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Analysis of Scientific Literacy among Fifth-Grade Students in the Context of Ecological Citizenship

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Abstract
This study aimed to analyze the scientific literacy of fifth-grade students at SDN Airlangga I/198 Surabaya within the framework of ecological citizenship, operationalized through four dimensions; (1) ecological foundations, (2) conceptual awareness, (3) investigation and evaluation, and (4) action skills. A mixed-methods descriptive design was conducted involving 30 fifth-grade students through purposive sampling. Data were collected using a validated 10-item multiple-choice scientific literacy test aligned with three PISA indicators; explaining phenomena scientifically (SL1), evaluating and designing scientific enquiry (SL2), and interpreting data and evidence scientifically (SL3). The qualitative data gathered through classroom observations and semi-structured interviews. Data were analyzed using descriptive statistics for the test results and thematic analysis for observational and interview data. The results showed a moderate overall mean score (52.3%), with SL1 and SL3 also categorized as moderate (56.7% and 57.5%, respectively), while SL2 was notably low (41.0%). These findings indicate that students performed better in explaining scientific phenomena and interpreting data, while inquiry-related skills remained limited. Observations and interviews also revealed that students had basic conceptual understanding but still lacked analytical and inquiry skills. This study provides a foundational assessment linking scientific literacy and ecological citizenship at the elementary level in Indonesia, addressing a gap in existing research.

Keywords: scientific literacy, ecological citizenship, science, elementary school

Introduction

Scientific literacy has become one of the most crucial competencies in the 21st century, especially for students in elementary school who are building their foundational understanding of the natural world (Kholili et al., 2022). Scientific literacy refers to the ability to apply scientific knowledge, reasoning, and inquiry skills to understand phenomena, solve problems, and make decisions based on evidence (Murti et al., 2024). In the context of sustainable development, scientific literacy extends beyond understanding scientific facts, it encompasses awareness of environmental issues, attitudes toward sustainability, and a sense of ecological responsibility (Baptista et al., 2025). This broader perspective aligns closely with the concept of ecological citizenship, which emphasizes the moral and civic responsibility of individuals to protect and sustain the environment for future generations (Harefa, 2023). For young learners, developing scientific literacy within an ecological citizenship orientation is essential to foster not only academic competence but also sustainable habits and environmental awareness from an early age (Nugraha et al., 2022).

However, data from the Programme for International Student Assessment (PISA) consistently reveal that Indonesia faces serious challenges in achieving adequate levels of scientific literacy. According to the PISA 2022 report, Indonesia's average science score was 383, significantly below the OECD average of 485 (OECD, 2023). This gap has persisted for more than a decade, with minimal improvement since the 2000s. The PISA data also highlight that only about 1% of Indonesian students reached the highest levels of science proficiency (Level 5 or 6), while more than 60% remained below Level 2, meaning they struggle to apply scientific reasoning in unfamiliar contexts. These results indicate that Indonesian students generally possess limited capacity to interpret data, analyze cause-and-effect relationships, and use evidence to justify conclusions—skills that are central to scientific literacy (Ramadhan et al., 2025).

At the primary level, this situation is particularly concerning because elementary school is the stage where curiosity, observation, and inquiry should be nurtured through hands-on experiences (Kurniawati, 2024). Yet, science learning in Indonesian elementary schools often remains textbook-centered and procedural, with limited opportunities for experimentation and reflection (Altun, 2023). Teachers tend to prioritize the delivery of factual content rather than developing students' reasoning and problem-solving abilities. Consequently, students may memorize concepts without understanding their relevance to real-life phenomena. Such instructional practices hinder the growth of ecological awareness and critical thinking, which are foundational to becoming scientifically literate citizens (Ricoy, 2022).

The low level of scientific literacy reflected in PISA is not merely an academic concern but also an indicator of broader societal challenges. In the era of climate change and environmental degradation, the inability to interpret scientific information critically can lead to misinformation, poor environmental decision-making, and lack of civic engagement (Arviani & Aria, 2025). This underscores the need to embed ecological citizenship within science education, as scientific literacy and ecological responsibility are deeply intertwined competencies for navigating contemporary environmental challenges (Monte & Reis, 2021). When students are guided to connect science learning with environmental issues, they are more likely to develop empathy for nature and a sense of stewardship for the planet. Therefore, fostering scientific literacy through the lens of ecological citizenship is both an educational and moral imperative for sustainable development (Pisa & Biasutti, 2022).

