https://doi.org/10.37420/j.cer.2025.086

The Timely Evolution of Scientific Literacy in Early Childhood Education from the Perspective of New Quality Productive Forces in China

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Abstract

Taking the demand for the early cultivation of innovative talents driven by the development of New Quality Productive Forces (NQPF) as the starting point, this study focuses on the evolutionary patterns and reform directions of preschool children's scientific literacy education in China. Using the CiteSpace bibliometric visualization method, it systematically analyzes 2,838 relevant documents indexed in China National Knowledge Infrastructure (CNKI) from 2001 to 2025, so as to reveal the knowledge structure, hot topics, trends, and core driving forces in this field. The research findings indicate that the study of preschool children's scientific literacy education in China presents a three-stage evolutionary characteristic: Concept Introduction and Policy Response Period (2001–2007), Practical Exploration and Connotation Deepening Period (2008–2018), and Integration Innovation and System Construction Period (2019–present). Research hotspots have gradually shifted from scientific knowledge enlightenment to interdisciplinary integration, innovative thinking cultivation, digital technology empowerment, and home-preschool-community collaborative education. As a core exogenous driving force, NQPF promotes the systematic transformation of preschool children's scientific literacy education in terms of goals, content, methods, and evaluation systems, which is specifically reflected in three major reform paths: "innovation-driven pedagogy, digital intelligent resource integration, and trinity synergistic education". China's explorations in policy-driven development, resource integration, and practical models not only possess distinct local characteristics but also provide referable experiences for global preschool science education in responding to the technological revolution.

Keywords

New Quality Productive Forces (NQPF); preschool children's scientific literacy; preschool science education; bibliometric analysis (CiteSpace); educational reform paths

1.Introduction

With the rapid advancement of the artificial intelligence field, it has been playing an increasingly crucial role in various sectors. The profound transformation of the times, driven by technological revolution and industrial upgrading, compels us to rethink and redefine the direction and purpose of education, especially the

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core positioning of science literacy education that underpins innovative talent cultivation.

To address such transformations, China has rolled out a series of strategic plans to promote the integration of technology and education. In 2018, The Action Plan for Education Informatization 2.0 leveraged information technology to enhance educational quality and efficiency as well as promote the all-round development of students. In 2021, the 14th Five-Year Plan for National Informatization launched social education experiments to explore the impacts of artificial intelligence. In 2022, both the Key Work Points of the Ministry of Education and the 20th National Congress of the Communist Party of China focused on educational digitalization, advancing the development of the "Internet + Education" model and a learning-oriented society. These strategies demonstrate the nation's emphasis on educational reform and point out the direction for the innovative development of education (Liu & Gou, 2022).

Meanwhile, policies issued by the Ministry of Education of China, such as The Guidelines for the Reform of Basic Education Curricula (Trial) and The Curriculum Plan and Curriculum Standards for Compulsory Education (2022 Edition), have clarified the core position of scientific literacy in basic education. They have also proposed measures including strengthening science teaching and popular science education, reflecting a systematic plan for improving scientific literacy and a strategic layout for cultivating talents in the new era.

In 2024, General Secretary Xi Jinping elaborated on the scientific connotation of "new quality productive forces (NQPF)" and clarified the requirement of accelerating its development, which has pointed out the direction for China's high-quality development. As the core engine driving high-quality development, the core essence of NQPF lies in being led by breakthrough technological innovation, promoting the leap of total factor productivity, and realizing in-depth industrial transformation and upgrading. Essentially, it is an advanced form of productive forces that breaks away from dependence on traditional growth paths, relying on revolutionary technological breakthroughs, innovative allocation of production factors, and in-depth industrial transformation and upgrading, with distinct characteristics of high technology, high efficiency, and high quality. Notably, the fundamental driving force for the development of NQPF lies in high-caliber innovative talents who possess interdisciplinary integration capabilities, innovative thinking, critical problem-solving literacy, and continuous learning adaptability. As the core link in talent cultivation, education bears the crucial responsibility of supplying these urgently needed talents. General Secretary Xi Jinping particularly emphasized deepening the innovation of talent work mechanisms, facilitating a positive cycle among education, science and technology, and talents, and optimizing the disciplinary setup and talent training models in colleges and universities. This also puts forward an urgent demand for the reform of preschool science enlightenment education, which serves as the foundation of the entire education system, to provide solid talent support for the development of NQPF (Xi, 2024).

The close correlation between NQPF and educational transformation, especially science literacy education, is manifested through a clear and refined mechanism, starting with the upgrading of educational goals driven by NQPF at the target level. The demand for talents' core literacy by NQPF has forced the education system, particularly the foundational basic education stage, to reshape its talent training goals. The traditional education model centered on knowledge transmission can no longer meet NQPF's demand for innovative talents. This has prompted the goal of science literacy education to shift from mere knowledge accumulation and skill training to a greater emphasis on the leap toward innovative thinking, critical inquiry, complex prob-

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lem-solving, and interdisciplinary understanding and application capabilities. For preschool education, which is a critical period for children's cognitive, emotional, and social development, this shift signifies that early childhood science enlightenment is no longer merely about recognizing natural phenomena. Instead, it needs to stimulate children's curiosity and imagination, encourage them to put forward bold hypotheses and conduct rigorous verification, and cultivate their initial ability to explore solutions amid uncertainty.

Innovation-driven development is the core of NQPF, and the cultivation of such innovation capabilities often takes root in early childhood science enlightenment. Science education in the preschool stage can fully stimulate children's desire to explore, trigger their exploratory behaviors, and help them initially develop scientific thinking patterns and a sense of innovation—abilities that are crucial for their growth into the high-caliber innovative talents required by NQPF in the future. In this context, exploring effective ways to cultivate preschool children's scientific literacy in response to the requirements of NQPF in the new era is not only an inevitable choice for the reform of preschool education but also has a profound impact on cultivating future innovative talents and enhancing the country's competitiveness in technological and scientific innovation. It ultimately provides a continuous stream of reserve forces for the sustainable development of NQPF and injects vitality into China's high-quality development.

