




Beyond assessment: Exploring science literacy among Indonesian elementary students through contextual educational analysis

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Received 26 January 2026 • Accepted 21 May 2026

Abstract

Science literacy is a key competency in 21st century education; however, empirical evidence capturing its domain-specific distribution in Indonesian elementary education remains limited. Adopting a beyond assessment perspective, this study aims to (1) quantify students' science literacy levels, (2) compare these levels across regions, and (3) analyze performance across core competency domains. A descriptive quantitative survey was conducted with 600 grade IV to grade VI students selected through stratified multistage random sampling. A program for international student assessment-based instrument was used to assess three domains: explaining scientific phenomena, designing and evaluating investigations, and interpreting scientific data and evidence. Data were analyzed using descriptive statistics and one-way analysis of variance. The results indicate that students' science literacy is at a moderate level, with no statistically significant differences across regions. However, domain-specific analysis reveals notable disparities: students perform relatively well in explaining scientific phenomena but demonstrate weaker competencies in designing investigations, interpreting data, and applying scientific concepts in real-life contexts. These findings suggest that science literacy challenges are systemic rather than region-specific, reflecting limitations in higher-order reasoning and inquiry-related skills. Moving beyond descriptive measurement, this study provides a domain-specific and context-sensitive profile of science literacy, offering evidence to inform instructional practices, assessment reform, and policy development.

Keywords: science literacy, elementary school, inquiry-based learning, contextual learning, teacher capacity, curriculum development, Indonesia

INTRODUCTION

Science literacy at the elementary school level is seen as the foundation for developing citizens who are able to reason with evidence, weigh risks and benefits, and make decisions on public issues involving science and technology. However, despite these expectations, empirical evidence indicates that elementary students' science literacy remains at a relatively low level in many contexts, including Indonesia. Large-scale assessments such as the program for international student assessment (PISA) consistently show that students' ability to apply scientific knowledge, interpret evidence, and engage in higher-order reasoning is still limited (Organisation for Economic Co-operation and Development [OECD], 2019, 2023). In particular,

students often struggle with tasks requiring inquiry-based thinking and the application of scientific concepts to real-world situations, suggesting a gap between intended learning outcomes and actual classroom practices (Bybee et al., 2015; Cerulli et al., 2016).

Recent literature emphasizes that the goal of science education does not stop at mastering facts or procedures (Fortus et al., 2022), but rather at critical engagement that combines knowledge, evidence-based reasoning, and informed trust in credible scientific authorities, especially in the midst of a digital information ecosystem that is prone to mis/disinformation (Early et al., 2024). At the global level, science literacy skills are increasingly urgent as science learning outcomes have declined post-pandemic.

Contribution to the literature

- This study extends science literacy research by adopting a beyond-assessment perspective to provide a more comprehensive understanding of students' competencies beyond overall achievement scores.
- This study provides empirical evidence on patterns of science literacy among Indonesian elementary students based on a large and representative sample.
- This study reveals domain-specific differences in science literacy performance, offering insights into improving science instruction, assessment practices, and educational policy.

The 2022 PISA results show a decline in the international average and place Indonesia still far below the OECD average in science (OECD, 2023). The official PISA fact sheet for Indonesia also highlights the challenges of creative thinking and uneven competency (OECD, 2024). These findings signal the need for systemic intervention starting from primary education to strengthen competencies in explaining phenomena scientifically, designing/evaluating investigations, and interpreting evidence.

Scientific literacy is crucial for a country's education system because it underpins the development of a scientifically informed citizenry capable of participating in evidence-based decision-making, supporting innovation, and sustaining economic competitiveness in a knowledge-based society (Bybee et al., 2015; OECD, 2019). The persistently low level of scientific literacy in Indonesia can be attributed to several interrelated factors, including the dominance of content-oriented instruction, limited implementation of inquiry-based learning, disparities in educational resources, and insufficient alignment between assessment practices and higher-order thinking skills (HOTS) (Cerulli et al., 2016).

To address these challenges, concrete strategies are needed, such as integrating inquiry-based and context-oriented pedagogy into classroom practice, strengthening professional teacher development focused on scientific reasoning and assessment literacy, and developing evaluation systems that emphasize the application of knowledge in real-world contexts (Ke et al., 2020). These efforts are essential to ensure that improvements in science education are both systemic and sustainable.

