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EXPERIENCE AND INSPIRATION FROM INTERNATIONAL SCIENCE EDUCATION DEVELOPMENT: A COMPARATIVE STUDY BASED ON POLICIES, RESOURCES AND PRACTICES

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Abstract: Against the backdrop of intensifying global scientific and technological competition and social change, science education has become a core indicator for measuring a country's innovation capabilities and future competitiveness. This article systematically examines and analyzes the reform experiences and development trends of leading science education countries and regions in terms of top-level policy design, resource supply ecosystems, and educational practice approaches through an international comparative perspective. The research reveals that international science education exhibits characteristics such as strategic policy, curriculum literacy, digital resources, teacher professionalization, and collaboration within and beyond schools. These countries promote interdisciplinary integration through top-level design, build open resource ecosystems based on digital platforms, strengthen professional support systems for teachers, and actively promote educational collaboration among diverse stakeholders such as schools, families, and communities. This study concludes that these international experiences offer important insights for my country in building a high-quality science education system. This research aims to provide international references and localized approaches for optimizing and innovating my country's science education system.
Keywords: Science education; International comparison; Education policy; Digital resources

1 INTRODUCTION

Driven by globalization and the Fourth Industrial Revolution, technological innovation represented by artificial intelligence and big data is profoundly reshaping social structure and future lifestyles. As a key way to cultivate innovative talents and improve the scientific literacy of the people, science education has become an important strategic area for education reform in various countries. The results of the PISA 2022 test released by the Organization for Economic Cooperation and Development (OECD) show that students' scientific literacy is not only closely related to their future academic careers, but also has a profound impact on the country's innovation capabilities and long-term competitiveness [1]. Therefore, building a science education system that adapts to the needs of future development has become a common goal and key task of education reform in various countries. However, in the process of promoting the development of science education, different countries face different social environments. How to find a balance between global trends and local realities and build a science education system that is in line with the development of the times and in line with the national conditions is still a common challenge. International experience shows that the reform of science education usually covers three core levels: policy guidance, resource supply and educational practice. The policy level focuses on top-level design and curriculum standard innovation, the resource level emphasizes digitalization, openness and multi-subject collaboration, and the practice level focuses on the deep integration of formal and informal learning fields.

How to build a science education system that adapts to the changing times and aligns with national conditions is a common challenge faced by all countries. Based on this, this article aims to systematically review the relevant policy documents of countries and regions with advanced science education development, as well as those of international organizations, analyzing their reform experiences and implementation paths in terms of policies, resources, and practices. Through comparative analysis, this article aims to reveal the common trends and differences in international science education reform, hoping to provide reference and inspiration for the deepening reform and innovative development of science education in my country.

2 POLICY TRENDS IN THE DEVELOPMENT OF INTERNATIONAL SCIENCE EDUCATION

2.1 Strategic Policy Layout: Systematically Building a New Framework for Science Education

International organizations and governments have placed science education in a national strategic position and attached importance to the top-level design of science education. Since 2024, UNESCO has promoted the "Revitalizing STEM Education" project, advocating the integration of STEM education with the Sustainable Development Goals SDG4 (quality education) and SDG9 (industrial innovation) to address the digital divide and gender gap. Secondly, many countries have released STEM education strategic plans. For example, the United States has released the "Federal STEM Education Strategic Plan (2024–2028)" and the "Computational Literacy Guidelines" [2], promoting national STEM education through systematic design [3]. Ireland, a member state of the European Union, has issued the "STEM

Education Implementation Plan (2023–2026)", proposing a full coverage training program from preschool to secondary school. The Finnish Ministry of Education and Culture released its national STEM strategy in 2023, which clearly stated the goal of achieving universal information literacy and lifelong learning by 2030 [4]. Overall, international science education policies are characterized by being guided by students' core literacy, focusing on interdisciplinary integration, and supported by digital technology, fully reflecting the consensus on cultivating future scientifically literate talents.

2.2 Curriculum And Teaching Reform: Emphasizing Core Literacy and Inquiry Practice

Curriculum standards are the bridge between macro-policies and micro-teaching. Countries have updated their science curriculum standards to meet the needs of interdisciplinary integration and core literacy cultivation. When updating their national curriculum, many countries emphasize inquiry and interdisciplinary teaching as core teaching activities. For example, the United States' Next Generation Science Standards (NGSS) proposed a "three-dimensional learning framework", including "science and engineering practices", "interdisciplinary core concepts" and "disciplinary core ideas", emphasizing that students explore knowledge with a scientist's mindset in real problem situations and realize knowledge construction [5]. The United Kingdom's National Curriculum for Science and the Australian Curriculum: Science (9.0) also emphasize inquiry-based and interdisciplinary teaching, encouraging students to improve their scientific literacy and critical thinking through experiments, projects and competitions [6].