2.Literature Review

2.1 International Experiences and Insights

Countries around the world are exploring teaching models suitable for their national conditions to improve students' scientific literacy. In the process of educational reform, they promote scientific literacy cultivation through policy support, curriculum integration, and teaching method innovation, striving to develop students' scientific literacy to meet the developmental needs of the times. The United States promotes STEM education through policies such as the No Child Left Behind Act (NCLB) and the Every Student Succeeds Act (ESSA), emphasizing interdisciplinary integration, inquiry-based learning, and scientific literacy assessment. In 2015, it further enacted the STEAM Education Act to fully implement K-12 STEAM education (Jolly, 2012; Hu, 2017). Germany proposed integrating scientific enlightenment into kindergarten education in 2009, and its unique forest kindergarten system is combined with STEAM education to promote interdisciplinary integration and interest development. Research based on German kindergartens shows that STEAM education blurs the rigid boundaries defining disciplines and allows thematic areas to be fluid, exerting a positive impact on the development of young children's early scientific literacy (Hunter-Doniger, 2021). Japan revised the "Course of Study" in 2017, setting the core goal of cultivating students' "survivability"—core competencies to adapt to an information-based and internationalized society. It emphasizes core competencies such as knowledge and skills, and thinking abilities, implements scientific literacy cultivation, and promotes curriculum and teaching method reforms (Li & Wang, 2019). Ireland released the STEM Education Policy Statement in 2017, constructing an integrated STEM education system covering preschool, primary, secondary, and high school education. At the preschool stage, it focuses on fostering young children's exploration and thinking abilities, communication skills, sense of well-being, and sense of identity and belonging (Li, 2022).

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2.2 Evolution of Policies for Scientific Literacy Cultivation in China's Basic Education

Centered on fostering virtue through education, China's basic education curriculum reform has constructed a K-12 scientific literacy cultivation system through curriculum reform, resource optimization, teacher capacity building, and international cooperation, responding to the strategic needs of building an educational power and technological innovation.

China launched a systematic curriculum reform with the Guidelines for Basic Education Curriculum Reform (Trial) in 2001, establishing a curriculum system oriented towards quality-oriented education. In 2014, the Ministry of Education issued the Opinions on Comprehensively Deepening Curriculum Reform and Implementing the Fundamental Task of Fostering Virtue Through Education to strengthen the educational function of curricula. In 2022, it revised the compulsory education curriculum plan and curriculum standards for 16 subjects, with the science curriculum clearly defining four core competencies: "scientific concepts, thinking, inquiry and practice, and attitude and responsibility." In 2023, the Action Plan for Deepening the Reform of Basic Education Curriculum and Teaching proposed the Scientific Literacy Improvement Initiative, enhancing experimental teaching and popular science education; the same year, the Action Plan for Expanding Excellence and Improving Quality of Basic Education in the New Era promoted the balanced development of high-quality basic education, requiring the improvement of teachers' scientific literacy and information technology capabilities; the Opinions on Strengthening Science Education in Primary and Secondary Schools in the New Era proposed nurturing young people's potential as scientists. In 2024, the Outline for Building an Educational Power (2024–2035) deployed the "Fertile Soil Program" for scientific literacy cultivation in primary and secondary schools, the "Emergence Program" for high school students with innovative potential, and constructed an international cooperation network for STEM education (MOE, 2001; MOE, 2014; MOE, 2022; MOE, 2023a; MOE, National Development and Reform Commission [NDRC], & Ministry of Finance [MOF], 2023; Central Committee of the Communist Party of China [CCCPC] & State Council, 2025; MOE et al., 2018; MOE et al., 2023b; MOE et al., 2022).

2.3 Connotation of Children's Scientific Literacy Education

Scientific literacy usually includes three aspects: scientific knowledge, scientific research methods and processes, and the impact of science and technology on society and individuals. It covers all contents of scientific activities, namely scientific concepts and knowledge, scientific abilities and methods, and scientific spirit and values. This is consistent with the three-dimensional goals of science education—acquiring scientific knowledge and skills, mastering scientific research methods and processes, understanding the environment, caring for society, exploring problems, promoting personal development and improvement, establishing a scientific worldview, and maintaining a good mental state (Wang, 2023; National Working Committee on Children and Women under the State Council, 2021).

Improving children's scientific literacy requires integrating the promotion of scientific spirit into the entire process of education (MOE, 2012). Scientific literacy education should be centered on "learning by doing" and "learning through play," providing young children with opportunities to observe scientific knowledge through daily life activities, cultivating their thinking and analytical abilities through independent inquiry, and stimulating their spirit of loving science and daring to innovate (MOE, 2001). Early childhood scientific

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enlightenment education, characterized by the daily relevance of resources, the breadth of knowledge, and the openness of inquiry, is an important preparation for science courses and subject education such as physics, chemistry, biology, and geography in primary and secondary schools. Supporting and promoting the development of preschool children's curiosity and imagination plays a crucial role in enhancing their innovative awareness and practical abilities, as well as their diverse and personalized development in the future. Compared with scientific literacy cultivation in other stages, preschool scientific literacy should focus on rational thinking, critical questioning, and scientific inquiry abilities (Lei & Xiang, 2020).

The orientation of preschool children's scientific literacy has shifted from life skills and moral education to the cultivation of scientific literacy and innovative spirit. The preschool children's scientific literacy used in this study includes three aspects: scientific knowledge, scientific abilities and methods, and scientific emotions, attitudes, and values. The scientific knowledge dimension covers common sense in natural science, material characteristics, life science, etc. The scientific abilities and methods dimension mainly focuses on cultivating abilities such as observation, experimentation, reasoning, and problem-solving. The scientific emotions, attitudes, and values dimension refers to emotional traits such as curiosity, desire for knowledge, sense of cooperation, and critical thinking, which are the internal driving forces for children to continuously explore nature. These three aspects are interrelated and interact with each other.

3.Research Methods

In recent years, research on scientific literacy education for preschool children has gradually increased, but there is a lack of systematic collation. This study adopts the bibliometric visualization analysis method of CiteSpace to comprehensively sort out the research hotspots and trends in this field over the past 25 years (2001–2025), aiming to reveal the knowledge structure and cutting-edge issues in the field.

