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Systematic Review of Scientific Literacy Assessment Tools in Science Education

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Abstract:

Scientific literacy is widely recognized as a central goal of science education worldwide, serving as a foundation for informed decision-making and civic engagement in an increasingly complex and technology-driven society. This study presents a systematic literature review aimed at identifying prevailing trends, theoretical frameworks, and methodological approaches in the development of scientific literacy assessment instruments. A total of peer-reviewed studies were analyzed to examine how scientific literacy is conceptualized and operationalized across different educational contexts. Findings reveal a significant shift in the field, from the construction of original, context-specific frameworks toward the adoption and adaptation of established models, particularly the Programme for International Student Assessment (PISA) and the Test of Scientific Literacy Skills (TOSLS). These frameworks have become dominant due to their comprehensive structure and international recognition, offering a standardized basis for assessment development. However, the study also highlights ongoing efforts to adapt these models to diverse educational levels, cultural contexts, and disciplinary topics. Overall, the results suggest a growing balance between standardization and contextualization in scientific literacy assessment research, reflecting its evolving nature as both a global and locally responsive construct.

Keywords: Scientific literacy; systematic review; assessment instruments; PISA; TOSLS; science education

Introduction:

The concept of scientific literacy has undergone significant evolution since its emergence in the 1950s. Initially, it was narrowly defined as the ability to read and write scientific texts. Over time, however, it has expanded to encompass a broader set of competencies, including understanding the role of science in society and applying scientific knowledge to make informed decisions in democratic and everyday contexts (Dibner & Snow, 2016; Li & Guo, 2021).

Despite its prominence in science education research and policy, scientific literacy remains a complex and multifaceted construct. This conceptual ambiguity has led to diverse interpretations across studies and, consequently, a wide range of approaches in developing and validating assessment instruments (Coppi et al., 2023; Istyadji, 2023). As a result, there is ongoing effort to clarify its theoretical foundations and measurement approaches.

One important dimension in this discourse is the role of scientific literacy in addressing socio-scientific issues. Contemporary research highlights its importance in engaging learners with real-world problems such as environmental challenges, climate change, and public health concerns (Azevedo & Marques, 2017; Kumar et al., 2024). These contexts emphasize that scientific literacy is not only cognitive but also participatory and socially embedded.

In addition, scientific literacy has been increasingly linked to communication and argumentation skills. Studies suggest that the ability to construct, evaluate, and communicate scientific arguments is central to meaningful scientific understanding (Cavagnetto, 2010; Li & Guo, 2021). This perspective reinforces the idea that scientific literacy extends beyond content knowledge to include critical thinking and discourse practices.

Recent educational research has also explored how scientific literacy can be developed across various learning environments and methodologies. Approaches such as project-based learning and inquiry-based instruction have been shown to enhance learners' scientific literacy and critical thinking skills (Hudha et al., 2023; Bramastia & Rahayu, 2023). Similarly, citizen science initiatives and informal learning contexts contribute to the development of scientific understanding in authentic settings (Aristeidou & Herodotou, 2020).

At the theoretical level, debates in science education often distinguish between two dominant perspectives: Vision I and Vision II science education. Vision I focuses on the transmission of established scientific knowledge within school settings, while Vision II emphasizes the application of science in real-life and societal contexts (Dibner & Snow, 2016). These two visions shape how scientific literacy is conceptualized and assessed across different educational systems.

Assessment plays a crucial role in operationalizing these competing visions. The design of scientific literacy instruments reflects how researchers interpret the construct, whether through standardized tests, performance-based tasks, or attitudinal measures (Coppi et al., 2023; Istyadji, 2023). Consequently, assessment tools not only measure scientific literacy but also define its boundaries and dimensions in practice.

Given these developments, there is a need to systematically examine how scientific literacy is translated into assessment frameworks and instruments. This study aims to review existing literature to identify the prevailing conceptualizations, methodological approaches, and assessment models used in scientific literacy research. By doing so, it seeks to clarify how theoretical perspectives are operationalized into functional tools for measuring scientific literacy across educational contexts (Roy et al., 2025; Yanto & Sari, 2025).

