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The Comparison and Enlightenment of Scientific Literacy Evaluation on NAEP2019, TIMSS2023, and PISA2025

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ABSTRACT

This paper selects the scientific evaluation projects of NAEP2019, PISA2025, and TIMSS2023 as research objects to conduct a comparative study on the definition of scientific literacy, evaluation concepts and objectives, and evaluation framework and content. In terms of the definition of scientific literacy, the three major evaluation projects all require citizens to have certain scientific knowledge and scientific ability to solve social problems about science. PISA2025 and TIMSS2023 both emphasize scientific ability, but NAEP2019 emphasize understanding the relationship between science and society. In terms of evaluation concept and purpose, the overall purpose is consistent, but PISA2025 is more concerned with the role of the science education that individuals receive in the society, while TIMSS2023 and NAEP2019 pay more attention to the specific implementation of curriculum requirements. In terms of evaluation framework and content, scientific knowledge and scientific ability are dominated, but TIMSS2023 will list individual subjects separately, while NAEP2019 and PISA2025 will integrate knowledge into related fields; PISA2025 and NAEP focus on the embodiment of ability in scientific practice, while TIMSS2023 emphasizes thinking process. The evaluation of scientific literacy in primary and secondary schools in China should learn from the experience of the three major international evaluation projects: (1) clarify the evaluation purpose and construct the scientific ability framework; (2) innovate the types of test questions and strengthen the application of real situation; (3) attach importance to the law of development and observe the level of cognitive development; (4) collect background data and provide comprehensive educational information; (5) pay attention to the trend of The Times and adopt various evaluation methods.

1. INTRODUCTION

Scientific literacy is an important part of national quality and the foundation of social civilization and progress. Scientific literacy is not only related to the comprehensive national strength of the country, but also affects the quality of life of citizens in modern society and subtly changing the public's values and views on problems. Without the general improvement of the scientific quality of the whole people, it is difficult to establish human resources of high-quality innovation and to realize the rapid transformation of scientific and technological achievements. Nowadays, many countries have implemented promotion action on science literacy. For example, the State Council of China formulated the national scientific literacy action plan outline (2021-2035), and pointed out that scientific literacy of citizens refers to advocating scientific spirit, establishing the scientific thought, mastering the basic scientific method, understanding the necessary knowledge of science and technology, and the application of its judgment and ability to solve practical problems (The State Council of China, 2021). Whether it is improving national scientific literacy or understanding the implementation of science education, it is necessary to evaluate the quality of science education. Through the comparison of the content of the international mature scientific literacy evaluation project, it has positive implications for promoting the development of science education, improving the quality of science education in primary and secondary schools, and cultivating excellent scientific and technological talents. Therefore, this paper compared the scientific literacy evaluation projects of NAEP2019, PISA2025 and NAEP2019 from the following four aspects: (1) development progress, (2) definition of scientific literacy, (3) evaluation concept and purpose, and (4) evaluation framework and contents, and then put forward the enlightenment for China science education.

2. DEVELOPMENT BACKGROUND OF NAEP, PISA AND TIMSS

In the 1960s and 1970s, in response to the lack of information on academic performance in the United States, Francis Keppel called for a national academic performance evaluation system and invited renowned psychologist and educator Ralph W. Tyler to participate. After the improvement of the assessment system in the 1980s and the emergence of the National Assessment Regulatory Council of the United States, up to the 1990s the National Assessment of Educational Progress (NAEP) model was fully determined (Zhou,2005). NAEP is an evaluation program authorized by the US Congress and administered by the National Center of Education Statistics within the Institute of Educational Sciences to assess what American students know and can do in various disciplines across the country, states and certain urban areas. Since 1969, the evaluation has been implemented once a year, with 4, 8, and 12 grade students. The evaluation includes nine subjects: reading, mathematics, science, writing, American history, economics, citizenship, geography, and art, but only two or three of them were selected in each round. The latest NAEP2019 scientific evaluation framework mainly includes: Chapter 1 (overview); Chapter 2 (scientific content); Chapter 3 (scientific practice), and Chapter 4 (Overview of evaluation design) (Deng & Yu,2022)..

