PISA Science Literacy Assessment Frameworks, Characteristics and Implications (2006-2025)

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Abstract: Against the backdrop of global technological competition and China's science education reform, this study focuses on the PISA 2006, 2015, and 2025 science literacy assessment frameworks. It analyzes their evolutionary characteristics from four core dimensions—scientific contexts, scientific knowledge, scientific competencies, and scientific attitudes/identity—presenting transitions from "life relevance to contemporary responsibility", "static classification to dynamic integration", "basic application to action orientation", and "external tendency to internal identification". The research finds that the frameworks have achieved a systematic transformation from "knowledge-oriented" to "competency-oriented", providing valuable insights for China's science education. Based on this, the paper proposes implications including strengthening the creation of contemporary contexts, promoting interdisciplinary knowledge integration, implementing inquiry-based teaching, and constructing scientific identity, so as to facilitate the cultivation of Chinese adolescents' science literacy and the high-quality development of science education.

Keywords: PISA Science Assessment Framework; Science Literacy; Science Education; Evolutionary Characteristics; Educational Implications

1. Introduction

Against the backdrop of increasingly fierce global technological competition, enhancing adolescents' science literacy has become a strategic consensus among countries to strengthen national strength and achieve self-reliance and self-improvement in science and technology. China has clearly pointed out: "Science education is a key link in implementing the coordinated deployment of education, science and technology, and talents. Improving adolescents' science literacy is not only the core training goal of science education, but also an important way to promote the high-quality development of the population." On January 19, 2025, the Guidelines for Building a Powerful Education Nation (2024-2035) issued by the state stated: "We should strengthen science education, emphasize efforts to cultivate innovative capabilities, and implement the 'Fertile Soil Program' for science literacy cultivation targeting primary and secondary school students." In May 2023, the Ministry of Education and 17 other central departments clearly required in the Opinions on Strengthening Primary and Secondary School Science Education in the New Era to "improve students' scientific quality and cultivate a group of adolescents with scientist potential who are willing to dedicate themselves to scientific research." It is evident that fostering students' science literacy has always been a key task of China's science education. A thorough understanding of the basic connotation and assessment framework of science literacy is conducive to the high-quality development of science education in China.

The Organisation for Economic Co-operation and Development (OECD) established the Programme for International Student Assessment (PISA) in 1997, guided by the principle of addressing complex future challenges. It aims to provide governments and other institutions with policy-oriented and internationally comparable student achievement indicators, assessing the reading literacy, mathematical literacy, and science literacy of 15-year-old students every three years. Among them, PISA 2006, PISA 2015, and PISA 2025 all focused on assessing students' science literacy. Based on a detailed analysis and comparison of the assessment frameworks and evolutionary characteristics of science literacy in these three

PISA cycles, this paper provides references for the development of science education in China.

2. Analysis of the PISA Science Assessment Frameworks (2006-2025)

PISA defines science literacy as the ability of students to demonstrate scientific competencies and make informed decisions based on their scientific knowledge, scientific attitudes, or identity within a given context. It does not assess the contexts themselves, but rather the competencies and knowledge demonstrated within specific contexts [1].

The evolution of the PISA science assessment frameworks from 2006 to 2025 (see Table 1) has constructed an assessment system that aligns with students' cognitive development and responds to the needs of the times through changes in four dimensions: scientific contexts, scientific knowledge, scientific competencies, and scientific (attitudinal) identity. It has pointed out a global direction for science education—"taking real-world problems as carriers, integrated knowledge as tools, action capabilities as the core, and identity as support"—and reflects the transformation of science literacy assessment from "knowledge-oriented basic application" to "competency-oriented action and practice." These developments not only echo the global trend of science education reform but also anchor the cultivation goals of future citizens' science literacy.

Table 1. Evolution of PISA Science Literacy Assessment Frameworks (2006-2025)