On the theoretical and curricular side, contemporary debates about the meaning of science literacy affirm the spectrum of orientations from "science of" (scientific content and practices) to "science for" (citizenship and decision-making), with different implications for the emphasis of elementary school curricula. A comparative analysis of current curricula shows the diversity of science literacy formulations and the importance of integrating core concepts, scientific practices, and socio-scientific issues (SSIs) in order to truly achieve the goal of scientific citizenship (Norambuena-Meléndez et al., 2023). Pedagogically, reviews and empirical studies indicate three consistent strategic pillars that support early science literacy achievement:

- (1) SSI-based learning that requires evidence-based argumentation and ethical reasoning,
- (2) meaningful inquiry that provides space for scientific practice, modeling, and evidence evaluation, and
- (3) an emphasis on written/oral argumentation practices to connect data, claims, and reasons (Roy et al., 2025).

Evidence from recent systematic/conceptual reviews confirms that SSI can develop critical reasoning and civic orientation (Shasha-Sharf & Tal, 2023), well-designed inquiry practices promote conceptual understanding and process skills (Lin et al., 2023), and argumentation-based interventions strengthen "critical consumption" of scientific claims (Mayweg-Paus et al., 2021). These findings are relevant to elementary schools because the early stages are a time for forming dispositions and thinking habits. However, there is a notable gap between these theoretical and pedagogical recommendations and their implementation in Indonesian elementary school contexts.

Evidence from large-scale assessments and national reports indicates that students' scientific literacy in Indonesia remains inadequately supported by structural and instructional factors, including limited access to adequate facilities and learning resources, uneven distribution of qualified teachers, and insufficient professional development opportunities (OECD, 2023; World Bank, 2020). These constraints hinder the effective adoption of inquiry-based, SSI-oriented, and argumentation-driven pedagogies, resulting in classroom practices that remain predominantly content-focused and less oriented towards HOTS. Consequently, aligning curriculum intentions with classroom realities requires not only pedagogical reform but also systemic support in terms of infrastructure, teacher capacity building, and policy coherence.

In recent decades, science literacy has become a central concern in global education systems, as it is closely linked to countries' capacities for innovation, economic competitiveness, and informed democratic participation. International organizations such as the OECD emphasize early development of scientific literacy because foundational competencies formed in primary education strongly predict later achievement and lifelong engagement with science (Bybee et al., 2015; OECD, 2019). Comparative evidence shows that several

countries in East Asia, such as China, Singapore, Japan, and Korea, have demonstrated consistently high or improving performance in science literacy, largely due to coherent curriculum frameworks, strong teacher professional development systems, and sustained emphasis on inquiry, problem-solving, and application of knowledge in real-world (OECD, 2023; Schleicher, 2019). Even countries such as Thailand have shown gradual improvement through targeted reforms in curriculum alignment and teacher capacity building (OECD, 2023).

Challenges in teaching science in Indonesian elementary schools include gaps in teachers' pedagogical competencies in facilitating inquiry and argumentation (Nida et al., 2020), limitations in assessments that truly capture the construction of scientific reasoning rather than content memorization (Wong et al., 2023), as well as limitations in resources and school ecosystem support (Rachmatullah et al., 2020).

Recent literature highlights that an unclear definition/framework of science literacy in the curriculum leads to classroom practices that tend to be "content-centric" and lack space for scientific and citizenship practices; Conversely, when the curriculum emphasizes practice and citizenship contexts, schools tend to adopt more authentic tasks and performance assessments that are more valid for science literacy (Norambuena-Meléndez et al., 2023).

In the Indonesian context, the urgency of strengthening science literacy is reinforced by PISA 2022 results, which indicate relatively low proficiency levels and persistent disparities among student groups (OECD, 2024). These outcomes can be attributed to systemic factors, including inconsistent curriculum implementation, limited emphasis on HOTS, unequal distribution of qualified teachers, and insufficient alignment between instructional practices and assessment systems (OECD, 2023; World Bank, 2020). Compared to higher-performing systems, where instructional coherence, teacher expertise, and assessment alignment are well established, these gaps highlight the need for more integrated reforms in Indonesia.

This implies the need for policies targeting three key areas (Osborne & Allchin, 2024):

- (1) practice-based teacher professional development (e.g., lesson study and coaching) focusing on inquiry, argumentation, and SSI,
- (2) improvement of assessment systems to evaluate scientific practices, evidence-based reasoning, and contextual problem solving, and
- (3) provision of locally relevant yet scientifically grounded teaching materials and authentic tasks.

Such directions align with global evidence positioning "critical engagement" as the core objective of

21st century science literacy, emphasizing not only knowledge acquisition but also the ability to apply, evaluate, and communicate scientific understanding in complex real-world contexts.

There is a need for evidence-based mapping of the science literacy profile of Indonesian elementary school students that not only captures content mastery, but also the dimensions of scientific practice, evidence-based reasoning, and civic orientation. International studies on science in elementary schools show that there are still limited instruments and surveys that capture the full spectrum of science literacy at an early age, as well as the dominance of studies in developed countries, which opens up opportunities for empirical contributions from Indonesia. A survey designed with the latest science literacy constructs will provide a stronger basis for curriculum intervention, teacher development, and education policy.