Ecological citizenship refers to the responsibility of individuals to minimize their ecological footprint, engage in sustainable practices, and actively participate in the protection of the environment (Dobson, 2003). Unlike conventional citizenship, which is bounded by national borders and reciprocal rights, ecological citizenship extends obligations across space and time, recognizing that human activities have consequences for both present and future generations and for non-human life. In the context of elementary education, ecological citizenship calls for nurturing students who not only understand environmental phenomena but also feel personally responsible for, and capable of contributing to, environmental sustainability from an early age (Hadjichambis & Reis, 2020).

For the purposes of this study, ecological citizenship is operationalized through four dimensions adapted from Karatekin & Uysal (2018): (1) ecological foundations: basic understanding of ecological systems and envirnmental phenomena (2) conceptual awareness: the ability to recognize, describe, and explain environmental issues using scientific concepts (3) investigation and evaluation: the capacity to design, evaluate, and interpret scientific enquiry related to environmental problems and (4) action skills: the disposition and competence to engage in responsible, evidence-based pro-environmental decision-making and participation. These four dimensions are directly aligned with the three PISA scientific literacy indicators used in this study: ecological foundations and conceptual awareness correspond to SL1 (explaining phenomena scientifically); investigation and evaluation maps onto SL2 (evaluating and designing scientific enquiry); and action skills action skills correspond to SL3 (interpreting data and evidence scientifically). Together, these dimensions informed the design of the test, observation protocol, and interview guide used in this study.

Nevertheless, empirical studies focusing on the baseline level of scientific literacy among Indonesian elementary students, especially within the ecological citizenship framework, remain limited. Previous research has mainly concentrated on media development or intervention programs, with few exploring students' initial competencies, perceptions, and contextual factors influencing their scientific literacy (Lesmi, 2022; Rahma et al., 2024). More critically, only a few studies have explicitly mapped PISA scientific literacy indicators onto the dimensions of ecological citizenship at the elementary school in Indonesia This gap is significant because understanding how each PISA indicator corresponds to specific ecological citizenship dimensions is essential for designing targeted instructional interventions that develop both scientific competency and environmental responsibility simultaneously.

As suggested by Muslimasari et al. (2025), preliminary studies are necessary to identify existing challenges, teaching practices, and students' cognitive readiness before developing instructional media or pedagogical interventions. Understanding this baseline is therefore essential as a foundation for designing effective learning innovations that are grounded in the real needs and conditions of schools (Yulianti et al., 2022). The results can guide curriculum development, teacher training, and educational innovation that align with both national and global sustainability agendas. Thus, this study aims to analyze the scientific literacy of fifth-grade students at SDN Airlangga I/198 Surabaya within the context of ecological citizenship.

Method

This study employed a mixed-methods descriptive design, integrating quantitative test data with qualitative observational and interview data. The quantitative strand served as the primary source of analysis, while the qualitative strand provided triangulation and contextual interpretation. This design was selected because the study aimed to establish a descriptive baseline of students' scientific literacy oriented toward ecological citizenship, without imposing any instructional treatment or experimental condition (Creswell & Creswell, 2023).

The participants consisted of 30 fifth-grade students (12 male, 18 female), aged 10–11 years, at SDN Airlangga I/198 Surabaya. Sampling was conducted using purposive sampling. SDN Airlangga I/198 Surabaya was selected because it has implemented environmentally oriented learning activities relevant to the context of ecological citizenship, making it a contextually appropriate site for examining the four EC dimensions. For the qualitative strand, six students were purposively selected to represent high, moderate, and low test performers (two per group), and the classroom teacher was also interviewed. Given the small, single-school sample, findings are interpreted as descriptive and exploratory, with limited generalizability beyond this context.