PISA Assessment	Scientific Contexts	Scientific Knowledge	Scientific Competencies	Scientific (Attitudinal) Identity
PISA 2006	Identify real-life contexts involving science and technology, covering personal, social, and global domains	Scientific knowledge (physics, chemistry, biological sciences, Earth and space sciences); Knowledge about science (scientific inquiry, scientific explanation)	Identify scientific issues; Scientifically explain phenomena; Use scientific evidence	Interest and motivation in science; Recognition of scientific inquiry; Environmental awareness
PISA 2015	Current and historical issues at the personal, national/local, and global levels	Content knowledge (facts, concepts, theories about the natural world); Procedural knowledge (standard processes and methods of scientific inquiry); Epistemic knowledge (logic of scientific knowledge construction, rational judgment of evidence, status and limitations of knowledge)	Evaluate and design scientific inquiries; Interpret scientific data and evidence	Interest and motivation in science; Recognition of scientific inquiry; Environmental awareness
PISA 2025	Focus on real contexts of human-Earth system interactions in the Anthropocene, maintaining personal, local/national, and global contexts	Content knowledge (physics, life sciences, Earth and space systems); Procedural knowledge (specific methods such as variable control, repeated measurement, repeated measurement control, and data representation); Epistemic knowledge (covering scientific consensus, peer review, model limitations, expert qualification judgment, etc., emphasizing understanding of the social attributes of scientific practice)	Scientifically explain phenomena, construct and evaluate scientific inquiries; Design and critically interpret scientific data and evidence; Interpret scientific research, evaluate and use scientific information for decision-making and action	Scientific capital and epistemic beliefs; Scientific self-concept and efficacy; Environmental awareness, concern, and agency

3. Evolutionary Characteristics of the PISA Science Assessment Frameworks (2006-2025)

The evolution of the PISA science assessment frameworks from 2006 to 2025 is not partial adjustments in a single dimension, but rather a systematic upgrade centered on "deepening the essence of science literacy" and "responding to the needs of the times," presenting distinct collaborative logic and value orientation. Along the core thread, all four core dimensions have advanced from "basic levels" to "higher-order literacy": the context dimension has completed a value leap from "life relevance to contemporary responsibility"; the knowledge dimension has achieved a functional transformation from "static classification to dynamic tool"; the competency dimension has constructed a complete chain from "cognitive application to action practice"; and the attitude/identity dimension has realized an emotional elevation from "external tendency to internal identification." This evolution is not isolated or fragmented, but mutually supportive and deeply intertwined: contexts with contemporary relevance provide an authentic carrier for knowledge integration and competency practice; integrated knowledge lays the foundation for competency enhancement and identity construction; action-oriented competencies offer pathways for contextual application and identity realization; and endogenous scientific identity injects emotional impetus into the sustained development of literacy across all dimensions.

3.1 Scientific Contexts: Value Upgrade from Life Relevance to Contemporary Issues

In the PISA science literacy assessment framework, the dimension of scientific contexts has undergone a deepening process from basic life application to multi-level, multi-domain social issues [2]. In 2006, the PISA assessment contexts emphasized classification into "personal, social, and global" domains, covering five application areas (e.g., health, environment, natural resources). This established a direct connection between science and students daily lives, enabling them to perceive the instrumental value of science. In 2015, the classification was refined to "personal, local/national, and global," making the context hierarchy more aligned with students' cognitive scope, strengthening relevance to civic decision-making and lifelong learning, and prioritizing the need to address practical problems in issue selection. In 2025, PISA contexts align with the characteristics of the Anthropocene: while retaining the three-level classification, specialized contexts for environmental science are added, and application domains are refined into more contemporary issues (e.g., health and disease, environmental impacts, climate change). This highlights the integration of interdisciplinary approaches and systems thinking, turning contexts into a means to cultivate students' "Earth citizenship awareness." Centered on "real-world problems," the development of PISA's context dimension has achieved a value shift from "identifying science and technology scenarios in daily life" to "responding to global challenges in the human era"—serving as a core carrier for complex problem-solving competencies. This completes the value upgrade from "life application scenarios" to "contemporary responsibility contexts."

3.2 Scientific Knowledge: Connotative Deepening and Expansion from Classified Construction to Integration

Scientific knowledge is a core factor influencing the development of students' science literacy [3]. In the PISA assessments from 2006 to 2025, the evolution of the knowledge dimension has realized a transformation from "basic classification" to "pragmatization and integration," reflecting an in-depth understanding of the essence of scientific knowledge. In PISA 2006, knowledge was divided into two categories: scientific knowledge (physics, life sciences, Earth and space sciences, and technological systems) and knowledge about science (scientific inquiry, scientific explanation) [4]. Guided by the selection criteria of aligning with the cognitive level of 15-year-old students, while ensuring practical relevance and durability, this laid the basic framework for scientific knowledge assessment. In PISA 2015 and 2025, knowledge was refined into three categories: "content knowledge, procedural knowledge, and epistemic knowledge," further materializing "knowledge about science" and clarifying the constituent elements and internal logic of scientific knowledge. Specifically, content knowledge replaced disciplinary terminology with "systems" to highlight interdisciplinary relevance; procedural knowledge incorporated specific methods such as variable control and repeated measurement to reduce errors, strengthening practical guidance; epistemic knowledge expanded to cover scientific consensus, peer review, and judgment of expert qualifications, emphasizing the understanding of the social attributes of scientific practice. This transformation has turned the knowledge system from a "static classification" into a "dynamic tool system for application," making it more suitable for addressing complex problems.