In addition, emerging evidence from national and international assessments suggests that regional variations in Indonesia are not always linear, with some findings indicating unexpected contributions from Eastern Indonesia in specific domains of science literacy performance (OECD, 2023; World Bank, 2020). These patterns may be associated with contextual factors such as stronger community-based learning practices, contextualized use of local environmental knowledge, and adaptive teaching strategies in resource-constrained settings, which can support meaningful engagement with scientific concepts despite infrastructural limitations (Shehu et al., 2025). However, such findings remain underexplored and require systematic empirical verification to understand whether these contributions reflect consistent patterns or context-specific anomalies.

Therefore, this study aims to present a science literacy survey of elementary school students in Indonesia to

- (1) map the level of science literacy,
- (2) identify background factors such as socio-demographics, school resources, teaching practices, and exposure to inquiry-argumentation activities that correlate with achievement, and
- (3) formulate educational policy implications in the context of Indonesian elementary school students.

By incorporating regional analysis, including insights from Eastern Indonesia, this study seeks to generate a more nuanced understanding of science literacy distribution and its underlying determinants. Thus, this study is expected to fill the national evidence gap and contribute to the global discourse on how education systems, particularly at the elementary level, can effectively foster science literacy relevant to 21st century challenges.

Table 1. Research instrument framework for science literacy

No	Aspect	Indicator	Question no
1	Explaining phenomena scientifically	Understanding basic science concepts, connecting phenomena with scientific principles	1, 2
2	Evaluating investigations and designing scientific	Determine simple tools and experimental steps, design an investigation	3, 4
3	Interpreting data and evidence scientifically	Reading graphs/ tables, identifying patterns, drawing conclusions	5, 6
4	Applying science in daily life	Relating science to daily activities, explaining contextual phenomena	7, 8
5	Demonstrating a scientific attitude	Demonstrating curiosity, openness to new ideas, and honesty in investigation	9, 10

METHODOLOGY

Research Design

This study uses a quantitative approach with a descriptive survey method. This design was chosen because it allows researchers to obtain a systematic, factual, and accurate picture of the level of science literacy among elementary school students in Indonesia. The survey method is considered appropriate for mapping literacy skills on a large scale and identifying disparities between regions (Creswell & Creswell, 2021).

Population and Sample

The study population consisted of all grade IV to grade VI students in public and private elementary schools in Indonesia. The sampling technique used stratified random sampling with strata based on region and school status (public and private) with A accreditation. The stratified random sampling technique was used because it can increase the representativeness of the sample by considering the differences in characteristics between strata, so that the survey results are more accurate and can be generalized (Etikan & Bala, 2017). The regional stratification in this study followed the commonly used classification of Western, Central, and Eastern Indonesia. Western Indonesia, such as Sumatra and Java, represents the largest concentration of elementary schools; Central Indonesia, including Kalimantan and Sulawesi, represents a moderate proportion; while Eastern Indonesia, including Nusa Tenggara, Maluku, and Papua, comprises a smaller yet geographically dispersed distribution of schools (Ministry of Education, Culture, Research, and Technology, 2023). The sample was proportionally drawn from these three regions to ensure balanced representation, reflecting the national distribution of schools across regions.

The sample size analyzed was 600 students, consisting of 120 students from each of five regions. Each region included five schools, with approximately 20-25 students selected per school. The study employed a stratified multistage random sampling technique to ensure adequate representation across geographic and

institutional characteristics. In the first stage, Indonesia was stratified into five regions based on geographical distribution. In the second stage, schools within each region were categorized by status (public and private) and accreditation level (A-accredited), from which schools were randomly selected proportionally. In the third stage, within each selected school, students from grade IV-grade VI were randomly sampled using class lists to ensure equal opportunity of selection. This multistage approach was designed to reduce sampling bias while maintaining feasibility in large-scale educational research (Creswell & Creswell, 2021). Inclusion criteria comprised:

- (1) students in grade IV-grade VI who had participated in formal science instruction,
- (2) schools with access to internet connectivity and basic ICT infrastructure to support the administration of the assessment, and
- (3) students who had prior exposure to digital devices in the learning process.

These criteria were applied to ensure that participants could meaningfully engage with the assessment instruments and that data collection procedures were implemented consistently across sites.

Research Instrument

This instrument was developed based on the science literacy framework of OECD (2024) and adapted to the context of elementary school science learning in Indonesia. The instrument takes the form of an objective multiple-choice test with four answer options, as well as several context-based assessment items to ensure relevance to students' real lives. The instrument is in the form of an objective multiple-choice test with four answer options, consisting of 10 questions, designed to comprehensively measure various aspects of students' science literacy. The outline of the science literacy research instrument is presented in [Table 1](#).

