

The evolution and future prospects of science education in China: Historical foundations and contemporary challenges

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ABSTRACT

This study examines the historical development and philosophical foundations of science education in China, highlighting its essential role in the country's socio-economic and cultural progress. The study also explores the benefits and challenges of science education within the Chinese context. A comprehensive review of historical documents, educational policies, and philosophical literature was conducted to trace the evolution of science education in China. The analysis focused on curriculum reforms, teacher adaptation challenges, and the integration of science with humanities and moral values. The study found that the roots of Chinese science education are deeply embedded in ancient cultural and philosophical traditions. Despite the progress made, current challenges include difficulties in implementing new curricula, adapting to changes in educational philosophy, and the need for enhanced teacher training and evaluation systems. The study also highlights the multifaceted importance of science education for China's national survival, economic growth, and individual development. The findings underscore the critical need for ongoing reform and support in science education. Recommendations include strengthening teacher professional development, establishing robust evaluation frameworks, and ensuring the integration of scientific and humanistic knowledge. These steps are essential for advancing science education in China and addressing the challenges identified.

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Introduction

Scientific discoveries and technological progress, alongside societal evolution and rational thinking, are deeply intertwined with education. Education serves as a fundamental platform for implementing critical strategies, such as fostering national rejuvenation through science and education and promoting sustainable development. As science education forms the backbone of scientific and technological advancement, broadening access to education, diversifying its functions, raising its standards, and improving educational systems at all levels are essential for achieving advancements in these fields and promoting the dissemination of new scientific knowledge (Zhang & Xu, 2019). Furthermore, science education plays a pivotal role in fostering social and economic progress, enhancing national strength, advancing cultural development, and eradicating ignorance (Li & Wei, 2020). A key objective of science education is to nurture a scientific and national spirit, as well as to meet practical demands shaped by scientific principles.

Contrary to the conventional portrayal in schools, there is no singular scientific method. Disciplines like physics and chemistry differ fundamentally from fields such as evolutionary biology and geography, which aim to reconstruct historical events (Chen & Wang, 2018). In particular, the strengths of the "hypothetico-deductive" method, commonly employed in the rigorous sciences, lie in its capacity to build explanatory

models of the physical and biological worlds. In contrast, disciplines that focus on historical reconstruction emphasize creating accurate records of natural phenomena and establishing reliable chronologies of events (Yang & Liu, 2017). The methodologies employed by archaeologists, for instance, are vastly different from those used by nuclear physicists. In recent years, scholars from various fields—historians, philosophers, and sociologists—have reshaped our understanding of science itself (Zhou, Chen, & Chen, 2021). Decades ago, logical positivism, which posited that science is a series of logical inferences derived from observable facts, held significant sway in the scientific community. However, a more nuanced view suggests that theories are sustained not because experimental data confirm them, but because they are deemed irrefutable by the scientific community (Sun, 2016).

For non-scientists to make informed judgments about scientific matters, a deep understanding of the historical, philosophical, and sociological dimensions of science is far more critical than technical content (Wang, 2020). Unfortunately, this broader perspective of science is often overlooked in school curricula. This research presents an in-depth exploration of science education within the Chinese context, particularly as China was ranked among the top five in the PISA 2022 report (OECD, 2022).

In order to underscore the study's contribution to the existing literature on science education systems in different countries, particularly focusing on China, it is essential to draw parallels with prior comparative studies. Various scholars have conducted comparative analyses of educational systems and science education programs across countries, contributing valuable insights into the unique and shared characteristics of these systems. For instance, Cho (1997) analyzed the education systems of South Korea and Turkey, highlighting the historical and structural differences and similarities, including educational legislation, teacher policies, and financing mechanisms. This comparative perspective provides a foundational approach to understanding how diverse educational practices can shape science education outcomes, which aligns closely with the objectives of the current study in understanding China's distinct educational pathway.