This study takes literature from CNKI (China National Knowledge Infrastructure) as the core data source. As the largest and most authoritative comprehensive academic resource platform in China, CNKI collects more than 90% of domestic core journal resources, 6.8 million doctoral and master's theses, as well as a large number of conference papers and newspaper documents. Among them, it covers 2,240 professional journals in the field of basic education and excellent doctoral and master's theses from more than 180 normal and comprehensive universities, with collection years traceable to the 1990s, which can fully cover the academic achievements in the field of scientific literacy education for preschool children over the past 25 years (China National Knowledge Infrastructure [CNKI], 2024a). The "Advanced Search" and "Topic Search" functions provided by CNKI support multi-dimensional precise screening, and combined with tools such as citation analysis and academic trend prediction, it can efficiently explore the internal connections between documents, providing a solid data foundation for bibliometric analysis (CNKI, 2024b).

To ensure the accuracy and comprehensiveness of literature retrieval, this study employed CNKI’s advanced search function, with the specific retrieval formula defined as:TS=(" 幼儿科学素养 " OR " 学前儿童科学素养 " OR " 幼儿科学教育 ")(Note: The Chinese terms correspond to "scientific literacy of young children", "scientific literacy of preschool children", and "science education for young children", respectively). The topic search mode was used with exact matching to minimize retrieval errors. The time scope of the

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retrieval was set as January 1, 2001 to November 7, 2025 (retrieved and exported on November 7, 2025), so as to cover the full development process of the field and ensure data integrity and coherence.

Subsequently, quality screening was implemented: CNKI's document type filtering function was paired with manual title review to exclude invalid content (e.g., conference notices, news reports) outside the research scope, ensuring all included literature was high-quality and research-significant. Finally, 2,838 valid documents were obtained, exported in Refworks format, and then converted to CNKI Format Conversion for import into CiteSpace.

The study uses CiteSpace 6.1.R6 software for visualization analysis. Based on co-citation analysis theory, it explores inter-document correlations through keyword co-occurrence, burst detection time-zone mapping, and co-citation analysis, thereby identifying research hotspots, their evolutionary changes, current status, and development trends. Changes in hot keywords can reflect educational policies, practical improvements, and resource allocation needs, providing empirical support for educational decision-making, as well as a reference framework for integrating science education resources, optimizing home-kindergarten co-education and teaching methods, and enhancing teachers' scientific literacy and teaching effectiveness.

To balance the clarity of the core network structure and information richness, CiteSpace parameters were adjusted as follows:

G-index setting: The scale factor \(k = 25\) was selected (adjustment principle: "To include more or fewer nodes, increase or decrease the scale factor k"), ensuring appropriate network density;

Top N% selection: The criterion "Select top 10.0% of most cited or occurred items from each slice" was adopted, with the maximum number of selected items per slice set to 100, to capture the most representative elements in each time segment.

It should be noted that CNKI, as the core data source, mainly focuses on Chinese-language academic literature—a key limitation of this study: it fails to fully cover the latest theoretical frontiers and practical explorations of international academia in scientific literacy education, especially in-depth discussions under specific research paradigms or non-Chinese contexts.

However, the core objective of this study is to systematically sort out and analyze the dynamic evolutionary characteristics and driving factors of preschool children's scientific literacy education in the Chinese context, and under this orientation, CNKI offers irreplaceable advantages. First, it excels in localization depth: by centrally collecting domestic scholars' studies focused on Chinese preschool science education practices, it provides the most direct, relevant, and abundant local empirical materials and theoretical discussions tailored to the specific domestic context. Second, its strong policy responsiveness aligns with the fact that Chinese preschool science literacy education is profoundly shaped by national educational policies—as the primary platform hosting domestic policy documents, official interpretations, and policy-responsive research, CNKI enables accurate capture of the interactive relationship between policy evolution and academic research in this field. Finally, it effectively reflects the practice ecology: covering research achievements spanning from high-level academic institutions to frontline kindergarten teachers, it comprehensively maps the complete ecology of this field, connecting initial theoretical construction to concrete practical implementation.

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Thus, despite the limitation of insufficient international literature coverage, CNKI provides the most appropriate and explanatory data foundation for this study's focus on the "Chinese context". Future research can integrate international databases (e.g., Web of Science, Scopus) for cross-cultural comparisons, to better understand the global commonalities and national characteristics of scientific literacy education.

4.Research Results

4.1 Analysis of Keyword Evolution and Publication Volume Trends

Combined with the Top 15 keywords with high burst strength and the annual publication volume trends in the field of preschool children's scientific literacy from 2001 to 2025 presented in Figure 1, the evolutionary context of research in this field is highly consistent with the policy orientation of China's preschool education reform and science education development, which can be roughly divided into three stages.