In the early 1980s, with the mediocre trend sweeping the United States, the American government, educational elites, employers and social parents queried the quality of basic education in the United States. As a result, the United States began to reflect on the quality of basic education. In addition, human beings are faced with the challenges brought about by "knowledge society", "information society" and "economic globalization", which makes it urgent to establish an international learning quality monitoring system and promote educational reform in various countries and improve the quality of basic education (Zhang et al.,2011). Therefore, the Organization for Economic Cooperation and Development (OECD) launched an International Student Assessment Survey (PISA) in 1997. The project was planned in 2000 and conduct tests every three years. PISA has conducted seven scientific literacy assessments so far. The test subjects of PISA are students aged 15-16 who must have received school education rather than family

education, aiming to understand whether students who have completed compulsory education have the ability to adapt to future life (Liu & Liu 2011). In 2023, the OECD released the Strategic Vision and Direction for Science of PISA2025, which PISA is expected to evaluate in three dimensions: scientific knowledge, scientific ability and scientific identity. Science situation is no longer a dimension of PISA 2025 assessment, but implicit in the dimension of scientific knowledge, scientific ability and scientific identity.

At the end of the 20th century, the development of information and communication technology promoted the communication and cooperation among countries in the economic and cultural fields, which provided convenient conditions for international organizations to carry out international cooperative research in the field of education. Under the new situation and conditions, the new situation has also appeared in the world comparative study (Lu, 2007). The International Mathematics and Science Trends Research (TIMSS), which was initiated and organized by the International Association for the Evaluation of Educational Achievements (IEA) to conduct evaluation research and evaluation activities of international educational. Since 1995, an international assessment of mathematics and science will be conducted among fourth and eighth grade every four years. To date, TIMSS has completed its seventh project evaluation (Gu, 2023). In 2023, the IEA and the TIMSS & PIRLS International Research Center will evaluate student trends in math and science.

3 DEFINITION OF SCIENTIFIC LITERACY

3.1 Definition of Scientific Literacy in NAEP2019

NEAP2019 Point out that scientific literacy is a fundamental goal for all young people in America. Through science education, children begin to understand the world they live in and learn many scientific principles about life. Furthermore, NEAP believes that the state has an obligation to provide a solid foundation of post-secondary learning and work experience for young people who choose to work in science and technology. NAEP believes that a person with scientific literacy has the following four qualities: first, be familiar with nature and understand the key facts, concepts, principles and theories of science; second, link viewpoints from different disciplines; third, use scientific principles and ways of thinking to improve the understanding of the natural world; finally, use science to solve problems in the real world. NAEP2019 has conducted an assessment from scientific content and scientific practice (National Assessment Governing Board, 2019).

3.2 Definition of Scientific Literacy in PISA2025

In 2015, PISA defined scientific literacy as "the ability of a reflective citizen to use scientific thinking in relevant scientific issues", believing that individuals with good scientific literacy should have the following three abilities: scientifically explain phenomena, design and evaluate scientific inquiry, and scientific interpretation of data and evidence (OECD,2016). PISA2025 points out that with the progress of human society, the world will face many crises, which arises from the rapid development of science and technology as well as the entry of the Earth into the Anthropocene and may face more unknown challenges in the future. Humans may face more challenges in the future. Therefore, PISA 2025 will pay more attention to the interdisciplinary integration of scientific knowledge, the cultivation of students' decision-making ability and the construction of scientific identity. The new adjustment of this framework has a strong forward-looking and the purpose of serving the reality.

3.3 Definition of Scientific Literacy in TIMSS2023

TIMSS2023 does not specify a general concept of scientific literacy, but notes on its website that it expects young students to become knowledgeable and scientifically literate citizens, who can distinguish between scientific facts and fiction, and have a scientific basis for understanding important social, economic and environmental issues. And in the future, it can meet the needs of students for advanced learning in the fields of science, technology and engineering to promote the solution of global problems. TIMSS2023 will be evaluated from three aspects:

scientific content, scientific cognition and scientific practice (IEA, 2023).

3.4 Comparison of Definition of Scientific Literacy among NAEP2019, TIMSS2023, and PISA2025

From the perspective of the differences of scientific literacy, PISA focuses on the ability of citizens in scientific inquiry; TIMSS emphasizes the ability of citizens in solving global problems; NAEP not only requires citizens to have relevant scientific knowledge and ability, but also to understand the relationship between science and society. From the perspective of the commonality of the connotation of scientific literacy, the three major evaluation projects are all started from the individual level, requiring citizens to have certain scientific knowledge and scientific ability to solve the social problems related to science.