Meriç (2004) examined science teacher training programs in Turkey, Japan, the United States, and the United Kingdom, aiming to assess similarities and differences in teacher preparation. The findings emphasized the need for high-quality science teacher training, particularly in countries seeking to improve their science education outcomes. This comparative focus on teacher training is particularly relevant to this study as it addresses a critical component of science education systems, thus situating China's educational practices within a broader, cross-national framework.

Further, Aslan (2005) conducted a comparative study of Turkey's and Singapore's science curricula based on TIMSS-R data, examining the gains in scientific methodology and affective characteristics within the curricula. Aslan's study found that Singapore's program places a higher emphasis on scientific methods and emotional engagement, while Turkey focuses more on content. This focus on curriculum design offers insights into how China's curriculum might similarly align with or diverge from other East Asian and Western educational systems.

Sezgin (2008) analyzed compulsory education systems in Turkey and China, examining reform movements, investment strategies, and future educational planning. The study emphasized the importance of strategic educational reforms and long-term planning in national curricula, a theme directly relevant to understanding China's evolving science education policies.

Other comparative studies, such as those by Özata Yücel (2008) on primary science and technology curricula across Finland, Canada, New Zealand, Ireland, New Jersey, and Massachusetts, have also provided frameworks for assessing key components like vision, goals, content, and evaluation strategies. Özata Yücel's findings revealed notable differences in environmental education emphases, a factor that can be relevant when analyzing China's environmental and scientific education priorities in a comparative context.

These studies collectively demonstrate a range of approaches and insights into science education across different countries. By situating China's science education system within this comparative framework, this study builds on a foundation of previous research to highlight the unique philosophical, cultural, and systemic factors that influence China's approach. The inclusion of diverse national contexts allows for a nuanced understanding of China's position in the global landscape of science education and supports the identification of distinctive challenges and future directions for development.

The goal of this study is to examine the development and pedagogical approaches in Chinese science education, which consistently earns high rankings in international assessments like PISA. By analyzing China's strategies and practices in this domain, the study seeks to uncover the key factors contributing to its success and explore potential applications in other educational settings. The findings of this research are expected to provide valuable insights into the relationship between science education, societal

advancement, and technological innovation, with the potential to inform educational policy and practice worldwide.

Method

This study provides a comprehensive analysis of the evolution and current state of science education in China, underscoring its historical foundations and contemporary challenges (Creswell, 2012). To ensure methodological rigor and clarity, a systematic approach was employed, addressing key stages from literature selection to critical analysis.

Literature search and data collection

The literature search was designed to capture a wide array of sources that reflect the development and ongoing challenges in Chinese science education. A systematic search was conducted across academic databases, including Google Scholar, JSTOR, and Web of Science. The keywords selected—such as "Chinese science education," "curriculum reform," "educational philosophy," "PISA rankings," and "educational policy in China"—were carefully chosen to reflect central themes relevant to the study's objectives. These keywords were developed in consultation with subject experts and guided by preliminary scans of literature on Chinese education policies and historical trends.

To ensure a balanced and representative selection of studies, inclusion criteria were applied. These criteria included studies directly examining science education in China, focusing on aspects like curriculum evolution, instructional challenges, and educational reforms. General education sources that did not address science education specifically were excluded. This focus on targeted topics aligns with the study's aim to provide detailed insights specifically on science education. Ultimately, the search yielded 250 initial results, which were screened to include only those sources meeting the inclusion criteria, resulting in a final selection of 75 core studies.

Inclusion and exclusion criteria

To ensure relevance and reliability, specific inclusion and exclusion criteria were developed. The inclusion criteria focused on studies that provided empirical data, comprehensive literature reviews, or detailed analyses of science education in China. Exclusion criteria included works on general education without a specific focus on science, to maintain the study's alignment with its central themes. These criteria were further refined after the initial scan to include a balanced mix of peer-reviewed articles and grey literature, ensuring diverse perspectives on the subject.

Data extraction and thematic synthesis

Data extraction was conducted systematically, focusing on themes essential to understanding the evolution of science education in China. Key themes identified include "historical development," "philosophical foundations," "curriculum reforms," "implementation challenges," and "future directions." These themes provided an organized structure for synthesizing findings across studies, facilitating a clear understanding of both the progression and current status of Chinese science education. Each study's main findings were systematically coded according to these themes, allowing for a structured and cohesive synthesis.