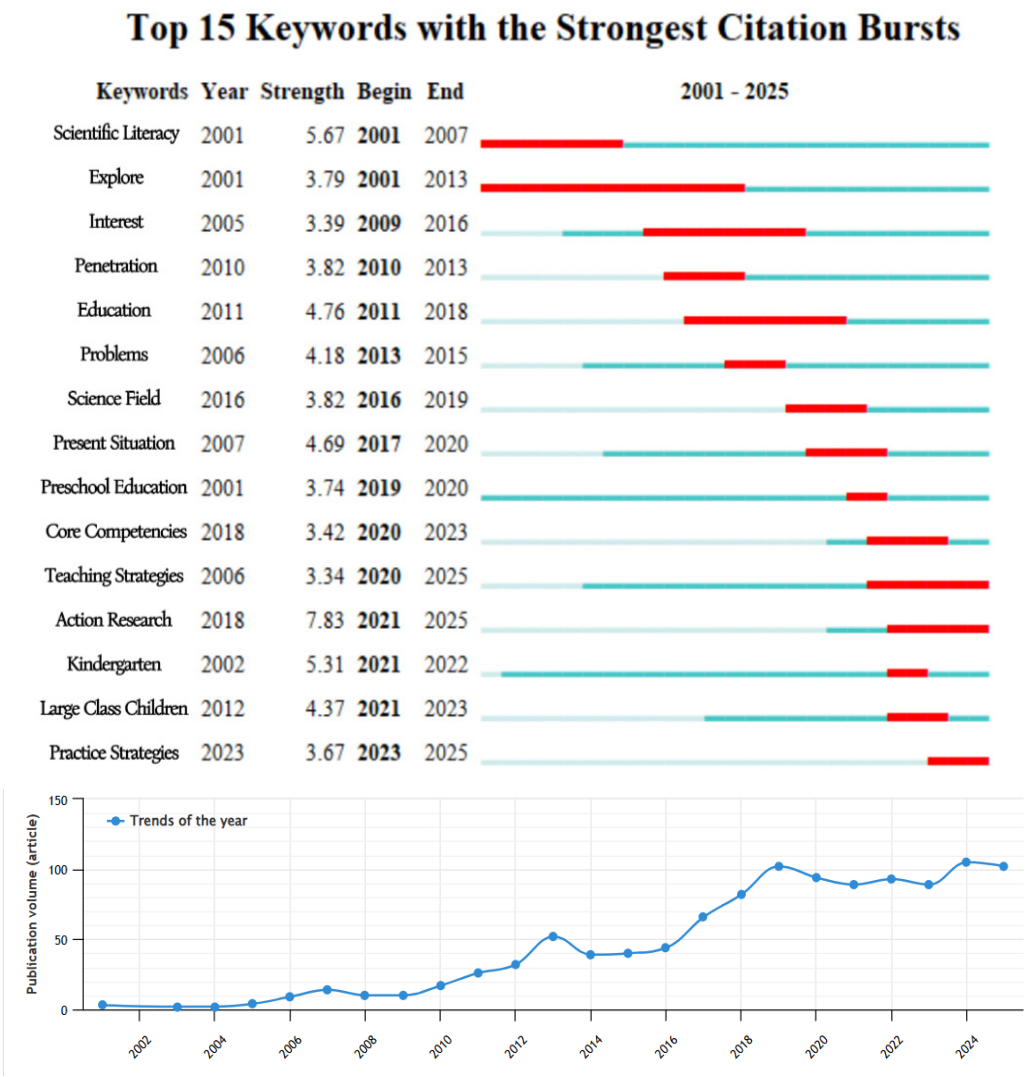


Figure 1. Top Keywords (Top Panel) and Publication Volume Trend (Bottom Panel) of Preschool Children's Scientific Literacy from 2001 to 2025

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First is the exploratory germination stage (2001–2007). The core burst keyword is typically "scientific literacy" (2001–2007, burst strength: 5.67), with simultaneous emergence of keywords such as "exploration" (initiated in 2001, 2001–2013, burst strength: 3.79). Research focused on the definition of basic concepts of preschool children's scientific literacy and preliminary exploration of enlightenment practices. Corresponding to this stage, the annual publication volume remained in a low range (see the trend chart below Figure 1), and research had not yet formed a scale. It only conducted basic discussions on the theoretical connotation of science education, the necessity of early scientific enlightenment in the preschool stage, and its initial integration into daily activities, reflecting the academic community's early attention to and theoretical groundwork for this field.

Subsequently, it entered the growth and development stage (2008–2018), where joint driving forces from policies and practical needs boosted research enthusiasm. During this period, keywords such as "education" (2011–2018, burst strength: 4.76), "penetration" (2010–2013, burst strength: 3.82), "interest" (2009–2016), and "problems" (2013–2015) emerged successively, reflecting in-depth academic exploration of issues such as "paths for integrating scientific literacy into preschool education", "localized practice models", and "children's interest-oriented teaching methods". Meanwhile, the annual publication volume showed a continuous upward trend, confirming the expansion of research scale and simultaneous deepening of research depth against the backdrop of growing emphasis on science education. On the basis of sorting out the "current situation" of science education at home and abroad (2017–2020), the academic community actively promoted localized curriculum reforms and explored integration paths between science education and other areas of early childhood education, embodying a shift from preliminary theoretical exploration to practical expansion.

After 2019, the research entered the deepening and stabilization stage. The annual publication volume climbed to a peak, followed by slight fluctuations and gradual stabilization, with research directions shifting toward refinement and systematization and a stronger focus on specific practices within the "kindergarten" setting (2021–2022). During this stage, keywords such as "core competencies" (2020–2023), "action research" (2021–2025, burst strength: 7.83, the highest among the 15 keywords), "teaching strategies" (2020–2025), "senior class children" (2021–2023), and "practice strategies" (2023–2025) emerged intensively. This reflects research focusing on subdivided issues such as "integration of scientific literacy and core competencies", "precision optimization of practice strategies", "implementation of action research", and "differentiated cultivation for young children of different age groups". It provides targeted theoretical support and practical guidance for the cultivation of preschool children's scientific literacy, demonstrating the academic community's in-depth attention to the systematicness, integration of science education, and children's long-term development.

4.2 Co-occurrence Analysis of Educational Hotspots in Preschool Children's Scientific Literacy Research

This study imported the literature into CiteSpace 6.1.R6, taking keywords as nodes and years as time intervals, and used the pathfinder algorithm to prune the network. A keyword co-occurrence knowledge map of theoretical research on preschool children's scientific literacy from 2001 to 2025 was constructed (see Figure 2). The map intuitively presents core issues, structural relationships, and developmental contexts. Combined with the analysis of indicators such as topological structure, cluster distribution, centrality, co-occurrence

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strength, and burst value, the research hotspots show distinct phased characteristics. The overall focus has shifted from macro-concepts to micro-practices, with increasing attention paid to the role of families in children's scientific literacy development.