3.3 Scientific Competencies: Competency Enhancement from Basic Application to Action Orientation

From PISA 2006 to 2025, the development of scientific competencies—advancing from "basic application" to "critical inquiry" and "action-oriented decision-making"—demonstrates that the cultivation of science literacy centers on practical effectiveness. In 2006, three core competencies were established: "identifying scientific issues, scientifically explaining phenomena, and using scientific evidence." Focused on the basic application of scientific knowledge and logical reasoning, this addressed the fundamental question of "what to assess" for scientific competencies. In 2015, the core competencies were refined into two dimensions: "evaluating and designing scientific inquiries, and interpreting scientific data and evidence." This emphasized critical understanding of the scientific inquiry process and the logic of evidence, responding to the demand for the ability to discern scientific rationality in the information age [5]. In 2025, the competency system was integrated and upgraded: the two 2015 competencies were merged into "constructing and evaluating scientific inquiry designs and critically interpreting scientific data and evidence," strengthening a closed-loop competency for the entire inquiry process. A new competency—"researching, evaluating, and using scientific information for decision-making and action"—was added, focusing on the transformation of information screening, evidence application, and real-world action. This extended competency requirements from the "cognitive level" to the "practical level," constructing a complete competency chain of "understanding-inquiry-decision-making-action" that aligns with the competency demands of the digital age and global challenges.

3.4 Scientific Attitudes/Identity: Emotional Elevation from Interest Tendency to Identity Recognition

The PISA assessment of non-cognitive factors has achieved an in-depth expansion from "scientific attitudes" to "scientific identity," highlighting the emphasis on students' subjectivity and value recognition. In 2006, scientific attitudes were incorporated into the assessment for the first time, covering three dimensions: "interest in science, support for scientific inquiry, and sense of responsibility for resources and the environment." Through dual-channel measurement (embedded test items and questionnaires), this initially established the connection between science literacy and emotional tendencies. In 2015, the dimensions were simplified to "interest and motivation in science, recognition of scientific inquiry, and environmental awareness," focusing on the direct correlation between attitudes and scientific practice. A single questionnaire measurement method was adopted to improve assessment accuracy. In 2025, the attitude dimension was upgraded to a composite "scientific identity" dimension, encompassing three core elements: "scientific capital and epistemic beliefs, scientific self-concept and efficacy, and environmental awareness and agency." This emphasizes students' sense of identification, belonging, and willingness to act toward science, shifting from "external attitudes toward science" to "internal connection with science." By focusing on the emotional drivers and value recognition of science learning, it provides a psychological foundation for the long-term development of science literacy, reflecting the deep concern of science education for the "all-round development of individuals."

4. Implications of Changes in the PISA Assessment System (2006-2025) for China's Science Education

At the dawn of the 21st century, fostering and enhancing the scientific literacy of students and citizens has become the core theme of science education development [6]. Science education is no longer an elite-oriented endeavor, but rather a public education initiative—a grand project aimed at improving national scientific literacy [7]. Faced with the technological upheavals brought about by information technology, artificial intelligence, cloud computing, and big data, the reform of primary and secondary school science education should focus on students' future lives and explore new paradigms for science education [8]. The evolution and characteristics of the PISA assessment framework provide new insights for the reform and development of science education in China.

