifies cultivation objectives and articulation mechanisms across educational stages, and establish a collaborative governance framework involving multiple departments. Optimize financial investment by creating dedicated funds and prioritizing support for central and western regions, rural areas, and other resource-poor locales to support empirical research on curriculum reform in higher and vocational education, teaching-effectiveness evaluation, and industry–education integration pilot programs. Develop a diversified evaluation and incentive system by incorporating STEM education outcomes into comprehensive school evaluations and providing recognition and substantive incentives to schools, teachers, and enterprises that demonstrate significant results.

Recommendations for industry and enterprises: Deepen industry–university–research collaboration by proactively establishing joint laboratories, training bases, and industry-customized programs with universities and vocational colleges, integrating cutting-edge technologies and job-competency standards into talent cultivation. Participate in curriculum co-creation and teacher co-development by encouraging senior engineers and R&D personnel to engage with educational institutions in curriculum design and textbook development, and to serve as industry mentors or adjunct instructors to bridge the gap between theory and practice.

Recommendations for higher education institutions (especially teacher-training and polytechnic universities): Promote interdisciplinary integration and evidence-based research by establishing cross-departmental STEM education research centers to conduct curriculum development, pedagogical innovation, and

longitudinal evaluation. Innovate teacher-training models by integrating STEM concepts, interdisciplinary instructional design, and project-based learning into core teacher-training modules in normal universities, while polytechnic universities should strengthen faculty capacity to translate engineering practice into teaching resources. Expand research perspectives by extending inquiry into vocational, undergraduate, and graduate education to connect the entire talent cultivation chain, and proactively establish action-research partnerships with enterprises and primary/secondary schools.

Recommendations for in-service teachers: Become reflective practitioners and collaborative innovators by actively engaging in peer collaboration and inter-school exchanges, experimenting with teaching methods such as project-based learning and design thinking, and continuously improving instruction through classroom action research. Attend to individual student differences and intrinsic motivation by providing learning tasks that offer choice and challenge, thereby stimulating students' interest in STEM and their career aspirations.

5.3. Research limitations and future directions

Although this study uses content analysis to outline the landscape of STEM education research in China, several limitations remain.

Regarding sample representativeness, the study selected only CSSCI-indexed journal articles from CNKI. While academically authoritative, this selection may omit important practice-oriented conference papers, dissertations, and research published in non-CSSCI journals. In addition, the longer publication cycle of CSSCI journals makes it difficult to capture emerging research dynamics promptly. Future research could expand the sample scope to include domestic and international databases such as CSCD and SSCI to obtain a more comprehensive view.

Regarding research methods, content analysis effectively describes external characteristics and thematic distribution but is limited in revealing deep-seated argumentative logic, internal knowledge structures, and the methodological rigor of individual studies. Subsequent research could combine bibliometric methods with more in-depth qualitative text analysis and systematic literature reviews to conduct detailed evaluations of key literature.

Finally, the conclusions of this study are based on academic literature and therefore reflect trends in academic research rather than the full picture of frontline educational practice. Caution is needed when generalizing these findings to practice. Future research should increasingly employ empirical methods—surveys, in-depth interviews, case studies, and ethnography—to investigate classrooms, schools, and industry–university–research collaboration projects, testing and refining existing theories and narrowing the gap between academic research and educational practice.

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