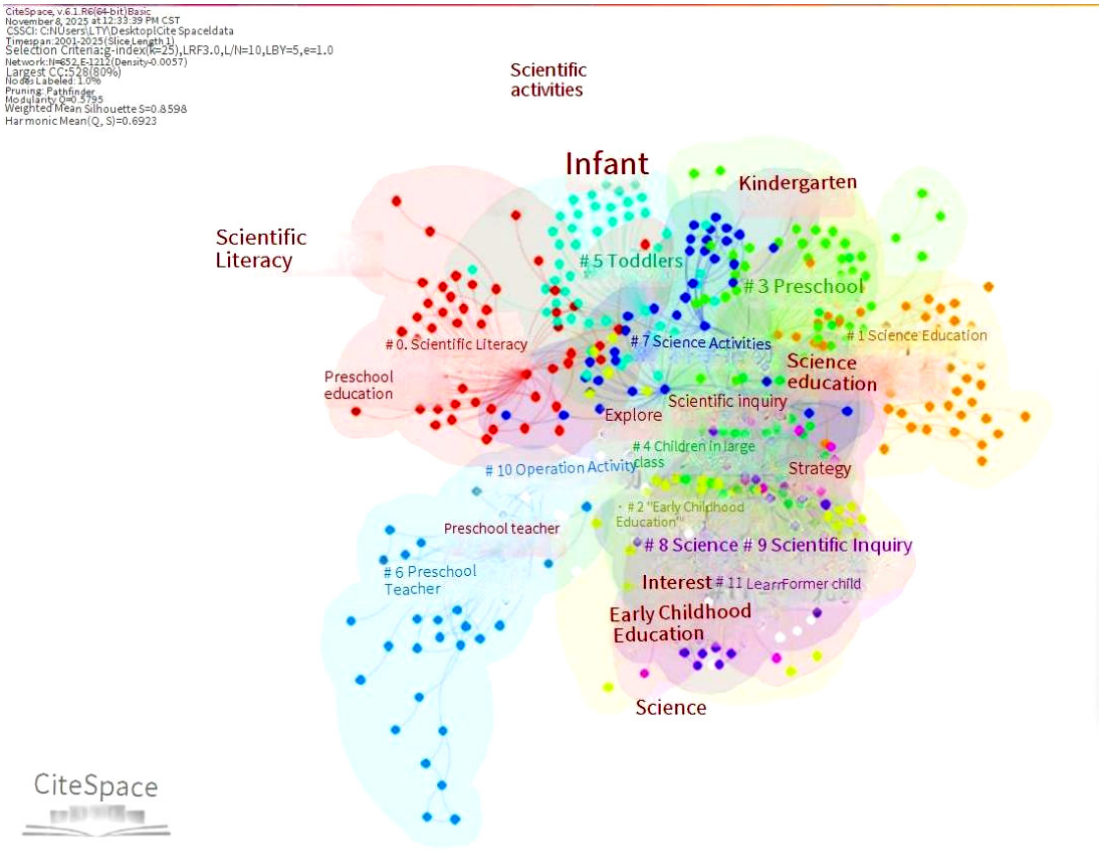


Figure 2 Keyword Co-occurrence Analysis Map of Theoretical Research on Preschool Children's Scientific Literacy in China (2001–2025)

Over the period 2001–2025, the evolutionary trajectory of research on preschool children's scientific literacy not only follows its own logical thread but also aligns closely with the demand for early cultivation of high-quality innovative talents driven by New Quality Productive Forces (NQPF). The early foundational phase (2001–2007), focused on the introduction and initial consolidation of macro-concepts, serves as the stage of laying the foundational legitimacy for NQPF-oriented literacy cultivation: core keywords in this phase centered on "preschool children" (Count=297, Centrality=0.07), "preschool education" (Count=227, Centrality=0.12), and "science" (Count=56, Centrality=0.18), with discussions revolving around the connotation and value of scientific enlightenment. Although "scientific literacy" (Count=12, Centrality=0.08) appeared with low frequency, its high co-occurrence intensity with the above core keywords initially established the consensus that "scientific education should be implemented in the preschool stage." This precisely provides the conceptual foundation for "preschool education to undertake the function of scientific literacy cultivation" in subsequent alignment with NQPF's demand for early literacy foundation of innovative talents. Research in this phase focused on necessity and basic connotation, while issues such as "how to implement in practice" had not yet become mainstream.

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Moving into the mid-term deepening phase (2008–2018), research is characterized by practical exploration and structural differentiation, which in essence is the phase of operationalizing the carrier for inquiry capabilities required by NQPF: "kindergarten" (Count=183) emerged as the core radiation node, indicating that the research focus had clearly shifted to the practical field of kindergartens and established the consensus that "kindergartens are the main front of scientific education." The emergence of high-burst keywords such as "exploration" (Burst=3.39, 2009–2016) and "education" (Burst=4.76, 2011–2018) drove research toward specific practices of preschool children's scientific literacy cultivation, focusing on the core logic of "teaching and learning," and established "exploration" as the core method of kindergarten scientific education—this shift directly responds to NQPF's demand for early cultivation of "critical inquiry competence" in innovative talents, incorporating the prototype of "bold hypothesis and rigorous verification" thinking into preschool education for the first time. The burst of the keyword "teacher" (Burst=4.69, 2017–2020) also laid the groundwork for teachers as key roles connecting practice and literacy goals: their scientific literacy, activity design, and guidance capabilities began to become core influencing variables affecting practice effects, implicitly matching NQPF's demand for teachers' professional supporting capabilities. In this phase, research constructed a refined network of "field-method-goal-process" around "implementation paths of kindergarten scientific education," strengthening attention to process-oriented and experiential learning.

The expansion and integration phase (2019–present) is marked by field synergy and literacy integration, representing the preschool response to NQPF's synergy demand: "kindergarten education" (Centrality>0.20, Burst=3.74, 2019–2020) served as a deepened integration node, connecting curriculum, teachers, and practice, highlighting sustained attention to the correlation between kindergarten education quality and scientific literacy. Meanwhile, high-burst keywords such as "core competencies" (Count=16, Centrality=0.28, Burst=3.42, 2020–2023), "parents" (Count=15, Centrality=0.25, Burst=3.67, 2023–2025), and "development" (Count=10, Centrality=0.22, Burst=7.83, 2021–2025) correspond to three core shifts driven by NQPF: the burst of "core competencies" indicates that the goal of scientific literacy education has transitioned from knowledge accumulation to high-order literacies such as "innovative thinking and interdisciplinary application competence" required by NQPF; the involvement of "parents" reflects the multi-field synergy feature advocated by NQPF, with the linkage of family-kindergarten-community fields serving as an ecological support for scientific literacy cultivation; the high centrality of "development" echoes NQPF's demand for "sustained learning adaptability" in talents, and research began to focus on the value of scientific literacy for children's long-term sustainable development.