Each item is scored dichotomously (1 = correct, 0 = incorrect), with a raw maximum score of 10, which is then converted to a standardized 0-100 scale for interpretation. Student science literacy levels are categorized as follows: very low (0-20), low (21-40),

Table 2. Validity of science literacy

Item number	INFIT MNSQ	Description
Item 1	0.97	Fit
Item 2	0.95	Fit
Item 3	0.80	Fit
Item 4	0.82	Fit
Item 5	0.85	Fit
Item 6	0.87	Fit
Item 7	0.91	Fit
Item 8	0.98	Fit
Item 9	0.96	Fit
Item 10	0.83	Fit

moderate (41-60), high (61-80), and very high (81-100), following commonly used educational assessment benchmarks (Nitko & Brookhart, 2014).

The content validity of the instrument was evaluated by three experts in science education and assessment, who reviewed the alignment between items, indicators, and the science literacy framework. Prior to the main study, the instrument was pilot-tested on 30 students outside the research sample to examine item clarity and administration procedures.

Further analyses of construct validity and reliability were conducted using item response theory (IRT)/Rasch modeling and internal consistency measures. The detailed results of these analyses are presented in the results section.

Data Collection Procedures

Data collection was conducted in several stages to ensure the validity and reliability of the research results. The first stage involved obtaining permission and coordinating with the local education office and participating schools.

Prior to the main study, the instrument was pilot-tested on 30 students outside the research sample. Although relatively small, this pilot size is considered adequate for preliminary testing aimed at evaluating item clarity, administration procedures, and initial reliability, rather than for statistical generalization (Hertzog, 2008; Johanson & Brooks, 2010). The pilot test was used to identify ambiguous items, estimate item difficulty, and refine the instrument before large-scale implementation.

Next, the main data collection was conducted through a science literacy test administered face-to-face in the classroom, under the supervision of both the researcher and the classroom teacher to minimize administrative bias. Students were given 35 minutes to complete all questions.

The test duration was determined based on the number and cognitive load of the items (10 items with contextual and reasoning components), as well as pilot findings indicating that most students were able to complete the test within the allocated time. In addition,

shorter testing durations are commonly recommended for elementary-level assessments to maintain students' attention and reduce fatigue, which may otherwise affect response quality (Mullis & Martin, 2017; OECD, 2023).

As supporting data, brief interviews were conducted with teachers and principals regarding science learning practices and school facility conditions. Documentation in the form of observation notes was also collected to strengthen data triangulation.

Data Analysis Techniques

Data were analyzed using SPSS software version 22 through several stages, namely descriptive analysis, one-way analysis of variance (ANOVA), and post-hoc (LSD) test. Descriptive analysis consisted of calculating the mean, standard deviation, and percentage distribution to describe the students' science literacy levels on each indicator. Inferential analysis with normality and homogeneity tests as prerequisites, then continued with one-way ANOVA to test differences in science literacy levels between regions. If significant differences were found, it was followed by an LSD test to identify specific groups that were different.

RESULTS

This study uses a descriptive quantitative approach with a survey method. The research sample involved 600 students in grade IV to grade VI who were selected using stratified random sampling. The instrument used to measure science literacy consisted of 10 multiple-choice questions referring to the OECD (2024) indicators covering the ability to explain scientific phenomena, design and evaluate experiments, and interpret scientific data.

Validity and Reliability of the Instrument

The validity of the science literacy test instrument was tested to ensure that the questions actually measured the intended construct. Validity analysis was performed using Quest software, which is based on IRT/Rasch model (Adams & Khoo, 1996). This analysis was conducted to test the extent to which the items were able to represent the science literacy construct being measured. Reliability testing was conducted to assess the internal consistency of the instrument. The results of the science literacy validity are presented in **Table 2**.

The analysis results show that all items have fit statistics within an acceptable range with Infit MNSQ 0.77-1.30. This indicates that the items function consistently in measuring the science literacy abilities of elementary school students. Several items that are outside the range show inconsistencies, so they need to be revised or eliminated in the next stage of instrument development. The reliability of the test was obtained from the person and item reliability indices generated by Quest.

Table 3. Summary of science literacy scores by region

Region	Average score	Category
A	57.33	Moderate
B	52.75	Moderate
C	53.92	Moderate
D	50.58	Moderate
E	49.58	Low

The person reliability value indicates the consistency of respondents' ability to answer questions, while item reliability indicates the accuracy of questions in measuring the same construct. In this study, person reliability was in the high category (0.83), while item reliability showed excellent consistency (0.90). These values confirm that the instrument has an adequate level of internal stability for use in science literacy surveys.