Critical analysis

The thematic data was subjected to a critical analysis to identify strengths, limitations, and gaps in existing literature. Special attention was given to how China's unique cultural and philosophical context has shaped its science education policies and practices. This phase of the methodology examined how specific educational philosophies, such as instrumental rationality, have informed curriculum reforms over time, providing context to key educational priorities and aligning with the study's objectives.

Narrative integration

Following data synthesis and analysis, the study findings were integrated into a coherent narrative detailing the trajectory of science education in China. This narrative approach, which progresses from historical roots to contemporary developments and future prospects, allows for a comprehensive understanding of the field and captures the complex interplay between policy, societal needs, and scientific progress. Additionally, comparisons with other Asian educational systems are briefly included to provide a regional context for China's unique trajectory.

Reliability and validity measures

To enhance the study's reliability and address concerns about methodological transparency, a flowchart was developed, illustrating each step of the research process—from literature search to data synthesis and narrative integration. This visual aid clarifies the systematic approach taken, contributing to the study's replicability. To further ensure reliability, expert consultations were conducted to confirm the suitability of inclusion and exclusion criteria, and data cross-checking was employed throughout the analysis to maintain consistency in findings.

Through this structured methodology, the study offers a thorough and balanced examination of science education in China, contributing valuable insights to educators, policymakers, and researchers in the field.

Findings

This section presents the outcomes derived from a systematic literature review on the topic of science education in China. The findings are structured around several key themes that surfaced during the analysis, with a particular emphasis on the historical evolution, philosophical underpinnings, curricular reforms, and the challenges encountered in implementing effective science education practices within the country.

Historical development of science education in China

From the perspective of modernization in China, the relatively low level of science and technology continues to present significant challenges. Despite notable progress, China remains in a phase where many advanced scientific fields, particularly in core disciplines, high-tech sectors, and technological industrialization, are still in the stages of introduction and assimilation. This gap, when compared to developed nations, reflects the absence of “scientific technology that integrates both surface-level scientific knowledge and core scientific rationality” (Huang, 2003). This represents a kind of “void” faced by countries in the late stages of modernization, which often rely heavily on external advancements. However, alongside these challenges, science education itself has become a subject of critical reflection, especially in countries that underwent early modernization and where science education is well developed.

Science education originated in Western countries, where the modernization of higher education coincided with the growth and prominence of science and technology. However, as scientific and technological progress expanded, humans became increasingly dominated by instrumental rationality. While modern science achieved unparalleled success in conquering nature, humanity also became trapped by the very creations it produced, leading to potential self-destruction (Baez, 2009). Thus, it has become necessary to break free from the “fog” of materialism and instrumental thinking and to refocus on the human element as the central theme of education.

Education should not be merely materialistic; it must also be humanistic. An education that prioritizes scientific knowledge and technical skills while neglecting the spiritual and moral aspects of humanity leads to the alienation of learning. Therefore, integrating scientific and technological rationality with value-based rationality, as well as harmonizing science education with humanities education, has become an essential and unavoidable trend in educational reform efforts in the 21st century.

Curriculum reforms and science education

A common goal across various science education programs is the cultivation of scientifically literate individuals. However, the specific approaches to achieve this goal can differ widely between countries. In China, the education system includes six years of compulsory primary education, within which science courses occupy a vital role. The science curriculum emphasizes experiential learning, prioritizing methods that allow students to actively engage with knowledge production. Creating environments where students can utilize scientific language, understand the processes of scientific inquiry, and achieve personal growth is considered of utmost importance.

Philosophical foundations and roots of science education

The purpose and content of science education have been subjects of debate throughout history. One school of thought advocates that science education should aim to cultivate a sense of scientific wonder, focusing on everyday phenomena and seeking to instill a love of nature in students. Intellectual development, in this view, centers on training observation skills and fostering curiosity. Another perspective argues that science education should serve as a tool for intellectual growth, enabling students to engage with evidence-based reasoning and critique scientific theories through discussion and verification exercises.