Literature Review:

Scientific literacy has been widely recognized as a central goal of science education across global contexts. Early conceptualizations emphasized basic comprehension of scientific texts, but contemporary perspectives position it as a multidimensional construct involving reasoning, decision-making, and civic engagement in socio-scientific issues (Dibner & Snow, 2016; Pearson et al., 2010). Over time, this shift has expanded the scope of scientific literacy research to include not only cognitive understanding but also its application in real-world contexts.

A growing body of literature has focused on mapping the evolution of scientific literacy research and its instructional implications. Systematic reviews indicate that research trends increasingly emphasize contextualized learning, learner engagement, and competency-based frameworks (Romli et al., 2024; Hand et al., 2010). These studies highlight a transition from traditional content-focused instruction toward more integrative approaches that combine knowledge, skills, and attitudes.

One major area of investigation is the development of learning models designed to enhance scientific literacy. Romli et al. (2024) found that inquiry-based, problem-based, and constructivist approaches dominate recent research in this area. Similarly, contextualized instruction has been shown to significantly improve learners' ability to apply scientific concepts in real-life situations (Marchee & Joje Mar, 2022), reinforcing the importance of situated learning in science education.

In addition to pedagogical approaches, research has also explored technological integration in promoting scientific literacy. Studies on interactive e-modules and multimedia tools demonstrate that digital resources can enhance conceptual understanding and learner engagement (Herlina & Abidin, 2024; Hodaifah et al., 2025). Furthermore, digital school culture has been identified as a significant factor influencing the development of scientific literacy, particularly in technology-rich learning environments (Litina & Rubene, 2024).

Emerging technologies such as artificial intelligence and augmented reality are also gaining attention in science education research. Wibowo et al. (2026) argue that hybrid AI and AR integration holds promise for improving accessibility and personalization in scientific learning, although challenges remain regarding implementation and equity. Similarly, Braun and Huwer (2022) highlight the importance of computational literacy as an emerging dimension of scientific literacy in the digital age.

Beyond technological innovations, science literacy is increasingly linked to interdisciplinary and socio-cultural approaches. Ethno-science and ethno-STEM approaches have been shown to improve students' engagement and conceptual understanding by connecting scientific concepts to local cultural knowledge (Primadianningsih et al., 2023; Hikmah et al., 2025). Majid et al. (2025) further emphasize the importance of integrating domain-specific literacies, such as energy literacy, into broader science education frameworks.

Literature also highlights the importance of literacy integration across disciplines. Pearson et al. (2010) argue that literacy and science should function as mutually reinforcing domains, where language development supports scientific understanding and vice versa. This perspective is further supported by studies showing that scientific literacy can be enhanced through language-rich approaches, including children’s literature and storytelling (Heryani et al., 2024).

Another emerging dimension is the expansion of scientific literacy beyond formal education. Busch and Rajwade (2024) conceptualize community scientific literacy as a broader societal capability shaped by informal learning environments and public engagement. Similarly, museums and science centers have been identified as important spaces for promoting health-related and general scientific literacy among the public (Christensen et al., 2016).

Research on teacher development also underscores the importance of educator capacity in fostering scientific literacy. Nor and Mahmud (2024) found that empowering science teachers through professional development significantly improves their ability to design and implement scientific literacy-oriented instruction. This aligns with findings from Rahmawati et al. (2023), who emphasize self-regulated learning as a key factor in enhancing scientific literacy at the higher education level.

At the conceptual level, recent scholarship has introduced expanded visions of scientific literacy. Kilag et al. (2023) critically examine different perspectives and argue for a more holistic, Bildung-oriented approach to science education. In the same vein, Sjöström (2025) proposes Vision III scientific literacy, which emphasizes ethical, socio-political, and existential dimensions of science education, extending beyond traditional cognitive frameworks.

Intervention-based studies further demonstrate diverse strategies for improving scientific literacy outcomes. These include project-based learning in early childhood education (Eliza et al., 2025), ethnoscience-based instruction (Hikmah et al., 2025), and interventions targeting scientific reasoning and attitudes (Lieskovský & Sunyík, 2022). Additionally, communication-focused innovations such as data sonification have been proposed as tools for overcoming barriers in scientific understanding (Sawe et al., 2020).