Data were collected using three instruments. First, a 10-item multiple-choice scientific literacy test distributed across three PISA indicators. All items were set in ecological contexts aligned with the four ecological citizenship dimensions as detailed in Table 1. The instrument was validated by two science education experts. Second, a structured observation sheet was used to document students' observable behaviors corresponding to each of the four ecological citizenship dimensions, with the researcher acting as a non-participant observer. Third, semi-structured interviews were conducted with each of the six selected students and the classroom teacher, covering topics including students' ability to explain environmental phenomena, experience with scientific investigation, data interpretation, and environmental attitudes.

Table 1. Scientific Literacy Test Outline and Ecological Citizenship Dimension Alignment

No.	Indicator	Ecological Citizenship Dimension	No. of Items
1	SL1 – Explain phenomena scientifically	(1) Ecological foundations: understanding ecological systems (2) Conceptual awarenes: describe environmental phenomena	4
2	SL2 – Evaluate and design scientific enquiry	(3) Investigation and evaluation: designing and assessing environmental investigations	3
3	SL3 – Interpret data and evidence scientifically	(4) Action skills: using evidence to inform environmental decisions and actions	3
Total	3 Indicators	4 EC Dimensions	**10**

Quantitative data were analyzed descriptively using measures of central tendency (mean, median), variability (standard deviation), and range (minimum, maximum). Student score distributions were tabulated across the three literacy categories (Low, Moderate, High) for each indicator and overall. Qualitative data from observations and interviews were analyzed thematically following the stages described by Braun & Clarke (2006): (1) familiarization with data, (2) generating initial codes, (3) developing themes, (4) reviewing themes, (5) defining and naming themes, and (6) writing up. Credibility was ensured through triangulation across three data sources (test, observation, interview) and member checking, in which three student participants were asked to review summary descriptions of their interview responses for accuracy. The classroom teacher also reviewed the thematic summary of teacher interview data to confirm its accuracy.

Results and Discussion

Scientific literacy was assessed across three PISA indicators: (1) Explain phenomena scientifically (SL1), (2) Evaluate and design scientific enquiry (SL2), and (3) Interpret data and evidence scientifically (SL3). These indicators were operationalized through the ecological citizenship dimensions described in Table 1. Table 2 presents the descriptive statistics of students' scientific literacy scores.

Table 2. Descriptive Statistics of Scientific Literacy Scores by Indicator

Indicator	M (%)	SD	Min	Max	Items	Category
SL1 – Explain phenomena scientifically	56.7	18.6	25	100	4	Moderate

Indicator	M (%)	SD	Min	Max	Items	Category
SL2 – Evaluate and design scientific enquiry	41.0	21.4	0	100	3	Low
SL3 – Interpret data and evidence scientifically	57.5	19.2	33	100	3	Moderate
Overall	**52.3**	**13.1**	**20**	**90**	**10**	**Moderate**

Table 2 presents the descriptive statistics for each PISA scientific literacy indicator and the overall score. The overall mean was 52.3% (SD = 13.1), categorized as Moderate based on the classification criteria: Low (<50%), Moderate (50%–74%), and High (≥75%). SL1 (explain phenomena scientifically) recorded a mean of 56.7% (SD = 18.6, range 25–100), and SL3 (interpret data and evidence scientifically) yielded 57.5% (SD = 19.2, range 33–100), both categorized as Moderate. In contrast, SL2 (evaluate and design scientific enquiry) produced the lowest mean of 41.0% (SD = 21.4, range 0–100), falling in the Low category. The relatively high standard deviation across all indicators suggests considerable variation in students' performance, reflecting differences in prior knowledge, reasoning ability, and exposure to inquiry-based learning. The contrast between SL1/SL3 (Moderate) and SL2 (Low) indicates that students are more capable of explaining and interpreting environmental phenomena than designing or critically evaluating scientific investigations.