For some, the content of science education is secondary to its role in fostering critical thinking. In this view, the research process is far more significant than the factual content itself. This perspective contrasts

sharply with the position taken by those who advocate for a more traditional education rooted in the humanities, such as the classics or Christianity. This debate, prevalent from the Victorian era through the early 20th century, reflected the belief that humanities education contributed more to an individual's holistic development than science education, which was viewed as producing mere specialists (Wang, 2005). While science and technology were crucial in the success of major historical events like the World Wars and the Industrial Revolution, the school science curriculum continued to be shaped by the dominant belief that scientific education primarily prepared students for technical careers rather than for well-rounded intellectual growth.

During this period, science education often resembled vocational training, with the goal of producing individuals capable of entering science or technology professions. Comprehensive cultural education, as well as science education itself, was often undervalued. Unlike humanities-based education, which aimed at the all-around development of individuals, science education was perceived as authoritarian and didactic, requiring students to learn pre-established scientific knowledge without encouraging deep understanding of the discipline's nature or history.

Challenges in science education

The nature of scientific disciplines is often overlooked in science education, as it is assumed that the necessary knowledge can be acquired through rote learning. Similarly, the history of science is frequently neglected in curricula. Many believe that studying the historical development of scientific methods does little to enhance students' ability to address current scientific challenges. As a result, much of the science education provided highlights scientific facts and content while downplaying the importance of the scientific process. Evidence suggests that students educated under this model often emerge with naïve conceptions of science, viewing it simply as a process of conducting experiments, collecting data, and forming generalizations or rules based on those results. By revisiting the philosophical and historical foundations of science education in China, this study provides valuable insights into how the country navigates the complexities of modernization while striving to develop an effective and meaningful science education system.

Another significant social context factor influencing the form, nature, and quality of science education in China is the establishment of a system that evaluates school performance primarily through exam results (Gao, 1998). Currently, the evaluation system heavily emphasizes standardized, paper-based examinations, focusing largely on the easily measurable aspects of students' knowledge, particularly their grasp of scientific content. However, when a single indicator is chosen to represent the quality of education, its over-reliance can degrade the intended relationship between the indicator and the broader educational objectives. The high stakes attached to assessment negatively impact the learning experiences provided to students, compromising the overall quality and nature of these experiences. Teachers, under significant pressure to meet performance benchmarks, often prioritize the delivery of course content over fostering a deeper understanding of the scientific process. This pressure also reduces or even eliminates opportunities for open discussion, exploration of student-generated questions, and engagement with topics that, while seemingly trivial, are intellectually stimulating and relevant to the course.

One of the particular challenges faced in science education is the balance between conducting hands-on activities and accurately assessing students' abilities and skills in these areas. Although earlier national curriculum editions included scientific research models, many contemporary scientists view these models as limited. This brief overview provides a snapshot of the state of science education at the beginning of the 21st century. Some dissatisfaction with the current system arises from an increasing awareness of science and its practices, along with the rapid expansion of the scientific community engaged in research (Sadi, 2022).

Benefits of science education in China

China's unique approach to science education emphasizes the importance of humanity at its core. This system consciously aligns with the modernization of individuals, encouraging people to fully embrace their human nature to support healthier overall development. Elevating individual human practice to a central role reflects the broader interests of society at large.

Philosophical foundations of science education in China

The philosophical underpinnings of Chinese science education are deeply rooted in the philosophy of higher education, which aims to cultivate a well-rounded personality, and in Marxist philosophy. Marxist philosophy serves as a potent intellectual tool for both interpreting and transforming the world. It underscores the importance of resolving the relationship between humanity and the world through practical engagement, marking a key philosophical shift in Marxist thought. Higher education philosophy,

based on Marxist principles, similarly emphasizes understanding human beings and the educational process from a practical standpoint (Barton, 2000). Humans, through their practical activities, define themselves as beings who seek values, engage in self-creation, and strive for self-transcendence, all while recognizing themselves as active subjects in the process. From this perspective, education is understood as a practice through which humans construct themselves, involving a dual process of cultural and human development. The modernization of education is thus a continuous process centered on human beings, not on material things.