Curriculum reforms are accompanied by changes in teaching methods. Countries are promoting teaching models such as inquiry-based learning, collaborative learning, and flipped classrooms to enhance students' critical thinking and practical skills. For example, some high schools in Japan are using collaborative inquiry and practice, while German schools are introducing research-based experiments and real-data analysis to strengthen students' scientific inquiry skills. Meanwhile, internationally, there is a growing emphasis on cultivating students' scientific literacy and global competence. Many countries are incorporating global issues such as climate change and sustainable development into science curricula to enhance students' understanding of the interaction between science and society. For example, Finland's core curriculum framework, centered on "phenomenon-based learning," encourages students to engage in interdisciplinary inquiry around global issues such as climate change and energy, fostering critical thinking and independent problem-solving skills. Countries like the United Kingdom and Australia emphasize the application and practice of scientific literacy. For example, Australia is implementing the "Science Innovation Competition," and German schools are establishing "Natural Science Laboratories" to provide students with rich experimental experiences. The core goal of science education has shifted from simply imparting knowledge to cultivating students' ability to address complex problems. This shift from a knowledge-based to a competency-based approach highlights the importance of advancing curriculum and teaching reform simultaneously.

2.3 Teacher Professional Development: Building a Systematic Support System

Teacher professional development is generally regarded as the key to whether the reform can be implemented. International experience shows that countries have established a multi-level and systematic teacher professional development system to ensure that teachers are able to meet the new teaching requirements. The US "Standards for Science Teacher Training" and Australia's "Strong Beginnings" report both emphasize that science teachers should have the ability to teach and instruct across disciplines [7-8]. In addition, the OECD (2020) survey shows that most countries require teachers to regularly participate in school-based training [9], online courses and cross-school exchanges. The EU's "Europe 2020 Strategy" and "European Digital Agenda" support member states in carrying out teacher STEM capacity building projects. The UK has established a national STEM learning center to provide summer camp training for science teachers, the US NSF provides a variety of teacher development programs, and the Singapore Ministry of Education organizes science education webinars and workshops through the "Teacher Development Committee" to help teachers master digital teaching and project-based learning methods. Countries such as the Netherlands have established communication and cooperation platforms such as "teacher communities" to encourage teachers to share experiences and grow together, and have incorporated participation in professional development into career advancement and salary incentive systems, effectively enhancing teachers' motivation for development [10].

3 THE SUPPLY MODEL AND ECOLOGY OF SCIENTIFIC EDUCATION RESOURCES

Scientific education resources are a crucial guarantee for the high-quality development of the science education system. With the advancement of digitalization, informatization, and globalization, the supply of scientific education resources is showing new trends of diversification, openness, and intelligence. International experience shows that the supply model of scientific education resources not only involves the coordinated development of multiple providers but also includes the diversification of resource content, the systematic development of platforms, and the continuous optimization of resource application and sharing mechanisms. The construction of this resource ecosystem directly impacts the fairness, effectiveness, and sustainability of science education.

3.1 Supply Entities: Diverse Collaboration Among Government, Society, and Learning

The main providers of scientific education resources are no longer limited to a single government or school, but have formed an ecosystem of "government-led, multi-party participation, and collaborative construction." Government departments still play a core role in policy and financial support, funding scientific education projects by establishing foundations. For example, the National Science Foundation (NSF) of the United States continues to fund scientific education projects and provide high-quality digital teaching resources for teachers and students [11]. The German Federal Ministry of Education and Research (BMBF) supports teachers' professional development and resource integration through the "Lehrer-Online" platform [12]. At the same time, non-profit organizations and foundations have become important supplementary forces. For example, STEM Learning in the UK is committed to providing digital educational resources and training courses for teachers. OpenSciEd, a non-profit organization supported by the Bill and Melinda Gates Foundation in the United States, develops and provides free three-dimensional science generative teaching materials that meet the NGSS standards, and promotes phenomenon-driven teaching methods. Technology companies and educational technology companies have also gradually become an important part of the resource ecosystem. For example, Khan Academy provides free online courses and educational resources, Canadian companies such as SMART Technologies develop interactive digital educational hardware and software tools, and Australia's CSIRO Science Institute promotes the "STEM in Schools" project to provide schools with professional digital STEM resources. Schools use online platforms and digital technologies to provide students with learning tools such as virtual laboratories and online courses, which is the "last mile" connecting resources and students. For example, some schools in Finland and Canada provide students with learning experiences such as virtual laboratories and online courses by establishing online teaching platforms.

