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Empowering Learners through Scientific Literacy: A Critical Analysis of Frameworks and Definitions in Light of PISA and CBSE Perspectives

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Abstract

In recent decades, scientific literacy has emerged as a foundational aim of science education, emphasized by educators, researchers, and policymakers globally. Despite its widespread use, there is no consensus on its precise definition. While some view scientific literacy as the mere acquisition of scientific facts and concepts, others interpret it more broadly to include scientific reasoning, inquiry skills, ethical decision-making, and the ability to apply science in everyday and societal contexts. The term has also been associated with reading and interpreting scientific texts and engaging in discussions on socio-scientific issues such as climate change, health, and technology. This lack of definitional clarity has led scholars to critique it as a vague and ill-defined concept. Nevertheless, in an era marked by rapid technological advancement and an overload of information, the importance of cultivating scientifically literate individuals has intensified. A scientifically literate citizen is expected to make evidence-based decisions, think critically, and engage responsibly with science-related matters. This paper explores the evolution of the concept of scientific literacy, analyzes major definitions and classifications from literature and global assessments such as PISA and CBSE, and highlights its core components—content knowledge, nature of science, inquiry, and socio-scientific engagement. It also examines alternative frameworks like Science through Education vs. Education through Science to illustrate how educational goals can shape its interpretation.

Keywords: Scientific Literacy, Science Education, Nature of Science, PISA Framework and Education through Science.

Scientific Literacy: An Overview

The concept of scientific literacy has been around for several decades and is now a widely used term in science education. Some sources suggest that the term was first introduced by Conant in 1952 (Bybee, 1997b, cited in Wenning, 2006a), while others attribute its origin to Hurd in 1958 (Laugksch, 2000). Regardless of who coined it, there is no doubt that scientific literacy has gained significant popularity and is now considered a key goal in science education (AAAS, 1989 & 1993; NRC, 1996; Millar & Osborne, 1998; Sadler, 2004; Holbrook & Rannikmae, 2009; NSTA, 2010; UNESCO, 2010).

Even though the term has been in use for more than forty years (Gallagher & Harsch, 1997, cited in Holbrook & Rannikmae, 2009), its definition remains unclear. Scholars like DeBoer (2000) have pointed out that defining scientific literacy precisely has always been a challenge due to its varied interpretations. Many educators, scientists, and philosophers have tried to give it a clear meaning (Wenning, 2006a), but it continues to lack a common or operational definition.

Anelli (2011) noted that any meaningful discussion on scientific literacy should begin with a clear definition, as the term has evolved and now means different things to different groups. In fact, scientific literacy is often used interchangeably with other terms such as *science literacy*, *scientific culture*, *public understanding of science*, and *public engagement with science*. For instance, *scientific culture* is common in Canada, while *public understanding of science* is widely used in England (Roberts, 2007).

Laugksch (2000) viewed scientific literacy as the essential knowledge the general public should have about science, but also acknowledged its vague nature due to differing interpretations. Fensham (2007) connected the term to science education for all, yet admitted it lacks a practical definition. Similarly, Feinstein (2011) described it as a term that has become so broadly used that it now seems to mean everything and nothing at once.

Meaning and Definitions

The concept of *scientific literacy* has been defined in various ways by educators, researchers, and reform documents over the years. One of the earliest attempts to define it was made by Pella, O'Hare, and Gale in 1966 (cited in Wenning, 2006a). After reviewing numerous scholarly works, they identified six key elements that shape the idea of scientific literacy:

- The relationship between science and society
- Ethical considerations in science
- Understanding the nature of science
- Possession of conceptual scientific knowledge
- The connection between science and technology
- The role of science in the humanities

Building on this, Pella (1967) described a scientifically literate individual as someone who understands how science interacts with society, appreciates scientific processes, and possesses basic conceptual knowledge, including how science links with the humanities.

Shen (1975) brought forward a more functional classification, dividing scientific literacy into three types:

- Practical scientific literacy, which involves applying scientific knowledge to improve daily life (e.g., health, food, shelter)
- Cultural scientific literacy, which reflects an interest in scientific ideas even among non-scientists
- Civic scientific literacy, which refers to using science in public decision-making and understanding science-related societal issues

Laugksch (2000) emphasized that while these three types are interrelated, they differ in their goals, audience, and delivery. He believed that all forms require a foundational understanding of scientific concepts, but they serve different purposes.