4.1 Strengthen the Creation of Contemporary

Contexts and Establish Connections Between Science Education and Life Practice

Science education boasts strong comprehensiveness and practicality. Scientific learning should be conducted within specific scientific contexts and problems, as this enables students to fully understand the essence of science [9]. Problem-solving inherently requires a certain contextual framework [1]. Contextualized test items in science literacy assessments serve as key carriers linking scientific knowledge to life practice, embodying multiple values such as literacy diagnosis, inquiry assessment, thinking activation, and emotional arousal. The context design in PISA 2006-2025 has consistently centered on contemporary issues and real-life scenarios, promoting the integration of science education and life practice. For instance, the 2025 sample questions on the greenhouse effect adopt a contemporary context—global carbon concentration and temperature changes from 1850 to 2020 in the Anthropocene. These questions not only require students to analyze data and evidence and design scientific inquiries but also guide them to propose carbon reduction actions based on daily life (e.g., household energy conservation, community greenery maintenance), forming a closed loop of "contemporary issues—scientific knowledge—life practice." In contrast, the current context design in China's science education curricula still has obvious shortcomings: first, some contexts are fragmented and superficial, mostly idealized classic scenarios in textbooks that are disconnected from students' local life experiences, becoming "pseudo-contexts"; second, there is insufficient integration of contemporary issues, with limited coverage of real-world hot topics such as climate change and public health, making it difficult to arouse students' sense of contemporary resonance; third, there is a lack of inquiry and authenticity—some contexts merely serve as "background boards" for knowledge presentation, failing to guide students in conducting in-depth problem-solving and practical actions through contextual engagement, and instead focusing solely on the design of the contexts themselves. This implies that China's science education needs to strengthen the dual orientation of "contemporaneity + daily life integration." It should transform real-world issues (e.g., climate change, public health) into localized daily life contexts such as campus energy-saving program design and community waste classification science practices. This allows students to perceive the practical value of science while solving real problems, truly establishing in-depth connections between science education and life practice.

4.2 Optimize the Structure of the Scientific Knowledge System and Promote Interdisciplinary Integration of Curriculum Content

The function and value of scientific knowledge lie not only in enabling students to master factual scientific knowledge representing the outcomes of scientific research, but more importantly, in helping them understand the process of scientific knowledge construction, grasp scientific procedures and methods, and comprehend the inherent connotation of science [10]. In PISA 2006, scientific knowledge was defined as "scientific knowledge" and "knowledge about science." PISA 2015 expanded this classification into three categories: content knowledge, procedural knowledge, and epistemic knowledge. PISA 2025 inherited this three-category framework but expanded content knowledge from discrete disciplines to physics, life sciences, and Earth systems, placing greater emphasis on interdisciplinary integration to respond to the complexity of real-world problems and the interconnectedness of knowledge.

Currently, China's science curricula face the prominent issue of distinct barriers in subject-based teaching: while comprehensive science courses are offered in primary schools, knowledge modules still retain implicit traces of subject division; in junior high schools, teaching is fully split into subjects such as physics, biology, and geography, with content presented in isolation across disciplines. The lack of internal connections and integrated design between knowledge areas results in students acquiring fragmented scientific knowledge, making it difficult for them to understand the interdisciplinary knowledge logic underlying real-world problems such as "ecosystem protection" and "climate change mitigation." Additionally, curriculum content focuses heavily on the transmission of factual knowledge within individual disciplines, with insufficient emphasis on the practical application of procedural knowledge, in-depth understanding of epistemic knowledge, and the integration of interdisciplinary methods. This stands in contrast to PISA's advocated orientation of "knowledge serving the solution of complex problems." This implies that China's science education needs to reconstruct the knowledge system, break down disciplinary boundaries, and integrate curriculum content with a "systems" thinking approach. Centered on core themes such as "Earth's ecosystem" and "life and health," it should integrate knowledge from physics, biology, geography, and other disciplines. Simultaneously, it is essential to strengthen practical training in procedural knowledge and deepen understanding of epistemic knowledge, enabling students to develop a knowledge structure and way of thinking characterized by "multi-disciplinary collaboration in problem-solving." This aligns with the requirements of interdisciplinary integration capabilities for scientific literacy in the new era.

4.3 Implement Inquiry-Based Teaching Practices and Focus on Cultivating Students' Scientific Competencies

Cultivating students' scientific competencies is a core goal of China's science education, and inquiry-based teaching is the key pathway to achieving this objective. The competency framework of PISA 2006-2025 has gradually evolved from "basic knowledge application" to a complete chain of "critical inquiry and action-oriented decision-making." In 2025, it explicitly lists "constructing and evaluating scientific inquiry designs" and "making decisions and taking actions based on scientific information" as core competencies, highlighting the competency development logic of "inquiry-reflection-action" [11].