The strong connections among these keywords are centered on "integration" and "synergy," and based on systematic and ecological perspectives, three consensuses have been gradually established: "scientific literacy is an important component of core competencies," "home-kindergarten co-education is a key support," and "attention should be paid to the long-term developmental value of scientific literacy." This means that the cultivation of preschool children's scientific literacy has shifted from single kindergarten practice to the construction of an ecological system aligned with NQPF's multi-factor synergy logic; the linkage between fields and the integration of goals and literacies jointly provide a more three-dimensional support framework for the early cultivation of high-quality innovative talents required by NQPF.

Across the period 2001–2025, research on preschool children's scientific literacy presents a clear evolution-

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ary context of "macro-concept foundation—micro-practice deepening—multi-field collaborative integration," and has now entered a new stage of mature systematization focusing on holistic environmental education. This evolutionary process is essentially a gradual response to NQPF's talent demand: from laying the foundation for NQPF literacy cultivation through early concept consensus, to anchoring the inquiry capabilities required by NQPF through mid-term practical exploration, and then to adapting to the cross-field integration logic of NQPF through late-stage field synergy, the deepening of research has consistently centered on NQPF's requirements for core literacies such as "interdisciplinary integration ability, innovative thinking, and sustained learning adaptability." Among them, "preschool teachers" serve as a key support point throughout all phases, and their scientific literacy, activity design, and guidance capabilities have always been core influencing variables, which also means that teachers' professional development needs to continuously adapt to NQPF-oriented educational goals and practical demands. The emergence of emerging keywords such as "STEM/STEAM," "information technology," "scientific evaluation," and "cultural integration" suggests that future research can further expand and deepen into these fields around NQPF's development needs, so as to construct a more comprehensive and diversified theoretical and practical system for preschool scientific literacy cultivation that is aligned with the development of New Quality Productive Forces.

4.3 Analysis of Research Trends in Preschool Children's Scientific Literacy in China

Using CiteSpace software, a keyword burst time zone map of research on preschool children's scientific literacy in China from 2001 to 2025 was constructed (see Figure 3). It shows that the evolutionary path of this research presents distinct phased characteristics. The following interpretation from dimensions such as deepened co-occurrence network structure, policy interaction, conceptual connotation, and paradigm transformation comprehensively demonstrates the complex evolutionary path of theoretical research on preschool children's scientific literacy in China from "empirical enlightenment" to "systematic construction."

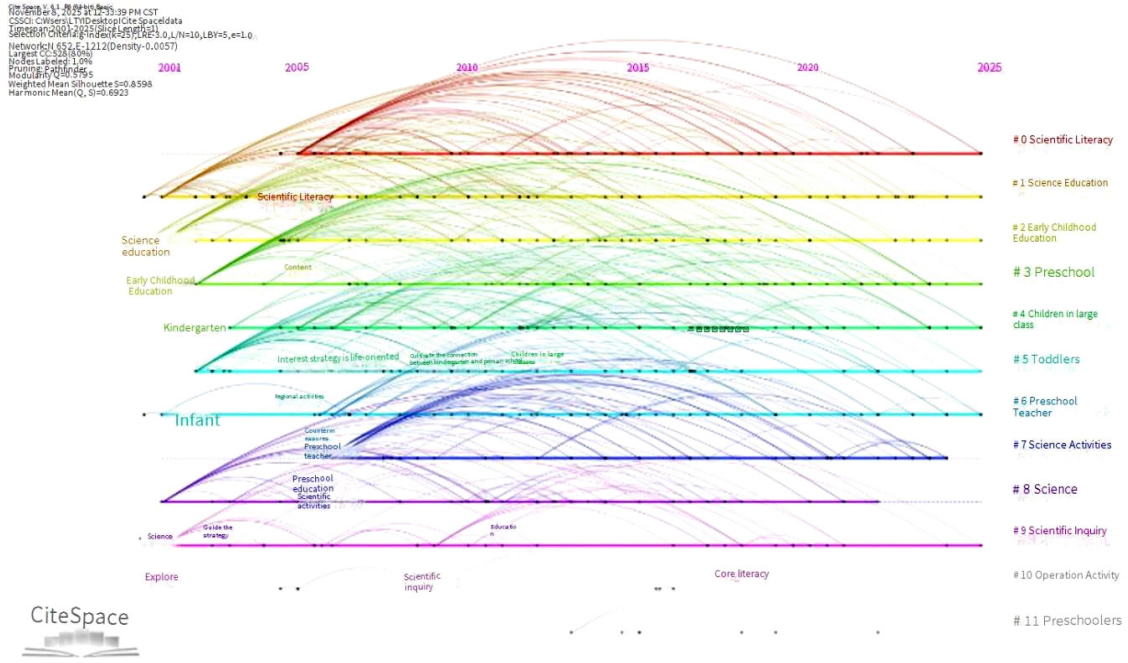


Figure 3 Keyword Burst Time Zone Map of Research on Preschool Children's Scientific Literacy in China (2001–2025)

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First, the development of preschool children's scientific literacy in China is driven by multiple factors including policy orientation, theoretical deepening, and practical needs, and the co-occurrence network of scientific literacy research has evolved from fragmentation to integration. The sparse network formed during 2001–2007 (modularity value < 0.3) indicates that early research was in a stage of partial exploration. "Science education" as an isolated core node (centrality = 0.32) only formed weak connections (strength < 5) with "preschool children" and "teachers," reflecting the initial attention to teaching subjects and objects at that time. Scientific literacy research during this period mainly responded to the policy controversy of "whether science education should be incorporated into preschool education," laying the foundation for subsequent research (Meng, 2025). A single high-density cluster was formed during 2008–2018 (modularity value = 0.81), with "scientific activities" as the leading node (centrality = 0.68, frequency accounting for 42%), radiating strongly to practical elements such as "exploration" and "materials," entering a period of deepened practice in kindergarten scenarios. After 2019, a multi-core collaborative network was established, with the centrality of "core competencies," "STEM," and "learning qualities" all > 0.4. The cross-field connection of "home-kindergarten co-education—community resources" (strength = 18) was formed, revealing the expansion of research horizons toward ecosystem construction, which directly responds to the popularization of the "holistic environmental education" policy concept (Liu, 2020).