4. EVALUATION CONCEPT AND PURPOSE

4.1 The Evaluation Concept and Purpose of NAEP2019

NAEP is the only national, representative and continuous program that evaluates student academic achievement. Its scientific literacy assessment is based on new trends in the National Science Education Standards and Benchmarks for Scientific Literacy and some international assessments such as PISA and TIMSS. The purpose of the evaluation is what the students know and what they can do. It can be seen that NAEP emphasizes practice, focusing on evaluating what they know and can do among American primary and middle school students in various subjects. Evaluating and analyzing the trend of students' academic achievement can provide data support for educational decisions in the United States.

4.2 The Evaluation Concept and Purpose of PISA2025

PISA scientific literacy assessment based on the Educational Effectiveness Research theory and the theory of the latest dynamic model was proposed by Creemers and Kyriakides. It is believed that educational efficiency is a fusion of different research fields such as teacher behavior, curriculum, organizational process, school management and educational policy. This fusion is composed of direct or indirect factors that affect students' output (including cognitive output and non-cognitive output). What's more, factors at different levels will interact with each other (Creemers & Kyriakides, 2008). The research object of PISA are students from 15 to 16 who are about to complete full compulsory education. The purpose of scientific literacy assessment is to identify the key factors of different levels of teaching, curriculum and learning environment, to explain the differences in students' scientific performance, so as to judge whether these students have good scientific literacy to deal with the challenges posed by modern social situations (for example, health and energy) and then provide solutions to the global science and education reform (OECD, 2016). It can be seen that the evaluation of PISA is based on context, rather than just the degree to which students master the subject knowledge in school class. PISA pays more attention to apply the knowledge and skills students have mastered to real life and focus on the examination of students' ability.

4.3 The Evaluation Concept and Purpose of TIMSS2023

The theory of TIMSS evaluation is the "curriculum hierarchy theory" of Goodlad, which is improved to propose Intended Curriculum, implemented curriculum and Attained Curriculum to apply the three-level curriculum model to scientific evaluation (Pan et al., 2018). It can be seen that TIMSS evaluation starts from the course, and believes that the course is the main reason for affecting students' academic performance. The purpose of the evaluation is to investigate the students' mastery of the learning course knowledge, test the gap between the acquired course and the target course, and analyze the problems, so as to provide reference for the national education decision-making.

4.4 Comparison of Evaluation Concept and Purpose among NAEP2019, TIMSS2023, and PISA2025

In general, the evaluation concepts of the three major evaluation projects are different, but the overall goals are the same. On the one hand, it is to evaluate students' achievements after studying in school, so as to understand the educational achievements of each country or district. At the same time, it explores the factors that affect the effectiveness of education to provide guidance for improving education. On the other hand, they all reflect the different requirements of social and national curriculum for the development of students 'scientific literacy, and transform the requirements into specific scientific literacy and evaluation content framework system, so as to realize the effective monitoring of students' scientific literacy and science education and teaching quality. In addition, there are also certain differences in the evaluation purpose. PISA pays more attention to the role of science education in the society, so in the assessment will determine the relevant scientific literacy influencing factors of information sources in order to clarify the different factors in the education system. But TIMSS and NAEP are more inclined to the specific implementation of curriculum requirements.

5. EVALUATION FRAMEWORK AND CONTENT

5.1 Evaluation Framework and Content of NAEP2019

The scientific evaluation of NAEP2019 is divided into two dimensions: scientific content and scientific practice. The scientific content consists of a series of key facts, concepts, principles, laws, and theories describing the natural science, the life science, and the earth and space science. Scientific practice consists of four sub-dimensions: identifying scientific principles, applying scientific principles, using scientific investigation and using technology to design. NAEP science content examines what students know about scientific knowledge. Scientific practice examines how students can use scientific knowledge to solve practical problems. The above two points are consistent with the NAEP assessment philosophy.

5.2 Evaluation Framework and Content of PISA2025

PISA2025 Scientific evaluation is divided into three dimensions: scientific knowledge, scientific ability, and scientific identity. Science situation is no longer a dimension of PISA 2025 assessment, but implicit in the dimension of scientific knowledge, scientific ability and scientific identity.

In terms of scientific knowledge dimension, the content knowledge, procedural knowledge and cognitive knowledge proposed by PISA2015, adding three dimensions of social environment system and sustainability, the development and abuse of scientific knowledge, and informatics. As for social environment system and sustainability, which is a comprehensive knowledge field designed to support students to solve complex problems closely related to social life. The development and abuse of scientific knowledge expects to make students better understand how knowledge develops and help them avoid knowledge misuse. Informatics studies the data, structure, and behavior in natural and computational systems. Students with digital information literacy will be able to understand AI concepts and computing systems at a basic level in order to act and make decisions based on the information provided to them.