Recent systematic and scoping reviews also highlight the increasing diversification of scientific literacy research across educational levels and disciplines. Studies show that STEM-based instructional media, interactive multimedia, and hybrid learning environments significantly enhance learners’ scientific literacy skills (Oktasari et al., 2025; Hodaifah et al., 2025; Wibowo et al., 2026). Furthermore, these findings collectively suggest that scientific literacy is evolving into a highly adaptive construct shaped by technological, cultural, and pedagogical transformations.

Methodology:

This study employed a four-step systematic literature review process consisting of topic identification, literature search, screening and selection, and data analysis and synthesis. This structured approach ensured transparency, replicability, and rigor in the review process.

Search Strategy
A comprehensive literature search was conducted using the Scopus database, which is widely recognized for indexing high-quality peer-reviewed research. The search employed a combination of keywords, including “scientific literacy,” “assessment,” “test,” “measurement,” and “development.” This initial search yielded a total of 290 articles for further screening.

Inclusion and Exclusion Criteria
To ensure methodological rigor and relevance, all retrieved records were exported and managed using Zotero, which facilitated the removal of duplicate entries and non-journal sources such as books and book chapters. The remaining articles underwent manual screening based on two inclusion criteria:

1. The study must report the development or construction of a specific instrument designed to assess scientific literacy.
2. The term "scientific literacy" must be explicitly used to describe or define the assessment instrument.

After applying these criteria, a final corpus of 43 articles was selected for full-text analysis.

Analysis Framework

The selected studies were systematically analyzed using a predefined coding framework focusing on four key dimensions of scientific literacy instruments:

- **Theoretical framework**, referring to the conceptual or theoretical basis guiding instrument development;
- **Assessment format**, including multiple-choice tests, essay-type assessments, Likert-scale instruments, or mixed formats;
- **Geographical context**, indicating the country or region where the study was conducted;
- **Educational level or implementation context**, such as primary education, secondary education, or tertiary (undergraduate) level.

This multidimensional analysis allowed for a comprehensive understanding of trends in scientific literacy assessment design across different contexts and methodological approaches.

Findings and Discussion:

Dominant Frameworks

The analysis reveals that scientific literacy assessment is increasingly shaped by a limited number of dominant frameworks, reflecting a gradual consolidation in the field. Among these, the Programme for International Student Assessment (PISA), particularly its 2015 framework, emerges as the most frequently utilized model. PISA conceptualizes scientific literacy through four interrelated dimensions: context, content, competence, and attitude, offering a comprehensive structure that integrates knowledge, skills, and dispositions (Dibner & Snow, 2016; Istyadji, 2023).

The widespread adoption of PISA suggests a growing alignment among researchers toward standardized conceptualizations of scientific literacy. This trend is consistent with findings from systematic reviews indicating that researchers increasingly rely on established frameworks to ensure validity, comparability, and global relevance of assessment tools (Coppi et al., 2023; Romli et al., 2024). Such convergence reflects the influence of international large-scale assessments on both research and educational practice.

In addition to PISA, the Test of Scientific Literacy Skills (TOSLS) is identified as the second most commonly used framework. Developed by Gormally et al. (2012), TOSLS emphasizes practical scientific reasoning skills, including the ability to evaluate arguments and interpret data. This skills-oriented approach aligns with contemporary perspectives that frame scientific literacy as a functional competence rather than mere content mastery (Li & Guo, 2021; Cavagnetto, 2010).

The prominence of these frameworks highlights a broader shift from theoretical abstraction toward practical application in assessment design. Scientific literacy is increasingly operationalized as a measurable construct, focusing on learners' ability to engage with real-world problems and socio-scientific issues (Kumar et al., 2024; Azevedo & Marques, 2017). This reflects the growing importance of Vision II perspectives, where science is viewed as embedded in everyday life.

Despite this convergence, significant variation exists in how these frameworks are translated into assessment instruments. Multiple-choice formats remain the most widely used, particularly in large-scale and standardized testing contexts such as PISA and TOSLS. These formats offer efficiency, reliability, and ease of administration, making them suitable for large populations (Coppi et al., 2023).