Student Science Literacy Scores

Descriptive analysis shows that the average science literacy scores of elementary school students in Indonesia range from 49.58 to 57.33, with relatively small variations between regions. The highest score was obtained by students in region A (57.33) and the lowest in region E (49.58). In general, this achievement is in the lower-middle category, which indicates that students' science literacy has not reached an optimal level. The distribution by region shows the variation in achievement presented in **Table 3**.

Distribution of Science Literacy Categories

The distribution per indicator shows the variation in science literacy achievement presented in **Table 4**.

The category classification is based on the scoring rubric described in the methodology section, adapted from international assessment frameworks such as PISA (OECD) and educational assessment standards (Nitko & Brookhart, 2014).

Prerequisite Tests for Analysis

Normality test

The Kolmogorov-Smirnov test results indicate that the distribution of science literacy scores is normal. This is evidenced by the asymptotic significance (2-tailed) value being greater than or equal to 0.05 for all groups. This meets the prerequisite for further parametric analysis (**Table 5**).

Table 5. Results of normality test of science literacy scores by region

Region	Asymptotic significance (2-tailed)	Conclusion
A	$0.057 \geq \alpha (0.05)$	Normal
B	$0.070 \geq \alpha (0.05)$	Normal
C	$0.300 \geq \alpha (0.05)$	Normal
D	$0.070 \geq \alpha (0.05)$	Normal
E	$0.450 \geq \alpha (0.05)$	Normal

Table 6. One-way ANOVA test results

	SS	df	MS	F	Sig.
Between group	4,446.667	4	1111.667	2.099	0.080
Within groups	315,136.667	595	529.641		
Total	319,583.333	599			

Note. SS: Sum of squares & MS: Mean square

Homogeneity test

Levene's test shows that the variance of science literacy scores among the five groups is homogeneous. This is evidenced by a significance value of 0.119, which is greater than 0.05. This homogeneity of variance is an important prerequisite for performing an ANOVA test.

One-Way ANOVA Test

The results of the one-way ANOVA test to determine the difference in the mean science literacy scores between regions are presented in **Table 6**.

Based on **Table 6**, the significance value obtained is 0.080, which is greater than 0.05, indicating that there is no statistically significant difference in the average science literacy scores of elementary school students across the five regions. Therefore, further LSD analysis was not conducted.

This finding suggests that students' science literacy levels tend to be relatively homogeneous across regions, despite differences in geographical and educational contexts. Considering that the sample was selected using a stratified multistage random sampling technique, which ensured proportional representation across regions, school types, and institutional characteristics, the absence of significant differences may reflect broader systemic patterns rather than sampling bias (Creswell & Creswell, 2021).

From a substantive perspective, this result may indicate that challenges in science literacy are not region-specific but systemic, including curriculum implementation, instructional practices, and assessment alignment that are relatively uniform across regions

Table 4. Summary of science literacy scores per indicator

Indicator	Average score	Category
Explaining phenomena scientifically	59.50	Moderate (41-60)
Evaluating and designing scientific investigations	45.10	Moderate (41-60)
Interpreting data and evidence scientifically	44.12	Low (21-40)
Applying science in everyday life	40.28	Low (21-40)
Demonstrating a scientific attitude	56.38	Moderate (41-60)

(OECD, 2023; World Bank, 2020). This aligns with previous findings showing that countries with centralized or standardized education systems often exhibit limited regional variation but similar overall performance constraints (Schleicher, 2019).

Furthermore, the lack of significant differences does not necessarily imply equity in educational quality but may instead reflect a uniformly moderate level of achievement, as indicated by the descriptive results. This highlights the need for nationwide interventions focusing on strengthening inquiry-based learning, scientific reasoning, and contextual application of knowledge, rather than region-specific policies alone (Bybee et al., 2015).

These findings are discussed further in the Discussion section to explore their implications for instructional design and education policy in Indonesia.

DISCUSSION

The results of the study show that the science literacy levels of elementary school students in five regions of Indonesia are still in the moderate category, with an average score of 49.58-57.33. The variation between regions is relatively small, indicating that science literacy is not yet a competency that is evenly distributed among students in various regions. These findings are in line with the 2022 PISA report, which places Indonesia far below the OECD average in the domain of science (OECD, 2023). Indonesia's scores in science are not only lower than those of developed countries, but also lag behind several ASEAN countries such as Singapore, Vietnam, and Malaysia. This fact indicates that there are systemic problems in science education at the elementary level.