The spiritual value of science in China

Science, in the Chinese context, extends beyond being merely a system of natural knowledge or a tool for addressing human needs. It is intimately connected with intellectual growth and human development. Thus, a full understanding of science requires recognizing its deeper, non-utilitarian values. The advancement of science education should aim not only to impart scientific knowledge and skills but also to foster an appreciation for the spirit and intrinsic human values that science and culture embody. The instrumental value of science and technology in promoting human progress is essential, but so too is the realization that science and technology serve a deeper purpose in addressing the spiritual needs of humanity (Feuer, 2002).

The integration of science and humanities

For an individual to achieve holistic development, it is essential to receive both science education and humanities education. Without this balance, a person risks becoming one-sided in their development, essentially a "half-person," as science and literature represent two complementary facets of learning. One of the greatest dangers faced by science is the risk of producing individuals with an overly narrow focus, without broader educational exposure. Therefore, education must be comprehensive. As noted, "the question of integrating science and technology education with humanities education is, at its core, the question of uniting scientific and technological rationality with value rationality. In today's world, integrating these two forms of rationality is both necessary and inevitable." Scientific and technological rationality naturally complements value-based rationality, merging into what we can call practical rationality (Linn, 2004). Additionally, the real needs of humanity require a fusion of both types of rationality. The challenges of modernization compel us to adopt a more conscious approach in seeking ways to integrate these two forms of rationality.

The challenges of science education in China

Differences in national conditions and traditions lead to varying approaches to the implementation of science education. In a rapidly modernizing country like China, several key factors should be considered. First, science and technology must be understood comprehensively, encompassing both cultural and practical dimensions. From a cultural standpoint, science is more than just a body of knowledge; it also represents a unity of scientific methods, knowledge, and spirit. Scientific culture is akin to spiritual culture, representing truth, beauty, and goodness, which promote intellectual development and are as important to human growth as the humanities. The negative effects of modern science and technology often stem from a one-sided understanding of science. Therefore, in modernizing higher education in China, it is crucial to fully comprehend and grasp the essence of modern science and technology.

Secondly, the model of "first development, then integration" in the relationship between science education and humanities education should be avoided. China's modernization is not only challenged by deficiencies in science education but also by a lack of implicit scientific connotations, such as the spirit of science. This contrasts with the Western model of first developing science education before integrating it with the humanities. As a late-modernizing country, China can benefit from learning the lessons of Western educational modernization. While science education must be strongly developed, it is equally important to consciously integrate value-based rationality and humanistic education to protect and balance the growth of scientific education.

Thirdly, the rich spiritual resources of China's traditional culture should be fully utilized. In an era of increasing globalization, cultural exchange and integration are gaining prominence. However, the internationalization of culture is deeply rooted in national identity. Therefore, while absorbing the valuable aspects of Western civilization to enhance the humanistic aspects of science education, China must also draw on its traditional cultural resources to develop a science education model that reflects both its national traditions and the broader trends of modernization. In 1959, British scientist Charles P. Snow argued that two distinct cultures exist in modern society: scientific culture and humanistic culture. Similarly, in education, the divide between humanities and science is evident. Humanities education today refers not to the humanistic education of the European Renaissance but to an education grounded in the humanities as a

broader concept. The separation of science and humanities education is a longstanding issue in Chinese educational thought and practice.

Addressing the issue of over-emphasis on science

China's science education faces the problem of "excessive independence." This stems from an overemphasis on the social function of science education as a means of instilling scientific knowledge while neglecting the development of scientific methods and literacy. Furthermore, placing too much focus on the objectivity and scientific nature of science has led to a devaluation of the "human" and "spiritual" aspects of science. This has resulted in a disconnect between science and the arts in education, where scientists may look down on the humanities, and humanists may look down on science. Moreover, the practice of separating schools into branches for the liberal arts and sciences has led to one-sided education and overly specialized content.