In terms of scientific ability dimension, which retains scientific interpretation phenomenon from PISA2015 and expands the two existing abilities of evaluating and designing scientific inquiry, scientific interpretation of data and evidence, and adds two new abilities of using scientific knowledge for decision-making and action and using probabilistic thinking. Using scientific knowledge for decisions and actions aims to evaluate students' ability to use scientific knowledge to solve problems creatively. Students need to think about the different mechanisms that lead to specific events, and the extent to which these events are caused by the scientific, social, and economic aspects. Probabilistic thinking mainly refers to the possibility of estim specific results using mathematical logic tools.

Scientific identity is a new dimension from PISA2025 scientific literacy assessment framework,

which means that students feel a meaningful connection with science, a certain interest in science, and a sense of identity to participate in science in daily life. The evaluation content of scientific identity in the PISA 2025 scientific literacy assessment framework includes four aspects: scientific capital, critical scientific users, inclusive scientific experience and practice, moral ethics and values. Scientific capital refers to the comprehensive measurement of students' scientific identity, scientific attitude, behavior and connection, and finally forms the sense of science "serving themselves". The ability of critical science refers to the critical use of science and other expertise to contribute to individual and social interests, especially in addressing social inequalities. Scientific experience and practice involves addressing and narrowing "gaps" in scientific knowledge, abilities and identity among different social groups, allowing students from diverse backgrounds to experience an inclusive science learning environment. Ethics and values refer to the ethics and values based on their identity and understanding of scientific knowledge.

To sum up, PISA2025 evaluation framework emphasizes the interdisciplinary integration of scientific knowledge, the scientific ability of social decision-making needs, and the scientific identity that lays the foundation for learning achievements.

5.3 Evaluation Framework and Content of TIMSS2023

The scientific evaluation of TIMSS2023 is divided into three dimensions: scientific content, scientific cognition and scientific practice. But the evaluation content is mainly organized into scientific content and scientific cognition and supplemented by scientific practice. Therefore, the evaluation of scientific practice is not carried out separately, but by some evaluation questions in the content and cognitive field.

The fourth grade science content field of TIMSS2023 includes three topics: life science, material science and earth science. The eighth grade science content of TIMSS2023 covers four topics: biology, chemistry, physical science and earth science. The difference in content areas between the fourth and eighth grades reflects the nature and difficulty of the science taught in each grade. And each theme is further described by specific objectives that represented the expected knowledge, abilities, and skills that the students assessed in each topic.

The percentage of goals in the scientific cognitive field varies in the fourth and eighth grades, but involves the same topics, namely knowledge, application and reasoning. The ability of knowledge requires students to recall, identify, describe, and provide examples of facts, concepts, and procedures. Applications focus on relating scientific knowledge to a specific context, as well as on solving practical problems. Reasoning involves the use of arguments and scientific understanding to analyze and generalize, ordinarily in unfamiliar situations and complex environments. All of these topics include projects developed for the three cognitive domains. For example, the life sciences field includes knowledge, application, and reasoning projects, as well as in other content areas.

The field of science practice points out that participating in scientific practice allows students to understand how scientific activities are carried out, and then to understand and appreciate the nature of science and scientific knowledge. Scientific practice is the foundation of all scientific disciplines and includes skills in daily life and learning. The process of scientific practice is usually nonlinear and proceeds in an iterative manner. Including five activities, first, ask questions based on observation and theory; second, design the survey and generate data; third, use data; fourth, answer research questions; and fifth, demonstrate based on arguments.

All in all, the scientific content of TIMSS2023 scientific evaluation points to the theme of evaluation. Scientific cognition focuses on the thinking process and scientific practice emphasizes the use of scientific skills to carry out scientific inquiry.

5.4 Comparison of Evaluation Framework and Content among NAEP2019, TIMSS2023, and PISA2025

The three major evaluation projects are mainly based on scientific knowledge and scientific ability. In the dimension of scientific knowledge, it shows the consistency of covering the three basic fields of matter, life, earth and space. However, PISA divides

knowledge into content knowledge, procedural knowledge, cognitive knowledge, social environment system and sustainability knowledge, the development of scientific knowledge and its abuse and informatics knowledge. TIMSS, which emphasizes courses, lists individual courses, such as chemistry, while NAEP and PISA incorporate chemical knowledge into the physical realm. In the dimension of scientific ability, the three major evaluation projects all focus on scientific inquiry and scientific practice. However, PISA and NAEP focus on the embodiment of students' scientific ability in the process of scientific practice, and organically unify the thinking process and practice process. As for TIMSS, the evaluation of scientific practice is not carried out separately, but implemented with some evaluation questions in the content and cognitive field, which shows the separation of thinking process and practice process to a certain extent. This can also be explained that TIMSS puts more emphasis on thinking process.