Further interpretation shows that students' highest achievement is in the indicator of explaining scientific phenomena, indicating that most students are able to relate simple phenomena to basic scientific concepts. For example, students can explain why water boils at a certain temperature or why shadows are formed. However, when they are faced with tasks that require designing experiments, interpreting data, or relating science to real-life contexts, their performance declines markedly. These results are consistent with the study by Osborne (2023), which emphasizes that conceptual understanding alone is insufficient to develop science literacy; investigative, argumentative, and contextual competencies are equally essential. More importantly, these findings indicate that students' scientific reasoning skills remain relatively weak, particularly in tasks requiring evidence evaluation, inference-making, and the justification of claims. This suggests that students are not yet adequately equipped to engage in higher-order scientific thinking, which is a core component of science literacy in contemporary frameworks (OECD, 2023).

Pedagogically, these results reflect the tendency of science learning in Indonesian elementary schools to remain oriented toward the transmission of information rather than the development of scientific practices. This aligns with previous findings indicating that instruction emphasizing memorization tends to produce students who understand factual knowledge but struggle to apply it in evidence-based reasoning and decision-making contexts (Bybee et al., 2015). In other words, Indonesian students appear to remain at the level of conceptual acquisition and have not yet reached the stage of "science for citizenship" as emphasized by Queiruga-Dios et al. (2020).

In addition, the findings presented in **Table 6**, which show no statistically significant differences in science literacy across regions, reinforce the interpretation that these challenges are systemic rather than region-specific. The relatively uniform performance across regions suggests that limitations in reasoning and inquiry skills are consistently experienced by students, regardless of geographical context.

To address these issues, several strategic interventions are recommended. First, instructional practices should shift toward inquiry-based and problem-based learning, which actively engage students in designing investigations and evaluating evidence (Songsil et al., 2019). Second, argumentation-based instruction should be integrated into science classrooms to strengthen students' ability to construct and justify claims using evidence Osborne (2023). Third, assessment practices need to be redesigned to emphasize HOTS and real-world application, rather than factual recall alone (OECD, 2019). Finally, sustained teacher professional development is essential to support the implementation of these approaches in classroom practice (Schleicher, 2019). These efforts are critical to moving students beyond basic conceptual understanding toward more advanced levels of science literacy that enable critical engagement, reasoning, and informed decision-making in everyday life.

From a child development perspective, this achievement also shows a disconnect between science learning experiences at school and students' real lives. Vygotsky (1978) emphasizes the importance of the zone of proximal development, where learning must be relevant to the child's socio-cultural context. However, practices in Indonesia often present science in an abstract manner, separated from local realities, making it difficult for students to connect science with their daily experiences. This condition becomes even more apparent when compared to practices in other countries. It was shown that the integration of technology-based learning and contextual reflection can significantly improve student inquiry performance. Conversely, the lack of access to technology and contextual teaching materials in Indonesia makes science learning tend to be monotonous. The results of this survey can be

interpreted as evidence that the Indonesian basic education system still needs to undergo a major transformation to bridge the gap between content mastery and scientific skills.

The main interpretation of the survey results is that the science literacy of Indonesian elementary school students is still at a basic to intermediate level, with relatively even achievements across regions, indicating that this is a national issue, and that investigative and contextual competencies lag far behind conceptual mastery. This is an important wake-up call for the formulation of science education policies that place greater emphasis on HOTS. An important finding in this study is the significant gap between the dimensions of science literacy. The relatively high score on the indicator of explaining scientific phenomena (59.50) shows the success of learning in instilling basic conceptual knowledge. However, low scores on the dimensions of evaluating and designing scientific investigations (45.10), interpreting scientific data and evidence (44.12), and applying science in everyday life (40.28) indicate weak, more complex scientific skills. This gap illustrates a phenomenon called the science of vs. science for (Osborne & Allchin, 2024). "Science of" refers to understanding scientific content, while "science for" refers to the ability to use science in decision-making and civic practices. Science education in Indonesia still leans toward "science of," so students can remember facts but have difficulty using them to analyze real-world problems.

The phenomenon of low science literacy can also be analyzed using the HOTS framework. According to Bloom's taxonomy revised by Anderson and Krathwohl (2001), the ability to explain phenomena is generally at the comprehension level, while designing investigations, interpreting data, and applying science are included in the analyzing, evaluating, and creating levels. Low scores in this dimension indicate that learning in Indonesian elementary schools still predominantly operates at the lower levels of Bloom's taxonomy. This is consistent with the findings of Arrafii (2021) that teachers in Indonesia give more memorization exercises than investigative experiences. Furthermore, weak investigative skills are also caused by limited opportunities for students to conduct direct scientific practices. Maisyaroh et al. (2024) found that many elementary schools in Indonesia do not have adequate science laboratories, even in big cities. Teachers also often avoid simple experiments due to time constraints, costs, and a lack of confidence in managing inquiry (Maeng et al., 2020). Ozkan and Umdü (2021) show that investigative skills develop optimally through direct experience, not just teacher explanations.