3.2 Supply Content: Development and Application of Digital Resources

International science education resources are shifting from traditional static knowledge carriers to dynamic, interactive, and immersive learning experiences. Open digital textbooks have become a key development direction for international science education resources. For example, the US-based OpenStax project offers a series of free science textbooks covering subjects such as physics, chemistry, and biology, providing students with high-quality educational resources. Video resources are a visual and engaging teaching resource. They present scientific knowledge and experimental procedures through videos, enabling students to understand and learn more intuitively. They can be used in class or during independent learning. For example, France's CLEMI TV sparks students' curiosity by offering a variety of science education videos. India's Mocomi website provides animated reading content in biology, chemistry, physics, and other fields for children aged 4-12.

Virtual laboratories and interactive simulations provide students with repeatable, low-cost, and highly safe experimental experiences, effectively solving the problem of insufficient experimental conditions in some schools. The virtual laboratory platform provided by Labster in New Zealand allows students to conduct experiments in a safe environment and explore various scientific concepts and principles without the need for real laboratory equipment and materials. This form of resource greatly expands students' experimental experience and learning opportunities. The PhET interactive simulation project developed by the University of Colorado and funded by NSF provides simulation software covering elementary school to university, helping students to intuitively understand abstract concepts [13]. Studies have shown that the use of virtual experiments can significantly improve student grades and course pass rates. In addition, some countries use scientific adventure games, immersive situational simulations, VR and AR experiments to enhance students' learning interest and motivation. For example, the Smithsonian Institution Museum in the United States uses AR technology to build "virtual adventures" to allow students to learn scientific knowledge in an immersive environment. NASA's "Climate Kids" project helps students understand climate change through games and animations.

3.3 Supply Platform: Open and Shared Online Learning Center

To effectively integrate and distribute massive resources, various online platforms have emerged. These serve not only as resource repositories but also as comprehensive service centers integrating teaching support, professional development, and interactive communication. Resource supply platforms focus on providing teachers with teaching tools and professional development resources. The US-based Teaching Channel offers a wealth of instructional videos, curriculum design examples, and teaching strategies to help teachers improve their classroom practices. Canada's SMART Notebook interactive whiteboard software provides a wealth of science education resources and tools, including virtual labs, animated demonstrations, and lesson templates, helping teachers design engaging science lessons and engage students in interactive learning. Meanwhile, many institutions have established dedicated educational websites for specific scientific fields. For example, the US Geological Survey (USGS) created the "Earthquakes for Kids" website, which not only provides information about earthquakes but also features a Q&A session where students can ask geologists questions directly. Some platforms connect with museums and research institutions to promote the integration of learning resources within and outside of schools. For example, the European "Scientix" platform serves not only schools but also scientific research institutions, museums, and science centers, fostering cross-sector educational collaboration. In addition, some online learning platforms provide one-stop resource sharing services, bringing together high-quality resources from different regions and institutions, and realizing the sharing and exchange of cross-border educational resources.

4 COLLABORATIVE PRACTICE BETWEEN SCHOOL AND INFORMAL SCIENCE EDUCATION

In promoting scientific literacy, synergy between school-based education and informal learning spaces is widely considered a key path to enhancing the depth, breadth, and authenticity of learning. Research on informal science education shows that learning is a process that relies on individual motivation, social interaction, and context. The "free-choice learning" offered by museums and science centers emphasizes intrinsic motivation and deep engagement within highly customized contexts. This experiential nature helps foster a scientific interest and identity. Informal spaces, with their authentic contexts, diverse resources, and experiential nature, complement and extend the limitations of the school classroom. On the other hand, school-based education, with its core focus on systematic curriculum and emphasis on knowledge systematization and academic assessment, provides an institutionalized pathway for transforming the effectiveness of informal learning. International experience suggests that the integration of formal and informal learning is becoming a key trend in science education, truly transforming "interest" into "competence."