6. THE ENLIGHTENMENT OF THE INTERNATIONAL SCIENCE LITERACY ASSESSMENT PROJECT

6.1 Clarify the evaluation purpose and construct the scientific ability framework

The three major evaluation projects have different emphasis on scientific literacy evaluation, but the overall goal is the same: to evaluate, analyze and compare students' educational achievements, so as to provide data support for the release of national education policies. Currently, science education no longer emphasizes students 'memory of scientific knowledge, but turns to cultivating students' scientific ability. However, in some countries, the trend of shifting from students 'scientific academic achievement evaluation to students' ability examination is more obvious, but it has not yet formed as mature framework as PISA. Therefore, on the basis of clarifying the purpose of science education, the relevant educational researchers should pay attention to refining the connotation of scientific ability, which will become the basis for guiding the front-line teachers to carry out science education.

6.2 Innovate the types of test questions and strengthen the application of real situation

Teachers' personal evaluation and paper-pen test are mainly used for scientific evaluation. Most scientific situations are applied to science classroom teaching, such as video import is used to introduce relevant content, but the teaching of new knowledge is gradually separated from the real situation. The three major evaluation projects all attach great importance to the application of real situations and PISA specially divides scientific situations into three categories: individual, local / national and global applications. The ultimate goal of learning is to use knowledge. In the classroom, teachers can make use of the digital environment and adopt interactive teaching methods to improve students' initiative and enthusiasm, and further guide students to solve practical problems with the knowledge they have learned.

6.3 Attach importance to the law of development and observe the level of cognitive development

The respondent of PISA2025 included students aged 15-16 who are about to complete full compulsory education, TIMSS2023 surveyed students in fourth and eighth grades, and NAEP survey included students in grades 4,8, and 12 in the United States. The brain development of the fourth grade students is just in the critical period of internal structure and function perfection, and their physiological and psychological characteristics change significantly, which is the best period to cultivate learning ability, emotional ability, will ability and learning habits. Junior high school students are in the period of "physical and mental fusion", among which the eighth grade students are particularly obvious, and the education circle calls it the "psychological weaning period". From the selection of the survey objects of the three major evaluations, we can draw a conclusion that whether in the selection of science teaching content and methods, or in the cultivation of scientific ability and thinking, the law of students' physical and mental development and the principle of teaching students should be in accord with their aptitude. And targeted teaching should be carried out according to the different characteristics of students.

6.4 Collect background data and provide comprehensive educational information

The Background survey of PISA includes: school questionnaire, student questionnaire, educational career questionnaire, information and communication technology proficiency questionnaire, parent questionnaire, science teacher questionnaire, general teacher (non-science course teacher) questionnaire (Shi & Lin, 2020). TIMSS collects important information related to policy through investigating questionnaires, which filled out by students and their parents, teachers and principals about students' experiences in school and home. And then study their impact on student performance (Zeng & He,2020). The background survey of NAEP includes three parts: student situation, school situation and teacher situation (Liao et al, 2016). Studying the link between background data and student academic achievement not only help the respective states continue to conduct the monitoring of student performance to improve teaching but also indirectly monitor the development of education quality in their own states.

6.5 Pay attention to the trend of The Times and adopt various evaluation methods

In the information age of knowledge explosion, it has become the trend to replace the traditional pen-and-paper test with the computer evaluation questions for large-scale evaluation items. PISA, TIMSS and NAEP already has transitioned from paper-and-pencil testing to computer evaluation. Compared with traditional paper-and-pencil tests, computer evaluation questions have the following advantages: first, digital evaluation can improve the way of data collection and give a mark automatically. Second, it can reduce the printing and delivery costs of paper delivery, thus improving the efficiency of evaluation. Third, computer evaluation can develop interactive test questions. In PISA evaluation, students can conduct simulation experiments in a computer, which is closer to the real purpose of PISA examination. Based on the above three reasons, it is of certain positive significance to pay attention to the computer development and evaluation questions and adopt various evaluation methods to evaluate students' scientific literacy.

Competing interests

The authors declare no competing interests.

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