Table 3. Distribution of Students Scientific Literacy per Indicator

Indicator	Low n	Low %	Mod n	Mod %	High n	High %	Overall Cat.
SL1	9	30.0	15	50.0	6	20.0	Moderate
SL2	22	73.3	7	23.3	1	3.3	Low
SL3	10	33.3	14	46.7	6	20.0	Moderate
Overall	**11**	**36.7**	**16**	**53.3**	**3**	**10.0**	**Moderate**

Table 3 shows the distribution of students scientific literacy per indicator. For SL1, 9 students (30.0%) were in the Low category, 15 (50.0%) in Moderate, and 6 (20.0%) in High, confirming a moderate overall performance in explaining phenomena scientifically. For SL2, the distribution was markedly skewed toward the low end: 22 students (73.3%) scored below 50%, 7 (23.3%) were Moderate, and only 1 (3.3%) reached the High category. This pattern confirms that the low SL2 mean was not driven by a few extreme scores but reflects a class-wide difficulty with scientific inquiry, a critical gap in the investigation and evaluation dimension of ecological citizenship. For SL3, 10 students (33.3%) were Low, 14 (46.7%) Moderate, and 6 (20.0%) High, indicating a slightly better but still uneven capacity to interpret data and evidence scientifically. At the overall level, 11 students (36.7%) were categorized as Low, 16 (53.3%) as Moderate, and only 3 (10.0%) as High, underscoring that the majority of students have not yet developed sufficient scientific literacy to fully engage with environmental issues as active ecological citizens.

The findings of this preliminary study provide an early depiction of fifth-grade students' scientific literacy at SDN Airlangga I/198. As shown in Table 1, the overall average was 52.3% which was categorized as "Moderate", suggests that students possess a moderate level of scientific literacy but still exhibit significant gaps across all three core indicators. From an ecological citizenship perspective, the moderate overall score (52.3%) suggests that while students are beginning to develop ecological foundations and conceptual awareness, their limited inquiry and evaluation skills (SL2 = 41%) indicate they are not yet equipped to fully participate as ecological citizens, specifically the investigation and evaluation and action skills dimensions are underdeveloped, meaning students can recognize ecological phenomena and explain them at a basic level but lack the reasoning tools to evaluate evidence, design investigations, or translate scientific understanding into responsible environmental action.

The first indicator, Explain phenomena scientifically (SL1), achieved 56.7%, categorized as "Moderate." This suggests that students have a reasonable grasp of basic scientific concepts and can provide simple explanations for everyday natural phenomena. During interviews, several students demonstrated the ability to articulate explanations about familiar topics. For example, one student explained, *"Rain comes from clouds that are full of water and then fall because they are heavy,"* which, although simplified, reflects an emerging conceptual understanding of precipitation (direct student response during interview). Classroom observations also indicated that students were quite confident answering direct questions from the teacher about science content. They actively participated when topics were concrete and commonly encountered in daily life.

However, despite this moderate performance, deeper examination shows that their ability to explain phenomena scientifically is often limited to surface-level reasoning. When students were asked to explain causal mechanisms, such as how greenhouse gases trap heat or why the absence of decomposers disrupts ecosystems—many struggled to provide scientifically accurate explanations. This pattern reveals that although memorization-based understanding exists, students often lack the underlying conceptual connections that characterize true scientific explanation. Misconceptions were also noted, such as the belief that *"plants only need water to survive without light,"* or that *"plastic waste will decompose if buried for a long time."* Such misconceptions highlight the need for more explicit instruction that emphasizes reasoning rather than fact recall (Hubbard & Hubbard, 2021).

The second indicator, Evaluate and design scientific enquiry (SL2), had 41%, categorized as "Low". This score reflects a broadly distributed pattern of underperformance: the majority of students (approximately 22 out of 30) scored below 50% on SL2 items, indicating that the low average was not driven by a few extreme scores but rather reflected a widespread difficulty across the class. This aligns with the results of many national studies, which show that Indonesian students frequently underperform on inquiry-related tasks (Ulumiyah & Pratama, 2025; Ramadhan et al., 2025). In the context of this study, students showed difficulty identifying variables, predicting outcomes, evaluating simple experimental designs, and judging whether a scientific procedure was valid or reliable. For instance, when presented with a question asking which setup would best test the effect of light on plant growth, several students chose options that varied multiple variables at once, indicating a lack of understanding about controlling variables.