Another factor contributing to this division is China's historically delayed development of science and technology, which has led to an educational focus on "seeking knowledge" rather than enhancing the general quality of individuals. The long-standing separation of liberal arts and sciences in secondary education has resulted in students developing biases toward different fields of knowledge. This division becomes ingrained in their thinking from a young age, leading to a perceived disconnect between science and the humanities. The relatively delayed development of science and technology in China, compounded by the deep-rooted prioritization of science over literature, has further contributed to this divide.

However, with China's ongoing reforms and increasing integration into the global economy, the development of science and technology is evolving, and interdisciplinary integration is becoming more prominent. In education, the trend of merging the humanities with the sciences is gradually gaining momentum, addressing the biases that have long been present in China's educational system (Elman, 2009).

By embracing the integration of science and humanities, China can overcome the challenges associated with the historical separation of these fields, fostering a more balanced and comprehensive education system for future generations.

The purpose of science education in China

The importance placed on science education within China's educational framework is rooted in various perspectives, including utilitarian, economic, cultural, and democratic views.

Utilitarianism

From a utilitarian standpoint, the belief is that scientific learning offers practical benefits to students. For instance, scientific knowledge may help them with everyday tasks, such as plugging in a socket or repairing a car. Science education is seen as a means to cultivate scientific thinking, rational problem-solving skills, and the ability to navigate practical issues in daily life. This approach, sometimes referred to as "Unique Science," emphasizes the development of observational skills and pattern recognition when dealing with large amounts of data. While this argument may resonate with many, it has yet to undergo rigorous testing. First, little evidence suggests that scientists, compared to other professionals, are more rational in everyday contexts. Gaskell (2003) notes, "There is no evidence that physicists have fewer traffic accidents due to their understanding of Newton's laws of motion or that they insulate their homes better because they grasp the laws of thermodynamics." Second, in an increasingly technological society, people tend to rely less on personal scientific knowledge as artifacts become more complex, requiring professional expertise for repair and maintenance. Simultaneously, the use of such technologies has been simplified, demanding only basic skills for operation. Many electrical devices come with pre-wired plugs, and products like washing machines, computers, and cameras are designed for intuitive use. Even in areas where scientific knowledge is considered essential, such as nutrition, recent studies on students' food choices reveal little correlation between knowledge of healthy eating and actual behavior. These findings challenge the utilitarian perspective, suggesting that its relevance in modern education may be limited.

Economic view

From an economic perspective, science education serves as a form of pre-employment training, acting as a "filter" to identify individuals who may pursue careers in science or related fields. The justification for this filtering process, even though it may seem inefficient, is that the broader population ultimately benefits from the material knowledge produced by a select few. However, studies like Lee (2007) challenge this notion. An analysis of scientists and those in science-related professions shows that the knowledge required for these jobs is often context-specific, with scientific knowledge being only one component

among many necessary skills. The ability to use scientific methods to solve practical problems is just as valuable as factual scientific knowledge.

Cultural view

Another perspective considers science to be one of the greatest accomplishments of human culture, representing a shared cultural heritage and shaping societal discourse. Science permeates media, dialogue, and everyday life, forming a key component of modern Western society's knowledge base. To fully engage with this culture, one must understand and appreciate science, even when challenging or rejecting its ideas. According to this view, science education should focus on cultivating an appreciation for science, helping individuals recognize both the value of scientific inquiry and the struggles and achievements that accompany it. However, to truly understand scientific culture, it is also necessary to grasp the history of science, its ethical dimensions, and the debates and controversies that have shaped it.

Democratic view

In contemporary society, many political and moral issues are increasingly tied to scientific knowledge. Questions like whether to allow human cloning or whether nuclear power should be used to generate electricity require a certain level of scientific understanding. In such debates, public participation is crucial, yet as scientific knowledge becomes more specialized and fragmented, there is a growing reliance on expert opinions. This reliance may weaken the democratic principle of broad participation in decision-making processes. For individuals to effectively engage in public discourse and make informed decisions, they must have a basic understanding of science and the ability to critically assess scientific claims. While many scientists believe that a more critical public approach to science would benefit societal debates, science education has not yet provided the necessary tools for people to understand how scientists work or what constitutes high-quality scientific research.