4.1 School Laboratory Environment: The "Hard" Support for Practical Learning

Science experimentation is a core component of science education. Developed countries attach great importance to providing students with safe, advanced, and inquiry-based experimental environments. Primary and secondary schools in countries like the United States, the United Kingdom, and Singapore are widely equipped with modern laboratories that adhere to strict safety standards. These laboratories serve not only as venues for validating knowledge but also as innovative spaces for students to raise questions, design experiments, collect evidence, and conduct argumentation. Furthermore, some countries are promoting the integration of virtual and real-world experiments. For example, some schools in Germany and Finland are using virtual laboratories and online platforms to expand students' inquiry experiences. Virtual experiments are an effective supplement to resource constraints or when experiments present safety risks. The quality and effectiveness of a school's science laboratory environment are directly related to the quality and effectiveness of experimental teaching.

4.2 Off-Campus Extension: Science and Technology Venues Promote In-Depth Learning Experience

Informal education venues, such as science museums, science centers, and natural history museums, have become an important extension of science education. International research shows that science centers and museums can significantly enhance the public's understanding and interest in science, especially in popularizing scientific knowledge and stimulating the innovative potential of young people [14]. The Exploratorium in San Francisco, USA, emphasizes the participation methods of "hands-on" and "thinking", and provides students and the public with immersive science learning experiences through interactive exhibitions and online resources. The Science Museum in London, UK, regularly holds experimental performances and science lectures for primary and secondary school students, and provides teaching support to teachers through the museum-school cooperation model. The Singapore Science Center is closely connected with the school curriculum, introducing rich resources into the school classroom, enhancing the practicality of the curriculum, and promoting the integration of classroom applications and off-campus resources. The Finnish Museum of Natural History provides students with online exploration tasks through virtual reality technology, realizing interdisciplinary and remote learning methods. The venue resources meet the scientific education needs of learners at different stages through museum-school integration, family and group learning, and individual visit experiences. These venue practices show that the educational function of science and technology venues has shifted from traditional exhibit displays to dynamic, learner-centered educational experience spaces.

4.3 Home-School-Community Collaboration: Building a Borderless Learning Environment

Science learning is not limited to schools and museums; families and communities are important learning venues. In recent years, more and more countries have advocated for collaboration between families, schools, and communities to jointly promote the improvement of young people's scientific literacy. For example, the American Museum of Natural History in New York launched the "Urban Advantage" project [15], providing guidance manuals and extracurricular resources for families and communities to help students better conduct scientific inquiry learning. Treating the community as a classroom and building a model of collaborative education between home, school, and community is an important manifestation of the socialization of science education. The Teton Science School in Wyoming, USA, proposed the concept of "community as classroom", using the local natural environment and expert resources to support student learning. At the same time, community art and environmental protection projects have also been incorporated into science education. For example, Philadelphia's public art mural project guides residents to understand local ecosystems and environmental protection by painting ecological-related murals and combining QR code technology. Enterprises and social organizations also play a role, such as the International Science and Engineering Fair (ISEF) hosted by the American Association for the Advancement of Science (AAAS), which provides a scientific research practice and display platform for young people around the world. These diversified collaborations have gradually enabled science education to move towards "borderless learning" and achieved in-depth linkage between education inside and outside the school.

5 EXPERIENCE SUMMARY AND ENLIGHTENMENT OF INTERNATIONAL SCIENCE EDUCATION

5.1 Summary of International Experience

Overall, the successful experiences of international science education all point to a systematic, open, and integrated development paradigm. At the macro level, countries are implementing top-level design through forward-looking national strategies and core competency-oriented curriculum reforms, emphasizing interdisciplinary integration and inquiry-based curriculum reform. At the meso level, they are prioritizing digitalization and open resource development, promoting the widespread use of virtual experiments, simulation platforms, and open textbooks. An open digital resource ecosystem, collaboratively built by diverse stakeholders including government, society, and the market, provides sustained momentum for educational innovation. At the micro level, they are breaking down school walls, emphasizing collaboration between schools and informal education venues, expanding learning spaces through museums, science and technology museums, and community projects, and building borderless learning communities, greatly enriching students' learning experiences and practical opportunities. By deeply analyzing the current status and development trends of international science education, we can draw valuable insights and provide powerful references for the digital development of science education in my country.

5.2 Implications for the Development of Science Education in China

5.2.1 Strengthen top-level design and systematically build an integrated curriculum and evaluation system

International experience shows that curriculum reform centered on scientific literacy is key to the sustainable development of science education. my country should further strengthen top-level design at the national level, incorporate science education into educational modernization and national innovation and development strategies, and build an integrated curriculum system that connects preschool through high school and integrates across disciplines. This requires not only the continued deepening of STEM/STEAM interdisciplinary educational concepts within curriculum standards, but also the development of detailed curriculum implementation guidelines and extensive teaching case studies to provide clear guidance for frontline teachers on how to effectively implement project-based learning and inquiry-based practice. At the same time, fundamental reforms in educational evaluation must be accelerated, focusing not only on knowledge acquisition but also on scientific practical skills, collaboration, innovation awareness, and social responsibility. A comprehensive evaluation system should be established to accurately measure students, thereby achieving an integrated "teaching-learning-evaluation" education model.