Miller (1983) defined scientific literacy as a blend of understanding scientific content and the norms that guide scientific thinking. Like Shen, he stressed the importance of relating science to societal contexts rather than limiting it to abstract facts.

Similarly, Hazen and Trefil (1991) focused on the knowledge people need to follow and understand public issues involving science. They emphasized that scientific literacy is not expert-level knowledge but rather a practical, accessible understanding for everyday citizens.

Durant (1993) echoed this idea, stating that scientific literacy involves knowing what is essential for the general public. Project 2000+ (1993) supported this view, describing scientific and technological literacy as the ability to read, write, and understand scientific texts, and to use this knowledge confidently in everyday contexts.

Jenkins (1994) proposed a more philosophical angle, suggesting that scientific literacy involves appreciating the aims, limitations, and key ideas of science. However, he did not include the societal aspect that many other definitions emphasized.

Shamos (1995) offered a critical perspective in *The Myth of Scientific Literacy*, arguing that while full understanding of science may be unreachable for most people, a general grasp of how science works is still essential. He introduced three levels of literacy:

- Cultural literacy: knowing basic science facts to understand media

- Functional literacy: being able to talk and write about science
- True literacy: understanding science processes, history, and thinking critically

The National Science Education Standards (NSES, 1996) provided a comprehensive definition, highlighting knowledge of concepts and processes for informed personal and civic decisions. They identified key skills that a scientifically literate person should have, including asking questions, interpreting evidence, reading scientific content, and evaluating information sources.

Millar and Osborne (1998) in their report *Beyond 2000*, emphasized curriculum's role in promoting scientific literacy. They saw it as enabling students to appreciate science, make informed life decisions, critically engage with issues, and pursue science further if needed.

The OECD's Programme for International Student Assessment (PISA) offered definitions over time (2000–2013) that consistently emphasized the application of knowledge to explain phenomena, solve real-world problems, and make evidence-based decisions. PISA also introduced three types of knowledge: content knowledge, procedural knowledge, and epistemic knowledge.

Roberts (2007) organized the different meanings of scientific literacy into two major visions:

- Vision I, which focuses on scientific knowledge and understanding science itself
- Vision II, which emphasizes applying science in societal contexts and everyday situations

Holbrook and Rannikmae (2009) offered a modern view, describing scientific literacy as the ability to creatively apply scientific knowledge and skills in everyday life and in careers, especially for solving meaningful personal and social problems. They emphasized communication and decision-making in science as essential competencies.

Lastly, Bybee (2012) explained scientific literacy simply as understanding science and its relevance to social experiences. He had earlier (1997) proposed four levels of literacy: nominal, functional, conceptual/procedural, and multidimensional. These levels reflect growth from mere recognition of scientific terms to a deep understanding of science's role in society.

Table 1

Summary of Scientific Literacy Definitions

Author/Source	Main Focus	Key Components	Notable Contribution
Pella et al. (1966, 1967)	Broad social connection	Nature of science, ethics, humanities, conceptual knowledge	Early framework emphasizing the

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			interdisciplinary nature of scientific literacy
Shen (1975)	Categorized usage	Practical, cultural, and civic literacy	Introduced typology based on real-world applications
Laugksch (2000)	Conceptual overview	Science-society connection, educational delivery	Emphasized different objectives and audiences for literacy types
Miller (1983)	Science and society	Scientific terms, norms, social relevance	Combined content and process with civic awareness
Hazen & Trefil (1991)	Public understanding	Vocabulary, history, philosophy of science	Highlighted layperson's ability to understand public scientific issues
Shamos (1995)	Realistic achievement levels	Cultural, functional, and true literacy	Proposed literacy as a tiered continuum, critiquing idealistic expectations
NSES (1996)	Civic and personal decisions	Inquiry, decision-making, evaluation	Provided operational skills that define a scientifically literate individual
Millar & Osborne (1998)	Educational curriculum focus	Appreciation, critical thinking, informed action	Emphasized curriculum design for future scientific engagement
PISA (2000–2013)	Global assessment of competence	Knowledge of/about science, inquiry, interpretation, decision-making	Introduced core competencies: explain, evaluate, interpret