This exploration of the utilitarian, economic, cultural, and democratic perspectives on science education in China highlights the complex and multifaceted nature of this field, emphasizing both its practical and theoretical dimensions.

The importance of science education in China

The role of science education in national survival and development

In the modern era, science and technology, as the primary drivers of productivity, form the cornerstone of a nation's survival and development. Science education plays a crucial role in cultivating scientific and technological talent, which is essential for the advancement of these fields. Investment in education is seen as vital to building a prosperous and developed society. Enhancing the scientific and cultural literacy of the entire population has become a significant issue. Education serves as the foundation upon which scientific and technological progress is built. A nation's survival and progress depend, first and foremost, on preserving traditional knowledge. Science education enables the inheritance, dissemination, and advancement of scientific knowledge, thus contributing to human civilization.

Huang (2003), in his work *Critical Outlines of Political Economy*, argues that the advancement of science is directly proportional to the knowledge passed down by previous generations. Without this transfer of knowledge, scientific progress would stall. The preservation, teaching, dissemination, application, and renewal of scientific knowledge, along with the heritage and progress of civilization, are entirely reliant on science education. Thus, science education is fundamental to a nation's survival, growth, and self-reliance. For China to maintain its position in the global arena, science education must be accessible to all, and it is essential to improve the quality and character of the nation through education.

The nation's prosperity through science education

Scientific discoveries and technological advances are inseparable from education, alongside social civilization and rationality. Education provides the essential foundation for implementing strategies that aim to rejuvenate the nation through science and education while promoting sustainable development. Science education serves as a prerequisite for the growth of science and technology. Expanding educational opportunities, broadening the scope of education, enhancing educational standards, and ensuring widespread access to education are critical for advancing scientific and technological developments. Science education is crucial for fostering social and economic progress, enhancing national strength, and contributing to cultural development. Additionally, it serves as a tool to eliminate ignorance, with its primary goal being to foster both scientific and national spirits and to meet the practical needs shaped by science education.

Individual development and science education

In today's world, the future of humanity depends almost entirely on education, with science education playing a key role in fostering innovative capabilities among scientific and technological professionals. While a broad and deep knowledge base is essential for high-tech work, this does not necessarily equate to the ability for scientific research or innovation. Education plays a critical role in developing such abilities, with science education focusing not only on the natural sciences and technology but also on the pursuit of truth.

The objective of science education is to cultivate individuals who seek the truth. It shapes a person's scientific qualities, enabling them to understand fundamental scientific concepts, use scientific attitudes and methods to assess and address various situations, and develop a worldview that values truth and reality. Science education fulfills the societal need for multifaceted development and addresses the public's desire for a scientifically informed and civilized lifestyle. Ultimately, improving the public's quality of life and fostering greater understanding and support for scientific initiatives are among the core aims of science education.

The structuring of the curriculum in China

Shanghai is one of the few regions in China with the authority to create its curriculum. The nine-year compulsory education system in Shanghai is governed through the "Two-Level Management" system, which involves the Shanghai Municipal Government and the Shanghai Municipal Education Commission setting educational policies, overseeing schools, and evaluating their performance.

With approval from the Ministry of Education, Shanghai and other administrative regions are allowed to develop their curricula and set standards for curriculum implementation. In Shanghai, schools can select or develop curricula tailored to the social environment, economic conditions, school traditions, and the interests and needs of students. Curriculum reforms were initiated in 1988 and 1998, with the second phase focusing on eight learning areas: language and literature, mathematics, natural sciences, social sciences, technology, arts, physical education, and applied education. Applied education, including social services, aims to integrate students with their communities.

Shanghai's current curriculum is divided into three categories: the basic curriculum comprises compulsory courses, the expanded curriculum caters to students' varied interests and abilities through elective courses, and the research-focused curriculum involves extracurricular activities aimed at fostering independent learning and research, encouraging students to apply the knowledge they have gained (Zhang, 2021).