Second, there is a clear interlocking relationship between the evolution of policy texts and the phased leaps of research, reflecting the transformation of policy interaction from macro advocacy to precise empowerment. After the issuance of the Guidelines for Kindergarten Education in 2001, "science education" showed a significant burst for the first time (Burst = 3.2, $\Delta T = 0$ years), clearly identifying science education as one of the five major areas of preschool education and promoting the introduction of the "scientific literacy" concept. Subsequently, supported by the Guidelines for the Learning and Development of Children Aged 3-6 and the Outline of the National Plan for Scientific Literacy (2021-2035), the emphasis on inquiry ability and refinement of scientific inquiry ability training goals led to a peak burst of "inquiry" and "material provision" reaching 4.8 in the following year ($\Delta T = 1$ year). After the launch of the "China STEM Education 2029 Plan" in 2018, "STEM" and "engineering design" became new burst words (Burst = 5.1, $\Delta T < 1$ year). Subsequently, led by the Opinions on Strengthening Science Education in Primary and Secondary Schools in the New Era, the proposal of "advancing scientific literacy cultivation to the preschool stage" promoted the collaborative education of families, kindergartens, and communities. This policy sensitivity highlights the academic community's rapid response mechanism to national strategies, and also confirms the distinct practical orientation of preschool education research in China (Huo, 2016). Meanwhile, the transformation of policies from "macro requirements" to "specific paths" has directly driven the practical orientation transformation of scientific literacy research (Gao, Pang, & Pan, 2025).

At the same time, the evolution of the connotation of research on preschool children's science education presents the characteristic of "three-dimensional expansion." In the early stage (2001–2007), it focused on a two-dimensional structure of "knowledge + interest." The strong co-occurrence of "knowledge" and "observation and recording" (strength = 32) did not extend to the emotional attitude dimension, reflecting a narrow skill-oriented orientation. In the mid-term (2008–2018), it expanded into a three-dimensional structure of "knowledge—ability—attitude." After 2019, new connections between "science" and dimensions such as "critical thinking" (strength = 24) and "ethical awareness" (strength = 15) emerged. "Core competencies"

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were simultaneously associated with "cultural identity" (strength = 18) and "environmental responsibility" (strength = 12), indicating that the concept of scientific literacy has evolved from skill training to process inquiry, and developed into a three-dimensional integrated literacy system of "literacy—field—development" (2019–present), which is highly consistent with the global humanistic turn of science education (OECD, 2023).

Finally, the transformation of research paradigms has experienced three leaps from empirical enlightenment to systematic integration. First, the early stage centered on "knowledge transmission," with the high-frequency word "teacher guidance" (frequency accounting for 60%), reflecting an "empirical enlightenment paradigm" that relies on teachers' experiential teaching and focuses on "what to teach." After 2008, it shifted to a practical inquiry paradigm centered on "young children's active exploration," with research focusing on path innovation of "how to teach." Then, the mid-to-late practical inquiry paradigm expanded from being limited to the single field of kindergartens to a multi-field collaborative paradigm constructing a trinity education network of "kindergarten—family—community." Research expanded from "activity design within kindergartens" to "whole-domain resource integration," and the role of families in scientific literacy cultivation transformed from "assistants" to "core participants." In addition, against the background of new-quality productive forces, the literacy integration paradigm, with "interdisciplinary integration" and "lifelong development" as core essence, fully incorporates scientific literacy into the children's core competencies system, driving the research focus to shift deeply from "short-term ability training" to "long-term literacy construction," forming a paradigm leap from "skill-oriented" to "literacy integration."

In summary, over the past 25 years, research on preschool children's scientific literacy in China has undergone a three-stage evolution of "foundation laying—practical deepening—systematic integration." The co-occurrence network has developed from scattered nodes to a multi-field collaborative network, the conceptual connotation has expanded from a single knowledge dimension to a multi-dimensional integrated structure, and the practical paradigm has completed three leaps from empirical enlightenment to systematic integration, which is highly consistent with the requirements of new-quality productive forces for talent training. In the future, it is necessary to strengthen three key areas: urban-rural balance, evaluation system, and interdisciplinary integration, promote the development of scientific literacy cultivation toward higher quality and greater inclusiveness, and lay a solid foundation for cultivating future talents with solid foundations and innovative thinking in the era of new-quality productive forces.

5.Conclusions

5.1 Core Requirements of New-Quality Productive Forces for Preschool Children's Scientific Literacy Education

New-quality productive forces (NQPF), centered on innovation-driven development, feature innovation, technology-drivenness, efficiency, and sustainability, with its core essence lying in breakthrough technological innovation leadership, total factor productivity leapfrog, and in-depth industrial transformation and upgrading. Its development logic puts forward three core requirements for preschool children's scientific literacy education, which are strongly supported by CiteSpace bibliometric findings: First, consolidating scientific

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thinking as the foundation. Guided by NQPF's demand for high-order cognitive abilities, it focuses on the development of logical, critical, and creative thinking. As evidenced by the significant burst of "innovation" (Burst=3.82, 2010–2013) and the high centrality of "scientific literacy" (Centrality=0.37), this requirement guides children to advance from "intuitive perception" to "abstract thinking" through direct experiential activities such as natural observation and hypothesis verification, thereby laying the foundation for problem-solving and innovative thinking abilities required by NQPF. Second, stimulating innovative capacity as the key. NQPF emphasizes original breakthroughs, which requires scientific education to move beyond confirmatory experiments. This is reflected in the post-2020 burst of "core competencies" (Burst=3.42, 2020–2023) and its strong connection with "preschool science enlightenment," urging the creation of an open and inclusive educational environment. Such an environment supports young children in conducting creative practices using diverse materials, allows trial and error iteration, and encourages breaking conventions in exploration, directly responding to NQPF's inherent demand for "0 to 1" original innovation. Third, strengthening practical ability as the core. Aligned with NQPF's requirement for interdisciplinary application and complex problem-solving capabilities, this requirement relies on "learning by doing" and "learning by applying" activities such as planting experiences and scientific experiments. It cultivates hands-on operation, data recording, and result analysis capabilities, helping children master basic skills in knowledge transformation and problem-solving, which is consistent with the practical application needs of new-quality productive forces and echoes the high co-occurrence frequency of "exploration" (Burst=3.39, 2009–2016) and "scientific activities" in CiteSpace results.