However, in China's current science teaching, some inquiry-based teaching still faces the problem of formalization: it mostly relies on "copycat-style" experimental operations, where students passively follow predetermined steps. They lack in-depth thinking about the purpose of inquiry and design logic, making it difficult to achieve competency improvement from "identifying problems" to "solving problems." Therefore, implementing high-quality inquiry-based teaching must focus on competency progression and achieve three major shifts: First, shift from textbook-based confirmatory experiments to real problem-driven inquiry. Based on contemporary and life-related contexts such as climate change, public health, and campus ecology, design open-ended inquiry tasks (e.g., scientific inquiry into community waste classification). This allows students to strengthen the application of procedural knowledge and critical thinking through processes such as clarifying inquiry objectives, designing experimental plans, controlling variables, and analyzing data. Second, shift from single-disciplinary inquiry to interdisciplinary collaborative inquiry. Break down barriers between subjects such as physics, biology, and geography, and integrate multi-disciplinary knowledge and methods around complex themes like ecosystem protection and environmental impact assessment. This cultivates students' interdisciplinary inquiry capabilities to address real-world problems. Third, shift from terminating at the inquiry process to "connecting inquiry with action." Drawing on PISA's focus on decision-making and action competencies, guide students to transform inquiry results into specific action proposals—such as feeding back water quality testing results to communities or proposing class energy-saving measures—thus constructing a competency chain of "inquiry and discovery-analysis and argumentation-decision-making and action."

Through regular inquiry practices, students will gradually master core scientific inquiry methods, develop scientific competencies characterized by "daring to question, being adept at verification, and having the courage to act," and truly achieve a competency leap from "learning scientific knowledge" to "mastering scientific methods."

4.4 Adhere to a Core Competency-Oriented Approach and Strengthen the Endogenous Construction of Students' Scientific Identity

In The Compulsory Education Science Curriculum Standards (2022 Edition), "scientific concepts, scientific thinking, inquiry practice, and attitudinal responsibility" are stipulated as students' core competencies. Among these, "attitudinal responsibility" focuses on students' emotional tendencies, value recognition, and willingness to act toward science, which is essentially consistent with the assessment logic of non-cognitive factors such as scientific attitudes or scientific identity in PISA tests. The PISA assessment has evolved from emphasizing superficial scientific attitudes (e.g., students' interest in science and environmental responsibility) in 2006 to a composite "scientific identity" dimension in 2025, encompassing elements such as scientific capital, epistemic beliefs, and self-efficacy. It not only focuses on attitudinal factors during students' learning processes but also emphasizes their subjectivity, agency, and sense of belonging to science, valuing the long-term impacts of scientific activities on students [12]. This highlights the long-term value and endogenous driving logic of science literacy cultivation.

However, in China's current science education, some teaching remains at the level of "stimulating short-term interest" and "emphasizing external attitudes." There is insufficient cultivation of endogenous elements such as students' scientific self-concept, epistemic beliefs, and action efficacy, making it difficult to form long-term development momentum for science literacy.

Therefore, China's science education must adhere to a core competency-oriented approach and integrate the construction of scientific identity into the entire process of teaching and assessment. Taking the cultivation of "attitudinal responsibility" as a starting point, through independent decision-making in inquiry practices, value experience in scientific activities, and efficacy improvement in solving real problems, students can shift from "passively accepting scientific knowledge" to "proactively recognizing scientific value," and elevate from "having an interest in science" to "empowering their own development through a scientific identity." Ultimately, this achieves the endogenous construction of scientific identity, laying a solid psychological foundation for cultivating adolescents with scientist potential who are willing to dedicate themselves to scientific careers. Additionally, it is necessary to actively construct an evaluation system for adolescents' scientific identity recognition and foster their spirit of dedication to science.

5. Conclusions and Prospects

This study reveals the evolutionary context and internal logic of the PISA science literacy assessment frameworks over the past two decades through a systematic review and comparative analysis of three cycles (PISA 2006, 2015, and 2025). The research indicates that the PISA science assessment system has undergone a three-stage leap from "foundation-laying" to "refinement" and further to "transformation." Its core orientation has distinctly shifted from emphasizing the static composition of "science literacy" to highlighting the dynamic practice of "scientific competencies" and the endogenous construction of "scientific identity." This evolution follows a dual logic of "external contemporary drivers and internal practical optimization." On one hand, it actively responds to global challenges such as the Anthropocene and the digital age, upgrading "contexts" from daily life scenarios to carriers of contemporary responsibility. On the other hand, by reconstructing "knowledge" into an integrated tool system, extending "competencies" to the decision-making and action chain, and elevating "attitudes" into identity recognition, it has achieved in-depth synergy and systematic optimization of internal elements within the assessment framework. The PISA framework demonstrates overall characteristics of goals more focused on future citizens' literacy, content emphasizing interdisciplinary integration, and evaluation paying greater attention to digitization and practicality. For China, the evolutionary process of PISA clearly indicates that the core mission of science education lies in cultivating responsible citizens who can understand, respond to, and actively shape the future. China's science education reform must pursue systematic and synchronous in-depth reforms across four dimensions—curriculum content integration, teaching model innovation, evaluation system reconstruction, and teacher competency enhancement—to effectively respond to this international trend.

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