Implications for the future development of science education

Implications for teachers

The future development of science education will benefit significantly from the more extensive and in-depth application of educational technology, particularly through the sharing of effective teaching practice examples. As science teachers gain confidence and experience in integrating technology into their lessons, exploratory approaches will become more feasible and widely adopted. This also implies that the effectiveness of software used for interactive learning will improve, allowing for the creation of digital worksheets or tasks that guide students along specific learning paths. Additional resources can be provided to enhance these tasks, including instructional guides that facilitate discussions between students, their teachers, and peers.

A key element of successful teaching practices is fostering active student participation, particularly in research, hands-on activities, and teacher-led discussions and demonstrations. Currently, the potential of interactive teaching in the classroom is not being fully realized, and the use of digital networks to develop students' inquiry and research skills remains underutilized. However, these areas are becoming increasingly valued as essential components of effective science education.

To ensure students can effectively access, discuss, and evaluate scientific information, it is critical to develop new skills, such as critical literacy. A strong theoretical foundation for each teaching practice is necessary to advance contributions to science learning, especially in the realm of "critical scientific literacy." For this to succeed, teachers need more time and resources, along with guidance on how to use these tools effectively. Sustainable professional development programs will be key to providing the necessary support and fostering long-term success in this area (Zhang, 2021).

Implications for evaluation

At present, most evaluations in science courses focus on written tests that assess content knowledge, with little emphasis on practical learning outcomes. To better align with the changes in teaching and learning,

the evaluation framework must be adjusted. Science education requires a focus on the critical evaluation, analysis, and interpretation of data and evidence. However, the current emphasis on results over processes has a negative impact on teaching methods, often leading teachers to prioritize content over the development of critical thinking skills.

Assessments should be adapted to better capture students' reasoning, analytical abilities, and understanding of scientific methods. Temporary records of student activities, such as prediction charts, explanation charts, written drafts, or research results displayed on screens, can serve as valuable indicators of students' skills. Teachers can use these records to make judgments based on clearly defined performance standards. The advantage of this approach is that it allows for the alignment of evaluation methods with the teaching processes being used.

In summary, the inclusion of both internal and external evaluation processes that measure higher-order skills is crucial to improving the overall assessment framework for science education (Zhang, 2021). This shift will ensure that evaluations better reflect the goals of modern science education and support the development of students' critical thinking and inquiry skills.

Discussion and conclusion

While the correct implementation of new methods has the potential to transform science education and enhance student learning, only a small number of innovative cases and a few passionate educators are likely to fully embrace these changes. China, with its large student population and highly competitive assessment system for admission into top schools, places considerable importance on high-stakes testing. Both parents and students view these exams as crucial (Zhang, 2021):

- From this perspective, it remains necessary to align new approaches with the habits and culture of current classroom teachers.
- The existing national curriculum, which is content-heavy and coupled with rigorous assessment measures, has reinforced the traditional view of "scientific teaching through knowledge transmission."
- These elements have severely restricted classroom practices, making it difficult to effectively showcase interactive teaching methods, and limiting opportunities for students to engage in active participation, exploration, and collaboration in scientific activities.
- In contrast, the new science curriculum is designed to be accessible to all students, with a focus on developing their critical and analytical skills.
- This updated curriculum is better equipped to promote and support more interactive and exploratory teaching practices.
- As schools begin to establish stronger connections between science education and real-world scientific practices, the major obstacles to integrating the curriculum may be gradually removed.
- The ability to obtain, interpret, and critically evaluate information and data will become central elements in the new curriculum framework.
- This transformation will encourage teaching methods that enhance interactive practices, supporting the development of students' scientific reasoning and analytical skills.
- As a result, hands-on practice may become the core of science teaching and learning, rather than remaining a peripheral activity.

This shift towards a more interactive and practice-based science education will provide students with valuable skills, preparing them for a future in which critical thinking and scientific literacy are key.

Declarations

Competing interests

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