The competency gap is also evident in the dimension of interpreting data. Students' low scores in reading graphs, tables, and data patterns indicate that basic education in Indonesia pays little attention to data

literacy. This is dangerous considering that the 21st century is characterized by a flood of information, where critical skills in interpreting data are key competencies for preventing misinformation (Dame, 2022). Fielding (2025) even emphasizes that data-based argumentation skills must be instilled early on so that students can become critical consumers of information. Meanwhile, the dimension of applying science in daily life, which also received a low score, indicates a disconnect between school science and students' real lives. This is consistent with the research by Kumar et al. (2024) which emphasizes the importance of SSIs to bridge science with social, environmental, and ethical contexts. Unfortunately, science education in Indonesian elementary schools rarely integrates SSI. Teachers are more focused on completing the curriculum than discussing local issues such as environmental pollution, energy use, or public health.

When analyzed from a curriculum perspective, this gap is also related to the weak integration of scientific practices in the national curriculum. Valladares (2021) comparative curriculum analysis shows that curricula that emphasize scientific practices and civic contexts are able to encourage more valid authentic tasks to measure science literacy. In Indonesia, although the independent curriculum emphasizes project-based learning, its implementation in the field is still limited. This gap analysis confirms that the science literacy of Indonesian elementary school students still leans toward one aspect, with relatively good conceptual mastery, but very weak scientific, argumentative, and applicative skills. This poses a serious challenge for the education system, because true science literacy requires a balance between content, practice, and context.

Science literacy among elementary school students in Indonesia is influenced not only by direct interaction with the curriculum, but also by contextual factors such as teacher competence, assessment systems, resource availability, digital ecology, and learning culture. Analysis of interviews and observations in this study shows that teacher pedagogical competence remains the main determinant, with a tendency to emphasize content delivery over inquiry facilitation. Teachers' limitations in integrating SSIs, low confidence in managing experiments, and minimal practical experience also explain students' weak achievements in investigative and applicative aspects. Assessment factors also contribute, as the evaluation system in Indonesia emphasizes memorization through multiple-choice tests, leaving no room for the development of data interpretation or investigation design skills. In addition, limited laboratory facilities, resource gaps between regions, and unequal digital access widen the science literacy gap between students. In the digital age, the inability to distinguish credible information from misinformation adds a new challenge. This condition is exacerbated by a learning culture that is oriented

towards exams and memorization, which limits students' opportunities to ask questions, discuss, and think critically.

Science literacy is not formed from a single interaction between students and the curriculum, but is influenced by contextual factors such as teacher competence, assessment, resource availability, digital ecology, and learning culture (Guo et al., 2022). Analysis of these factors is important to understand why the science literacy achievements of elementary school students in Indonesia are still moderate and uneven. Teacher pedagogical competence is a dominant factor, where student achievement is relatively high in the ability to explain phenomena, but weak in investigative and applicative aspects. This shows that teachers still tend to focus on content delivery rather than facilitating inquiry. Another obstacle is teachers' lack of confidence in managing simple experiments, which is also due to their lack of practical experience and facility support (Fischetti et al., 2022), unlike countries such as Finland, which emphasize scientific practice in teacher education. In addition, assessments in Indonesia that are too content-oriented are a significant obstacle. Multiple-choice-based evaluation systems measure memorization rather than scientific skills, so students have minimal opportunity to practice data interpretation and investigation (OECD, 2023). In fact, project-based assessments have been proven to be more effective in building science literacy (Krajcik et al., 2023). Limited resources and facilities also exacerbate the situation; many schools lack laboratories or even basic materials for experiments, even though hands-on experience is central to science learning (Darling-Hammond et al., 2020).

The digital divide is widening the gap in achievement between urban and rural schools. In the digital age, science literacy requires the ability to distinguish credible information from mis/disinformation (Herman et al., 2024). However, this survey shows that Indonesian elementary school students are still weak in interpreting data and evidence. Cultural factors also contribute to the problem, as an orientation towards test scores makes teachers focus more on memorization than on scientific thinking processes. Thus, science literacy in Indonesia is influenced by an ecosystem that is not yet conducive. Learning reform must shift from a content orientation to meaningful inquiry (Al Mamun & Lawrie, 2023), integration of SSIs (Kumar et al., 2024), a collaborative STEAM approach (Winarni et al., 2024), authentic assessment that encourages critical engagement (Wen et al., 2020), and integration of technology even with simple devices (Barton & Dexter, 2020). The implication is that teachers need to change their role from content deliverers to scientific learning facilitators, with the support of continuous professional development through learning communities. At the policy level, there is a need for reform of the science curriculum based on

scientific practice that is in line with international standards such as the next generation science standards (Lowell et al., 2021) and the development of contextual teaching materials that are relevant to local life (Chankseliani et al., 2021). Support from the educational ecosystem in the form of simple laboratories, digital access, and cross sector collaboration is also very important (Bowser et al., 2024).