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Roberts (2007)	Two visions (I & II)	Knowledge vs. application in society	Classified definitions along a continuum of cognitive vs. societal focus
Holbrook & Rannikmae (2009)	Everyday and career relevance	Creativity, evidence-based problem-solving, communication	Focused on applied literacy for life and work
Bybee (2012)	Practical, developmental progression	Nominal, functional, conceptual, multidimensional	Outlined developmental stages of becoming scientifically literate

This classification shows how scientific literacy has grown from a narrow academic focus to a broader vision that includes ethics, public engagement, decision-making, and lifelong learning. The table also helps distinguish between those definitions that prioritize scientific knowledge (Vision I) and those that emphasize its social application (Vision II), bridging both views through evolving education reforms.

Core Components of Scientific Literacy

While definitions of scientific literacy may differ in focus and depth, there is broad agreement that it involves a set of interconnected components. These core elements help translate the abstract idea of scientific literacy into observable and teachable educational outcomes.

1. Content Knowledge

This refers to the factual and conceptual understanding of scientific principles, theories, and laws. It includes knowledge of physical, biological, and earth sciences that helps individuals make sense of the natural world. Content knowledge is essential not just for academic success but also for interpreting everyday experiences and global challenges (OECD, 2013).

2. Nature of Science (NOS)

The Nature of Science explains how scientific knowledge is constructed, validated, and communicated. It draws from the philosophy, sociology, and history of science (Wenning, 2006b). Understanding NOS means recognizing that science is not just a collection of facts, but a dynamic, evolving process.

Table 2

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A comparison of similarities and differences in emphases between 'Science through Education' and the alternative 'Education through Science'(taken from Holbrook & Rannikmae, 2007).

Science through Education	Education through Science
Learn fundamental science knowledge, concepts, theories and laws.	Learn the science knowledge and concepts important for understanding and handling socio-scientific issues within society.
Undertake the processes of science through inquiry learning as part of the development of learning to be a scientist.	Undertake investigatory scientific problem solving to better understand the science background related to socio-scientific issues within society.
Gain an appreciation of the nature of science from a scientist's point of view.	Gain an appreciation of the nature of science from a societal point of view.
Undertake practical work and appreciate the work of scientists.	Develop personal skills related to creativity, initiative, safe working, etc.
Develop positive attitudes towards science and scientists.	Develop positive attitudes towards science as a major factor in the development of society and scientific endeavours.
Acquire communicative skills related to oral, written and symbolic/tabular/ graphical formats as part of systematic science learning.	Acquire communicative skills related to oral, written and symbolic/tabular/ graphical formats to better express scientific ideas in a social context.
	Undertake socio-scientific decision making related to issues arising from the society.
Apply the uses of science to society and appreciate ethical issues faced by scientists.	Develop social values related to becoming a responsible citizen and undertaking science-related careers.

The table presented by Holbrook and Rannikmae (2007) contrasts two approaches to scientific literacy: *Science through Education* and *Education through Science*. This comparison highlights the evolving understanding of scientific literacy from a purely academic focus to a broader, socially responsive perspective.

The "Science through Education" approach emphasizes traditional scientific knowledge—concepts, theories, inquiry skills, and understanding the work of scientists—essential for becoming a scientist. In contrast, "Education through Science" reflects a more holistic view, promoting the application of science in real-life contexts, including socio-scientific problem-solving, ethical reasoning, communication in social settings, and preparing students to be responsible, informed citizens.

3. Scientific Inquiry

Scientific inquiry refers to the processes and skills involved in investigating questions, gathering evidence, and forming explanations. It includes both the activities scientists engage in and the practices students use to explore scientific ideas. According to the National Research Council (1996), inquiry develops students' ability to think critically and solve problems.