5.2 Reform Paths of Preschool Children's Scientific Literacy Education in the Context of New-Quality Productive Forces

To meet the above requirements, NQPF drives a comprehensive transformation of preschool children's scientific literacy education in concepts, content, methods, and evaluation systems, achieving systematic reform with its mechanism deeply supported by theoretical logic and empirical data. Educational concept innovation centers on shifting from "knowledge transmission" to "innovation empowerment" while strengthening teacher team building. As reflected by the burst of "teacher" (Burst=4.69, 2017–2020) and its high intermediary centrality (Centrality=0.23) in CiteSpace results, children are regarded as creative individuals and teachers as supporters and guides for their exploration. Through divergent question design, group cooperative learning and other forms, it balances the development of innovative thinking, problem-solving abilities and collaborative spirit, which requires establishing a systematic teacher training mechanism centered on the core connotation of new-quality productive forces and scientific education methods to improve teachers' technological literacy and innovative teaching capabilities. Meanwhile, aiming at the prominent "urban-rural resource imbalance" in China's context, a regional balanced development mechanism should be established to narrow the gap in preschool science education between urban and rural areas and different regions, leveraging digital technology to promote educational equity and respond to the practical demand for balanced development of NQPF.

Teaching content upgrading needs to break disciplinary boundaries and build a digital and intelligent resource support system. It integrates cutting-edge technological concepts such as artificial intelligence and big data with scientific phenomena in daily life into forms accessible to young children—including popular sci-

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ence picture books, animations and interesting experiments—to infiltrate knowledge, which echoes the trend of "information technology" and "STEM/STEAM" becoming research hotspots. It also explores scientific education resources in daily life to realize the integration of scientific enlightenment and life practice, constructing a "technology + life + interdisciplinary" knowledge content system from an early age. This not only makes abstract concepts concrete through immersive technologies such as VR/AR and IoT data collection but also embeds the thinking mode of "human-machine collaboration" in early childhood, promoting the digital and intelligent transformation of educational elements to adapt to the technological characteristics of NQPF.

Teaching method innovation should focus on inquiry-based, project-based and gamified learning as the core, and build a trinity scientific literacy cultivation environment of "classroom—family—community." By improving the home-kindergarten-community collaboration mechanism, it integrates multi-party resources including science and technology museums, universities and high-tech enterprises to carry out thematic activities such as "scientists entering campuses" and "parent-child science carnivals," which stimulates children's learning initiative. This allows children to independently discover and comprehensively apply knowledge in problem situations such as "how to make a paper bridge more load-bearing," enhancing their observation, inquiry and comprehensive application abilities, and serving as an important practice of NQPF's collaborative ecological logic.

Evaluation system improvement is equally crucial. Guided by NQPF's emphasis on practical contributions and innovative capabilities, it establishes a multi-dimensional evaluation model emphasizing both process-oriented and developmental evaluation. Breaking away from the traditional focus on knowledge memory and standardized skill assessment, the evaluation focuses on process-oriented performance such as the uniqueness of raising questions, the feasibility of inquiry plans, the rigor of experimental operations (age-appropriate) and the effectiveness of cooperative communication. It also adopts multi-subject evaluation combining teacher observation, children's self-evaluation/peer evaluation, work analysis and parent feedback, forming a comprehensive "literacy portrait" to accurately reflect children's innovative potential and developmental trends.

5.3 Global Reference Value of Chinese Experience

China's theoretical exploration and practical advancement of preschool children's scientific literacy education under the background of new-quality productive forces have provided unique experiences for global preschool science literacy education to respond to the technological revolution, with distinct Chinese characteristics and universal reference significance. At the conceptual level, China takes the "innovation-driven development" strategy as the guide and extends the goal of "cultivating innovative talents" to the preschool education stage, which is an important embodiment of the theoretical logical chain of "NQPF → educational goal transformation → connotation reshaping of scientific literacy education." It exports an interdisciplinary integrated education model that integrates art, language and other fields into science education, emphasizing "child-centered" personalized enlightenment. This not only responds to the strong policy-driven characteristics of China's education development but also provides ideas for other countries to balance technological development and humanistic care in the context of global technological revolution.

At the content level, China focuses on "the combination of technological enlightenment and life practice."

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It not only infiltrates cutting-edge technological knowledge through popular science picture books and interesting experiments but also guides children to observe physical phenomena and life processes in daily life, avoiding the educational misunderstanding of "technology supremacy." For developing countries facing a shortage of digital educational resources, China's experience in developing low-cost and easily promotable technological enlightenment resources for young children—such as simplified AI popular science animations and portable experimental toolkits—is of great reference value. Meanwhile, this content construction path also responds to the research trend of "integration of technology and life" reflected in CiteSpace's keyword co-occurrence network, ensuring the practicality and popularization of science education.

At the method level, the models explored by China such as "gamified inquiry" and "project-based learning" organically unify the "efficiency" of new-quality productive forces with the "fun" of preschool education. It conveys the concept of green and sustainable education, integrating the green characteristics of new-quality productive forces into preschool education. The model of combining environmental education with life practice—including community nature observation stations and planting experience activities—provides a replicable practical paradigm for improving educational quality. Moreover, the trinity collaborative education ecosystem constructed by China breaks the barriers between different educational fields, which has universal reference significance for global preschool education to optimize resource allocation and practice the concept of sustainable development.

This exploration not only constructs a "three-stage dynamic model" for the evolution of China's preschool children's scientific literacy education (supported by CiteSpace's phased data) but also originally proposes three core practice paths of "innovation-driven pedagogy, digital resource integration, and trinity collaboration," enriching the theoretical and practical system of early science education responding to macro-social development demands. In the future, research can be further deepened on the construction of core literacy evaluation systems, the promotion mechanism of urban-rural educational equity, and the in-depth application of AI in personalized education, so as to better connect preschool science education with the development of new-quality productive forces and provide more solid support for cultivating innovative talents.

Funding

Hebei Provincial New Liberal Arts Research and Reform Practice Project: Construction of a Three-Dimensional New Liberal Arts Innovation and Entrepreneurship Practice System and Talent Cultivation Reform (2021GJXWK070).

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