From a global perspective, high-achieving countries such as Finland, Singapore, and Japan consistently emphasize the integration of concepts, practices, and context with adequate facility support (Tonga et al., 2022). Meanwhile, developing countries such as Vietnam and Chile have succeeded in improving science literacy through contextual strategies based on simple experiments and community projects (Bórquez-Sánchez, 2025; Son et al., 2024). The lesson for Indonesia is the importance of policy consistency, contextual learning, and improving teacher competence as determining factors. This is in line with the idea of Taragin-Zeller et al. (2022) that 21st century science literacy requires citizens to be "competent outsiders" in assessing and using scientific information. Socio-culturally, Indonesia faces challenges of passive learning culture, digital divide, and low family support. However, the wealth of local wisdom and relevant SSIs can be opportunities to strengthen contextual science literacy. With the right intervention strategies, curriculum reform, teacher development, authentic assessment, technology integration, and cross-sector collaboration, Indonesia has the opportunity to accelerate the improvement of science literacy while making a significant contribution to the global discourse that is still dominated by studies from developed countries.

Overall, this discussion has outlined the results of research on Indonesian elementary school students' science literacy from various perspectives, namely interpretation of achievements, competency gaps, contextual factors, learning implications, policy directions, international comparisons, socio-cultural contexts, and global research agendas. The main findings show that students are relatively strong in understanding basic concepts but weak in investigative, interpretive, and applicative skills. Contextual factors such as teacher competence, content-centered assessment, facility limitations, the digital divide, and learning culture reinforce these weaknesses. The practical implications are the need for inquiry based pedagogical transformation, integration of SSI and STEAM, authentic assessment, and continuous teacher training. From a policy perspective, curriculum reform, strengthening the education ecosystem, and cross-sector collaboration are key. From an international perspective, Indonesia can learn from the good practices of other countries, while also contributing its unique experience as a developing country. Finally, this study emphasizes the importance of science literacy as a foundation for 21st

century citizens. Efforts to strengthen science literacy in Indonesia are not only about improving PISA scores but also a long-term investment in creating a society capable of critical thinking, evidence-based argumentation, and active participation in addressing global challenges.

CONCLUSION

This study shows that elementary students' science literacy within the sampled regions is at a moderate level, with strengths in conceptual understanding but persistent weaknesses in inquiry, data interpretation, and real-world application. These findings, derived from structured assessment data, should be interpreted within the scope of the sample and instrument.

Importantly, the results reveal that science literacy challenges are systemic rather than region-specific and are associated with both instructional factors and students' limited engagement in higher-order cognitive processes. This indicates a continued emphasis on knowledge recall over reasoning and application.

From a beyond assessment perspective, this study demonstrates that measuring literacy alone is insufficient; understanding domain-specific gaps and their instructional roots is essential.

These findings align with contemporary science literacy frameworks, particularly the PISA framework developed by OECD, which conceptualizes science literacy as the integration of knowledge, scientific practices, and the capacity to engage with SSIs in real-world contexts.

The study contributes to a context-sensitive and domain-based profile of science literacy, offering a more nuanced basis for intervention. To address these gaps, this study recommends strengthening inquiry-based and socio-scientific learning, aligning assessment with HOTS, and enhancing practice-based teacher development. Future research should extend this approach through longitudinal and mixed-methods designs to capture students' reasoning processes more comprehensively.

Author contributions: WSH: conceptualization, data curation, formal analysis, investigation, methodology, supervision, and writing—original draft; ASP: data curation, investigation, validation, visualization, and writing—review & editing; & SAK: formal analysis, methodology, project administration, validation, and writing—review & editing. All authors agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Acknowledgments: The authors would like to thank the Yogyakarta State University for its financial support through the group research program.

Ethical statement: This study was conducted in accordance with established ethical standards for educational research involving human participants. Prior to data collection, permission was obtained from the relevant educational authorities and participating schools. Informed consent was secured from parents or legal guardians, and participation was voluntary. The confidentiality and anonymity of all participants were maintained throughout the study, and the collected data were used solely for

research purposes. The authors declare that this research was conducted with integrity and in compliance with applicable ethical guidelines.

AI statement: The authors used generative AI tools solely to support language editing, grammar refinement, and improvement of manuscript readability. All scientific content, research design, data collection, data analysis, interpretation of findings, and conclusions were developed and verified by the authors. The authors take full responsibility for the accuracy, integrity, and originality of the work presented in this manuscript.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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