5.2.2 Build a scientific education cloud platform to create an open and collaborative high-quality resource ecosystem

High-quality resources are the foundation for the balanced development of science education. Drawing on international experience, my country should accelerate the construction of national and provincial science education cloud platforms to achieve centralized resource aggregation and intelligent distribution. Platform construction is more than simply a collection of resources; it also requires the establishment of a rigorous resource review mechanism to ensure the scientific nature, cutting-edge nature, and educational applicability of the content. At the same time, schools, teachers, research institutions, and businesses should be encouraged to participate in resource development, fostering an open, collaborative, and shared ecosystem of high-quality resources, providing teachers and students with a wealth of learning resources. Through resource co-construction and sharing, while improving the overall quality of science education resources, it can also effectively alleviate the imbalance in educational resources between regions and between urban and rural areas.

5.2.3 Innovate the teacher professional development model and build a multi-dimensional empowerment system

The key to teacher training in the digital age lies in online professional development and collaborative learning communities. International experience shows that teacher professional development has shifted from single training to continuous, practical, and networked. In the pre-service training stage, the competency standards for science teachers should be clarified, and interdisciplinary teaching design, digital teaching skills, and scientific inquiry guidance capabilities should be included in the core training objectives. In the post-service development stage, a hierarchical and classified training system with three levels of linkage between the national, local, and school levels should be established, and online professional learning communities, school-based training, and cross-school collective lesson preparation models should be vigorously promoted to promote peer assistance and collaborative growth among teachers. In addition, an evaluation and incentive mechanism related to teacher professional development should be established, and participation in training, resource development, and innovative practice should be linked to professional title promotion and remuneration, so as to promote the endogenous and normalized development of teachers.

5.2.4 Deepen the integration of in-school and out-of-school education and build a learning community that collaborates with families, schools, and communities

At the level of educational practice, the international community generally attaches importance to the combination of formal and informal learning. For my country, we should further promote the linkage of science education inside and outside the school, and build a learning community of "home-school-community collaboration". On the one hand, schools should take the initiative to cooperate with science and technology museums, museums, and research institutes to incorporate social education resources into the curriculum system to achieve integration inside and outside the classroom. On the other hand, through science festivals, community projects, and parent-child exploration activities, families and communities should be introduced into science education, guiding parents to become the "first mentors" of their children's scientific exploration, and forming a scientific education atmosphere where everyone participates and learns everywhere. This cross-border collaboration between home, school, and community can not only expand students' learning space, but also deeply embed science education into real-life situations, effectively promoting the comprehensive improvement of young people's scientific literacy.

6 CONCLUSION

Against the backdrop of increasingly fierce global scientific and technological competition, science education has become a strategic project crucial to a nation's future. This study, through a comparative analysis of the policy frameworks, resource ecosystems, and practical approaches of several leading science education countries, reveals the strategic, digital, and socialized trends in contemporary science education reform. The study finds that a successful science education system must be an integrated, coordinated whole, encompassing top-level design, resource provision, and practical innovation. For my country, efforts must focus on the following areas: First, strengthen top-level design, systematically construct a competency-based, integrated curriculum and assessment system, and promote the alignment of science education with the national innovation strategy; second, foster an open and collaborative ecosystem of high-quality resources to mitigate regional disparities and achieve educational equity; third, innovate teacher professional development models, establishing a multi-dimensional empowerment system that integrates online and offline learning, prioritizing both school-based and online learning, and enhancing teachers' interdisciplinary and digital teaching capabilities; fourth, deepen the integration of in-school and out-of-school education, promoting the joint participation of schools, families, and communities in science education, and building a borderless learning ecosystem.

The development of science education must grasp global trends while also grounded in local realities. Each initiative requires long-term strategic focus, sustained resource investment, and meticulous implementation. Only through the coordinated promotion of policies, resources, teachers, technology, and the environment can we truly achieve inclusive, equitable, and innovative science education. Building a high-quality, future-oriented science education system will truly inspire every child's curiosity and creativity, laying a solid foundation for cultivating a generation of young people with a scientific spirit, innovative capabilities, and a sense of social responsibility.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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