Interviews reinforced these findings: most students reported that they rarely conducted experiments in class. Science lessons were described as *"mostly reading and answering questions,"* with a heavy emphasis on worksheets and textbook explanations rather than exploration or experimentation. During classroom observations, students showed enthusiasm when hands-on materials were mentioned, yet such opportunities were not frequently part of their routine learning experiences. This limited exposure to inquiry activities likely contributes to the low score in SL2. Without structured experiences in asking questions, testing ideas, or evaluating experimental setups, students naturally struggle to interpret the logic of scientific investigation.

Furthermore, the SL2 results indicate that students are not yet accustomed to thinking about the nature of scientific enquiry, such as why evidence matters or how bias can affect results. These cognitive skills require explicit modeling from teachers and opportunities to engage in activities where students generate questions, test assumptions, and evaluate findings (Baptista et al., 2025). Research in Indonesian elementary schools often shows similar trends: inquiry-based learning remains limited, especially in urban public schools where large class sizes and tight schedules constrain hands-on activities (Muslimasari et al., 2025). This highlights a structural issue in science education that affects not only conceptual knowledge but also the development of critical scientific habits of mind.

The third indicator, Interpret data and evidence scientifically (SL3), achieved 57.5%, categorized as "Moderate". Students showed moderate ability to read simple charts, identify patterns in data, and make basic interpretations. Several students could describe what a bar graph or table was showing but struggled to explain why the data showed that pattern. They could state *"data increased"* or *"data decreased,"* but interpreting relationships or drawing evidence-based conclusions was more challenging. In interview sessions, students often interpreted data descriptively rather than analytically. For example, when shown a table comparing water clarity before and after filtration, many students answered, *"the water after filtration is clearer,"* but could not explain which variable caused the change or what evidence from the table supported their conclusion. This suggests that students are able to recognize data patterns but not yet able to translate these patterns into scientific meaning. Classroom observations also revealed that activities involving data interpretation were rare. Most tasks focused on reading rather than analyzing information.

The triangulation of test results, observations, and interviews provides several insights into the students' overall scientific literacy profile. First, students are stronger in conceptual recall than in reasoning or analysis—an outcome consistent with national and international assessments, including Indonesia's persistent PISA performance trends . Many students were able to identify basic scientific concepts related to environmental phenomena, such as pollution sources or characteristics of living organisms, yet experienced difficulty when asked to explain underlying mechanisms or justify their answers using scientific reasoning. This pattern indicates that science learning remains predominantly content-oriented, with limited emphasis on analytical thinking and evidence-based explanation. As a result, students' scientific understanding tends to be fragmented and procedural rather than integrative and transferable.

Second, students' low exposure to scientific enquiry and data interpretation activities contributes significantly to their challenges in SL2. Observational data revealed that classroom activities rarely involved designing investigations, analyzing experimental results, or interpreting data presented in tables or graphs. Instead, learning was largely centered on textbook explanations and teacher-led discussions. This limited engagement with inquiry-based practices restricts students' opportunities to develop higher-order scientific skills, such as formulating investigable questions or evaluating the reliability of evidence. Consequently, students struggle to apply scientific knowledge beyond familiar contexts, particularly when confronted with problem-solving tasks that require reasoning and decision-making.

Third, although students demonstrate some awareness of environmental issues, their ability to link this awareness with scientific evidence remains limited. During interviews, students expressed concern about familiar environmental problems, one student said, *"plastic is dangerous because it cannot rot,"* yet when asked why this is harmful to soil ecosystems, the student could not provide a scientific explanation. This disconnect suggests that environmental awareness is developing at a surface level, not yet supported by scientific reasoning. This gap has important implications for ecological citizenship, which requires students not only to develop ecological foundations and conceptual awareness, but also to develop investigation and evaluation skills and action skills. Without this foundation, students may adopt superficially positive environmental attitudes without being able to critically evaluate environmental information or translate their awareness into informed, evidence-based environmental participation (Omodan & Mtshatsha, 2022).

Another important pattern emerging from the findings is that scientific literacy is not uniformly distributed across students. Observations showed that some students displayed strong curiosity during science discussions, asking follow-up questions about pollution or animal adaptations, while others appeared passive or hesitant to participate. This variation suggests differences in prior knowledge, confidence, and learning experiences among students. During the test, students with stronger reading comprehension skills tended to perform better, particularly in data interpretation tasks. This suggests that scientific literacy at this stage is influenced not only by science learning but also by literacy skills more broadly. Because science assessments often rely on students' ability to comprehend written texts, graphs, and instructions, students who struggle with reading may underperform in science even if they possess basic conceptual understanding (Pisa & Biasutti, 2022). Therefore, scientific literacy development in elementary school should be viewed as an integrated process that involves both science instruction and language literacy support.