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4. Implications in Socio-Scientific Issues (SSI)

Scientific literacy today goes beyond content and process to include the ability to apply science in social and ethical contexts. Socio-scientific issues are real-world problems that are rooted in science but require decision-making that considers ethics, sustainability, and societal values (Ratcliffe & Grace, 2003).

Examples include:

- Climate change
- Vaccination policies
- Water resource management

Assessment of Scientific Literacy

A variety of approaches have been developed to assess scientific literacy, each using different tools and strategies. Researchers such as Aikenhead and Ryan (1992), Champagne et al. (2000), Korpan et al. (1994), and Laugksch & Spargo (1996) have proposed diverse methods for evaluating an individual's scientific literacy. Over time, the format and structure of scientific literacy assessments have undergone significant changes and refinements, reflecting evolving definitions and educational goals (Tsabari & Yarden, 2005; Schleicher, 1999).

In recent years, the OECD's Programme for International Student Assessment (PISA) has become a significant global reference point for assessing scientific literacy. The PISA framework (OECD, 2007) outlines three core competencies that form the foundation of scientific literacy:

1. Identifying scientific issues
2. Explaining phenomena scientifically
3. Using scientific evidence

According to PISA, "A scientifically literate individual is expected to participate thoughtfully in science-related societal debates". To do so, they must demonstrate the following competencies:

1. Explain Phenomena Scientifically

This involves the ability to:

- Recall and apply relevant scientific concepts
- Use and generate explanatory models and representations
- Make justified predictions
- Propose explanatory hypotheses
- Discuss how scientific knowledge impacts society

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2. Interpret Data and Evidence Scientifically

This includes the skills to:

- Convert data between different forms of representation
- Analyse and draw conclusions from data
- Evaluate claims and arguments in scientific texts
- Distinguish between scientific reasoning and other forms of argumentation
- Assess the reliability and credibility of sources like newspapers, journals, etc.

3. Evaluate and Design Scientific Inquiry

This competency reflects the ability to:

- Recognize scientific questions under investigation
- Identify questions that can be addressed scientifically
- Suggest scientific methods to explore these questions
- Critically evaluate the methods used in scientific studies
- Understand how scientists ensure the reliability, objectivity, and generalisability of their findings

Earlier, PISA 2006 categorized scientific literacy into two knowledge dimensions: knowledge of science (content) and knowledge about science (process and nature). By PISA 2015, the definition evolved further to emphasize the application of knowledge in real-life contexts, and the ability to participate in science-based discourse as part of democratic citizenship.

CBSE & Scientific Literacy

The Central Board of Secondary Education (CBSE, 2019) defines scientific literacy as *"the capacity to use scientific knowledge, to identify questions, and to draw evidence-based conclusions to understand and help make decisions about the natural world and the changes made to it through human activity."* This definition aligns closely with the PISA framework, emphasizing the application of science in real-life contexts and decision-making.

According to CBSE, a scientifically literate individual is expected to demonstrate several important abilities:

- The curiosity to ask meaningful questions about everyday experiences and seek answers through scientific thinking
- The skill to describe, explain, and predict natural phenomena based on scientific understanding

- The ability to comprehend science-related content in the media and engage in informed discussions about its conclusions
- The capacity to identify and analyze scientific dimensions of local and national issues and express viewpoints grounded in scientific and technological knowledge

However, current data suggest that India lags behind global standards in scientific literacy. As noted by Sharma (2019), many Indian students still struggle to apply scientific concepts in unfamiliar or problem-solving contexts. Instead of using knowledge analytically, they often rely on rote memorization, which limits their performance in international assessments like PISA.

Conclusion

Scientific literacy involves students' capacity to comprehend scientific concepts, use that understanding to address real-world problems, and make informed decisions grounded in scientific evidence. In summary, scientific literacy is a multidimensional construct that cannot be reduced to a single skill or knowledge area. The four components—Content Knowledge, Nature of Science, Scientific Inquiry, and Socio-Scientific Application—together form a robust framework that captures what it truly means to be scientifically literate. Educational programs that aim to foster scientific literacy must intentionally integrate these dimensions to develop learners who are not only informed but also thoughtful and engaged participants in a science-driven world.

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