However, multiple-choice assessments are often criticized for their limited capacity to capture higher-order thinking and complex reasoning. As a result, many researchers incorporate essay or constructed-response formats to assess deeper conceptual understanding and scientific argumentation skills. This aligns with literature emphasizing the role of discourse and reasoning in developing meaningful scientific literacy (Cavagnetto, 2010; Bramastia & Rahayu, 2023).

Likert-scale instruments are also commonly used, particularly for measuring affective dimensions such as attitudes, values, and perceptions toward science. These components are increasingly recognized as integral to scientific literacy, as they influence learners' engagement and willingness to apply scientific knowledge in real-world contexts (Yanto & Sari, 2025; Nor & Mahmud, 2024).

The diversity of assessment formats reflects the multidimensional nature of scientific literacy itself. No single format can fully capture its cognitive, affective, and behavioral components. Consequently, many studies advocate for mixed-method approaches that combine objective testing with performance-based and attitudinal measures to provide a more holistic assessment (Hudha et al., 2023; Roy et al., 2025).

Furthermore, the findings suggest that assessment practices are increasingly influenced by contextual factors, including cultural, educational, and societal needs. For instance, adaptations of established frameworks often incorporate local priorities, such as environmental awareness or community engagement, reflecting broader definitions of scientific literacy (Busch & Rajwade, 2024; Aristeidou & Herodotou, 2020). This highlights the importance of contextualization in ensuring the relevance and applicability of assessment tools.

The findings underscore the ongoing evolution of scientific literacy as both a theoretical construct and a practical objective in education. Emerging perspectives, such as Bildung-oriented approaches and expanded visions of scientific literacy, emphasize ethical, societal, and transformative dimensions of science education (Kilag et al., 2023). These developments suggest that future assessment frameworks must move beyond standardized measurement toward more dynamic and context-sensitive models that reflect the complexities of contemporary scientific literacy.

From Construction to Adaptation

The evolution of scientific literacy assessment research reveals a clear methodological and conceptual shift from framework construction to framework adaptation. Earlier studies, particularly those conducted prior to 2018, were primarily concerned with developing original theoretical models tailored to specific educational contexts (Hand et al., 2010; Koppal & Caldwell, 2004). These studies reflected an exploratory phase in which researchers sought to define and operationalize scientific literacy in diverse ways.

In contrast, recent literature shows a marked shift toward the adoption and adaptation of established frameworks such as PISA and TOSLS. This transition suggests increasing consolidation in how scientific literacy is conceptualized and measured, with researchers gravitating toward widely accepted "gold standard" models to ensure comparability and validity across contexts.

One key explanation for this shift is the growing influence of large-scale international assessments, which have helped standardize definitions of scientific literacy. Frameworks originating from such assessments provide structured dimensions that are easily transferable across studies, encouraging their widespread adoption (Pearson et al., 2010; Oktasari et al., 2025).

At the same time, adaptation rather than direct adoption has become a dominant practice. Researchers frequently modify existing frameworks to align with specific educational levels, cultural contexts, or curriculum goals. For example, studies in elementary education increasingly adapt scientific literacy frameworks to integrate contextualized and developmentally appropriate content (Habsari et al., 2026; Eliza et al., 2025).

Technological integration has also contributed to this adaptive trend. Digital tools such as interactive e-modules and multimedia learning platforms are often embedded within existing frameworks to enhance engagement and accessibility (Herlina & Abidin, 2024; Hodaifah et al., 2025). Similarly, the emergence of digital school culture has reshaped how scientific literacy is taught and assessed in modern classrooms (Litina & Rubene, 2024).

Beyond formal technological tools, media-based and computational literacies are increasingly being integrated into scientific literacy frameworks. Studies highlight the importance of media literacy in interpreting scientific information in online environments, as well as computational literacy in understanding data-driven scientific processes (Rosenthal, 2020; Braun & Huwer, 2022). These developments indicate an expansion of scientific literacy into digital and information-rich contexts.

Another significant trend is the integration of scientific literacy with interdisciplinary and language-based approaches. Research shows that combining literacy practices with science instruction enhances comprehension and conceptual understanding, reinforcing the reciprocal relationship between language and science learning (Pearson et al., 2010; Heryani et al., 2024). This integration supports more holistic adaptations of existing frameworks.