From a pedagogical perspective, the findings highlight several important implications. First, improving scientific literacy requires more than increasing students' science knowledge; it requires opportunities to practice reasoning, inquiry, and evidence-based decision making. Teaching strategies such as guided inquiry, problem-based learning, and environmental field studies can help students engage more deeply with scientific concepts and develop scientific reasoning skills (Nurdiana et al., 2020; (Tyas et al., 2020). For instance, teachers can engage students in simple environmental observations around the school, such as identifying types of waste in the schoolyard, observing changes in plants near polluted versus clean areas, or comparing water sources in their neighborhood, and guide them to record findings, identify patterns, and draw conclusions. These approaches encourage students to actively construct knowledge rather than passively receive information, thereby strengthening their ability to explain phenomena and evaluate evidence.

Second, contextual learning that connects science to real environmental issues can improve students' ability to interpret data and evidence scientifically (SL3). When students analyze data derived from their own surroundings, such as waste produced in their school, water quality in nearby drainage systems, or plant growth under different conditions, scientific concepts become more meaningful and relevant. Specific school-based ecological citizenship projects can provide structured opportunities for students to practice all three PISA indicators in real ecological contexts. Such activities not only enhance data interpretation skills but also support the development of ecological citizenship by helping students understand how scientific evidence informs environmental responsibility and sustainable practices (Sadler et al., 2016).

Third, teachers require adequate support to design and implement inquiry-oriented science learning. Interviews with the classroom teacher indicated that while they recognize the importance of practical and inquiry-based activities, they face constraints related to limited resources, instructional time, and curriculum coverage demands. For example, the teacher noted that *"there is not enough time to do experiments because we have to finish the book before the exam,"* and that *"we don't have enough equipment for all 30 students to do hands-on activities at the same time."* These challenges often lead teachers to prioritize content completion over deep exploration. Professional development programs, collaborative lesson planning, and access to simple inquiry-based learning resources can help teachers integrate scientific enquiry into everyday instruction in manageable and sustainable ways (Widyasari & Haryanto, 2022). Even small-scale classroom investigations or routine data interpretation exercises can significantly enhance students' scientific literacy when implemented consistently.

Taken together, these findings reveal that fifth-grade students at SDN Airlangga I/198 Surabaya show moderate levels of scientific literacy in explaining phenomena scientifically and interpreting data and evidence but demonstrate low ability in evaluating and designing scientific enquiry. These findings underscore the need for instructional practices that place greater emphasis on inquiry, reasoning, and the meaningful integration of science with environmental contexts. By addressing these gaps, educators can help students develop stronger scientific literacy while simultaneously fostering ecological citizenship.

Conclusion

This study provides an initial overview of the scientific literacy of fifth-grade students at SDN Airlangga I/198 Surabaya based on three indicators: explaining phenomena scientifically, evaluating and designing scientific enquiry, and interpreting data and evidence scientifically. The findings show that students demonstrate a moderate level of competency in explaining scientific phenomena and interpreting data, yet exhibit a low level in evaluating and designing scientific enquiry. These results indicate that while students possess basic conceptual understanding and can interpret simple information, they still struggle with inquiry-related reasoning, identifying variables, and making decisions based on scientific evidence.

Triangulation through interviews and classroom observations reinforces that science learning in the observed classroom places greater emphasis on factual recall than on inquiry, experimentation, and analytical thinking. Consequently, their scientific literacy has not yet developed into the deeper reasoning required to engage with environmental issues scientifically, which is essential for fostering ecological citizenship. Overall, this study highlights the importance of strengthening inquiry-based learning, integrating real-world environmental contexts, and providing structured opportunities for students to engage in scientific reasoning. The results serve as a baseline for designing future interventions aimed at improving scientific literacy while simultaneously promoting students' understanding, awareness, and responsibility toward environmental sustainability.

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