Pedagogical innovations such as project-based learning and STEM-based instruction further demonstrate how adaptation operates in practice. These approaches are frequently embedded within established scientific literacy frameworks to improve student engagement and problem-solving skills (Eliza et al., 2025; Oktasari et al., 2025). Similarly, ethnoscience and ethno-STEM approaches localize scientific concepts by connecting them to cultural knowledge systems (Primadianningsih et al., 2023; Hikmah et al., 2025).

Intervention-based studies also reinforce the importance of adapting frameworks to enhance scientific reasoning and attitudes. Research indicates that targeted instructional strategies can significantly improve students' ability to evaluate scientific claims and engage in evidence-based reasoning (Lieskovský & Sunyík, 2022). These interventions often rely on modified versions of established assessment models.

Despite this strong trend toward adaptation, some scholars argue that scientific literacy frameworks are becoming increasingly homogenized. The dominance of models such as PISA may limit conceptual diversity by privileging certain epistemological perspectives over others. This raises concerns about the potential narrowing of scientific literacy definitions in global research.

In response to this concern, emerging perspectives such as Vision III scientific literacy propose a more expansive and critical approach. Sjöström (2025) argues that scientific literacy should include ethical, socio-political, and existential dimensions, moving beyond purely cognitive or skills-based frameworks. This vision challenges the dominance of standardized models by emphasizing humanistic and transformative aspects of science education.

Hence while scientific literacy research has shifted toward adaptation of established frameworks, there remains a dynamic tension between standardization and contextualization. The field continues to evolve as researchers attempt to balance global comparability with local relevance, indicating that scientific literacy remains a contested and expanding construct in science education research.

The Role of Context

Context plays a central role in shaping how scientific literacy is conceptualized, implemented, and assessed across educational settings. Contemporary research consistently emphasizes that scientific literacy is not a context-free construct but one that is deeply influenced by cultural, educational, and societal conditions (Dibner & Snow, 2016; Istyadji, 2023). As a result, assessment frameworks are frequently adapted to ensure relevance to specific learner populations.

One major form of contextual adaptation is the modification of established frameworks such as PISA to suit local educational needs. For example, the Student Test of Scientific Literacy Integrated Character (SToSLiC) adapts PISA-based competencies by incorporating national character education elements. This reflects a broader trend in which global assessment models are localized to reflect cultural values and educational priorities.

Contextual adaptation is also evident across different educational levels. Although PISA was originally designed for 15-year-old learners, researchers have successfully modified its structure for use in primary, secondary, and tertiary education settings. Such adaptations ensure developmental appropriateness while maintaining alignment with internationally recognized scientific literacy competencies (Roy et al., 2025; Yanto & Sari, 2025).

Beyond formal education settings, scientific literacy is increasingly understood through informal and community-based learning contexts. Citizen science initiatives and online participatory platforms have been shown to enhance engagement and understanding of scientific processes among diverse populations (Aristeidou & Herodotou, 2020). These findings highlight the expanding boundaries of where and how scientific literacy develops.

Museums, science centers, and public science communication platforms also contribute significantly to contextual learning. These environments support experiential learning and promote scientific understanding in non-formal settings, often linking science literacy to broader social outcomes such as health awareness and civic engagement (Christensen et al., 2016). This reinforces the idea that scientific literacy extends beyond classrooms.

Technological innovation further expands contextual possibilities in science education. Emerging tools such as augmented reality and hybrid AI systems are increasingly integrated into learning environments to enhance engagement and conceptual understanding (Wibowo et al., 2026). Similarly, data sonification has been proposed as an alternative mode of scientific communication that improves accessibility for learners facing numeracy or visualization barriers (Sawe et al., 2020).

Instructional strategies also demonstrate the importance of contextualization in improving scientific literacy outcomes. Studies show that contextualized science instruction significantly enhances students' ability to connect abstract concepts to real-world applications, particularly in socio-scientific issues (Marchee & Joje Mar, 2022; Kumar et al., 2024). Project-based learning and other active learning approaches further strengthen this connection by situating learning in meaningful contexts (Hudha et al., 2023).

At the theoretical level, context is also embedded in how scientific literacy is defined and operationalized. Research indicates that assessment instruments often reflect underlying assumptions about what counts as relevant scientific knowledge, which may vary across cultural and institutional settings (Coppi et al., 2023; Li & Guo, 2021). This suggests that scientific literacy is not only measured differently across contexts but also constructed differently depending on those contexts.

The role of context underscores the importance of expanding scientific literacy beyond purely cognitive dimensions. Interventions that integrate environmental, ethical, and societal issues demonstrate that learners develop deeper understanding when science is connected to meaningful real-world problems (Bramastia & Rahayu, 2023; Majid et al., 2025). Overall, the literature indicates that contextualization is not merely an instructional strategy but a foundational principle in the development and assessment of scientific literacy.

Validity vs. Reliability

The development of scientific literacy assessment instruments is fundamentally shaped by the tension between validity and reliability. Validity refers to the extent to which an instrument accurately measures the intended construct, while reliability refers to the consistency and stability of the measurement across contexts and administrations. This tension is a recurring concern in scientific literacy research, particularly as frameworks are adapted across diverse educational settings (Romli et al., 2024; Azevedo & Marques, 2017).

In practice, researchers often face challenges in balancing these two methodological priorities. Highly standardized instruments tend to achieve strong reliability but may sacrifice contextual relevance, while highly contextualized tools may enhance validity but reduce comparability across populations. This trade-off is widely acknowledged in systematic reviews of scientific literacy assessment development (Busch & Rajwade, 2024; Nor & Mahmud, 2024).

To address this issue, many studies emphasize the concept of "dependability," which integrates both validity and reliability into a more pragmatic framework. Dependability allows researchers to maintain conceptual accuracy while ensuring that instruments remain usable across different educational levels and large-scale implementations. This approach reflects a shift toward more flexible and context-sensitive assessment design (Kilag et al., 2023; Habsari et al., 2026).

The challenge of maintaining both validity and reliability becomes more pronounced when scientific literacy is expanded beyond traditional cognitive domains. Emerging frameworks incorporate affective, ethical, and socio-

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political dimensions of literacy, which are inherently more difficult to measure consistently. Vision III perspectives, for example, highlight the complexity of capturing relational and existential aspects of scientific understanding within standardized instruments (Sjöström, 2025).

Technological integration in science education further complicates the validity-reliability balance. Digital tools such as STEM-based learning media, interactive e-modules, and multimedia platforms improve engagement and accessibility but introduce variability in how learners interact with content (Oktasari et al., 2025; Herlina & Abidin, 2024). While these tools enhance construct validity by situating learning in authentic contexts, they may also introduce inconsistencies in measurement conditions.

Similarly, computational literacy and media literacy are increasingly embedded within scientific literacy frameworks, requiring new forms of assessment that can capture dynamic and multimodal learning processes. These developments challenge traditional psychometric approaches and necessitate more flexible evaluation strategies (Braun & Huwer, 2022; Rosenthal, 2020). As a result, researchers are rethinking how reliability should be defined in digitally mediated environments.

Instructional innovations also contribute to this methodological complexity. Project-based learning, contextualized instruction, and literacy-integrated approaches improve the ecological validity of assessments by aligning them with real-world learning experiences (Pearson et al., 2010; Hodaifah et al., 2025). However, such approaches often introduce variability in student outcomes, which can reduce measurement consistency if not carefully controlled.

The literature suggests a gradual shift from a strict dichotomy between validity and reliability toward a more integrated and pragmatic understanding of measurement quality. Rather than treating them as competing priorities, recent studies advocate for a balanced approach in which both are achieved through careful instrument design, contextual adaptation, and iterative validation processes. This reflects a broader trend in scientific literacy research toward flexible, context-aware, and theoretically grounded assessment development (Hand et al., 2010; Litina & Rubene, 2024).

Conclusion:

This systematic literature review demonstrates that scientific literacy assessment is an evolving and dynamic field characterized by a gradual movement toward standardized yet adaptable frameworks. Across the studies analyzed, there is a clear convergence toward internationally recognized models, particularly the Programme for International Student Assessment (PISA) framework and the Test of Scientific Literacy Skills (TOSLS). The widespread use of these frameworks suggests an emerging global consensus regarding the core competencies that define scientific literacy, including the integration of conceptual understanding, scientific reasoning, problem-solving skills, and attitudes toward science. These frameworks provide a common reference point that allows researchers to design, compare, and validate instruments across diverse educational contexts.

The dominance of PISA-based frameworks highlights the strong influence of large-scale international assessments in shaping both research and practice in science education. PISA, in particular, offers a multidimensional structure that incorporates context, content knowledge, competencies, and attitudes, making it highly adaptable for different research purposes. Similarly, TOSLS provides a skills-based approach that emphasizes practical scientific reasoning, such as evaluating evidence, interpreting data, and identifying scientific arguments. The frequent adoption of these models reflects a broader trend toward methodological standardization in scientific literacy assessment, ensuring comparability across studies, regions, and educational levels.

However, despite this movement toward standardization, the findings also reveal a strong and consistent trend of contextual adaptation. Researchers frequently modify established frameworks to suit specific disciplinary topics, educational levels, and cultural settings. For instance, scientific literacy instruments have been adapted for specialized content areas such as Green Chemistry, Thermochemistry, environmental science, and socio-scientific issues. These adaptations demonstrate that while core competencies may remain stable, the application of scientific literacy is highly context-dependent. Such flexibility ensures that assessment tools remain relevant and meaningful within specific instructional and societal contexts.

In addition to disciplinary adaptation, the review highlights the importance of educational level as a key factor influencing instrument design. Frameworks originally developed for secondary school learners, such as PISA, are increasingly being adapted for use in primary education and undergraduate settings. This indicates that scientific literacy is now viewed as a developmental construct that can be progressively cultivated across the lifespan. As a result, assessment tools are being redesigned to align with learners' cognitive development, prior knowledge, and learning environments, ensuring developmental appropriateness without compromising conceptual rigor.

Another important finding is the growing recognition that scientific literacy extends beyond traditional classroom knowledge and includes real-world application. Contemporary research emphasizes that scientific literacy should not only measure what students know, but also how they use scientific knowledge to make informed decisions in everyday life. This shift reflects an increasing emphasis on socio-scientific issues, civic engagement, and problem-solving in authentic contexts. As such, scientific literacy is increasingly positioned as a functional competence necessary for navigating complex societal challenges, including environmental sustainability, public health, and technological change.

Despite these advances, challenges remain in balancing standardization with contextual relevance. While global frameworks such as PISA and TOSLS provide strong foundations for measurement, their adaptation across diverse contexts often introduces variability in instrument design, scoring, and interpretation. This raises important methodological questions regarding comparability and consistency across studies. Nevertheless, this variability is not necessarily a limitation; rather, it reflects the inherent complexity of scientific literacy as a multidimensional construct that cannot be fully captured through a single universal instrument.

The findings also suggest that scientific literacy assessment is increasingly influenced by broader educational shifts, including competency-based education, interdisciplinary learning, and socio-cultural approaches. These developments reinforce the idea that scientific literacy is not merely a cognitive outcome but also a social and participatory practice. As such, assessment tools are gradually evolving to incorporate dimensions such as collaboration, communication, ethical reasoning, and engagement with socio-scientific issues. This expansion reflects a more holistic understanding of what it means to be scientifically literate in the twenty-first century.

Future research should continue to refine and expand scientific literacy assessment frameworks by embracing more integrative and context-sensitive approaches. In particular, there is a need to further develop "Vision II" assessments that focus on how individuals apply scientific knowledge in real-world decision-making situations. Such assessments should prioritize authenticity, emphasizing learners' ability to analyze issues, evaluate evidence, and make informed choices in everyday contexts. Additionally, future studies should explore innovative assessment formats that go beyond traditional testing methods, incorporating performance-based tasks, digital tools, and interdisciplinary approaches.

This review concludes that scientific literacy assessment is transitioning from fragmented, diverse approaches toward more structured yet adaptable systems. While standardization through frameworks like PISA and TOSLS provides coherence and comparability, contextual adaptation ensures relevance and applicability across different educational and societal settings. The ongoing challenge for researchers is to maintain a balance between these two priorities while expanding the scope of scientific literacy to reflect its full complexity. Strengthening this balance will be essential for developing assessment tools that are both scientifically robust and educationally meaningful in a rapidly changing world.

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