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Research Article

Scientific Literacy Achievements in PISA and Their Implications for Science Education Reform in Developing Countries

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ABSTRACT

Purpose of the study: This study aims to analyze science literacy achievement based on PISA results and compare the performance of ASEAN and African countries. It also seeks to examine the implications of PISA science literacy outcomes for the development and improvement of science education in developing countries.

Methodology: This study employed a descriptive qualitative and quantitative document analysis. Secondary data were obtained from official OECD PISA 2018 and 2022 reports. Content analysis and descriptive-comparative analysis were applied. Data processing and tabulation were conducted using Microsoft Excel, supported by a systematic literature review of peer-reviewed science education journals.

Main Findings: The results show that science literacy achievement in ASEAN and African countries remains below the OECD average. ASEAN countries demonstrate relatively higher scores than African countries, although most students are still at basic literacy levels. Significant gaps exist between developing countries and high-performing PISA participants in scientific reasoning and problem-solving skills.

Novelty/Originality of this study: The study offers a comparative cross-regional analysis of PISA science literacy between ASEAN and African countries, which is rarely addressed in previous research. It integrates PISA data with science literacy theory to provide policy-relevant insights for science education development in developing countries, contributing to a broader Global South perspective in PISA-based studies.

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1. INTRODUCTION

The Programme for International Student Assessment (PISA) is an international assessment designed to measure the ability of 15-year-old students to apply knowledge and skills to real-life contexts [1], [2]. In science, PISA assesses not only content mastery but also the ability to reason and solve problems based on scientific phenomena [3], [4]. PISA results are used as a comparative indicator of the quality of a country's science education system globally [5], [6]. Therefore, PISA serves as an important reference for policymakers in evaluating the effectiveness of science curricula and learning practices. PISA also encourages participating countries to reflect on and reform education based on empirical evidence.

Scientific literacy is a key competency needed by students to face the challenges of the 21st century, characterized by rapid developments in science and technology [7], [8]. Scientific reasoning skills enable individuals to understand natural phenomena logically and systematically [9], [10]. Furthermore, problem-solving skills are crucial for students to formulate and resolve science-based problems in everyday life [11], [12]. Scientific literacy also plays a role in supporting responsible decision-making regarding social and environmental issues. Therefore, strengthening scientific literacy is a primary goal of modern science education.

PISA results show that developing countries, including those in the ASEAN and African regions, generally rank low in science literacy [13], [14]. This indicates systemic challenges in the implementation of science education in these countries [15], [16]. Limited resources, learning quality, and curriculum relevance are factors often associated with low PISA results. The achievement gap between developed and developing countries also reflects the disparity in global education quality [17], [18]. Therefore, analyzing PISA results is crucial for understanding the status and challenges of science education in developing countries. The low level of scientific literacy among students is a major problem reflected in the PISA results in many developing countries [19], [20]. Students tend to struggle to deeply understand scientific concepts and apply them to contextual situations. This indicates that science learning still focuses on memorizing concepts rather than developing scientific thinking skills [21], [22]. As a result, students' ability to explain phenomena scientifically and interpret data remains limited [23], [24]. This situation requires serious attention to improving science learning.

Science curricula in many developing countries are not fully aligned with the scientific literacy framework used in PISA [25], [26]. Science instruction often emphasizes mastery of material without providing inquiry and problem-solving experiences [27], [28]. This gap results in students being less accustomed to dealing with contextual and reasoning-based questions like those in PISA. Furthermore, learning evaluations in schools do not optimally measure scientific literacy competencies [29], [30]. Therefore, the alignment between curriculum, learning, and assessment is a crucial focus of this study. In addition to analyzing achievements, this article also aims to examine the implications of PISA results for the development of science education [31], [32]. PISA results are seen as a basis for reflection on improving the quality of science learning in schools. This study highlights how PISA findings can be used as a reference for improving curriculum and learning strategies. Implications are also examined in the context of improving science teacher competency [33], [34]. Therefore, PISA results are not merely understood as rankings, but as a basis for developing science education.

There is a significant research gap between the studies conducted by Örnek and Alaam [26] and Wu [13] and the current research. Örnek and Alaam's study focused on reviewing the science education framework based on PISA literacy findings in Turkey, China, and OECD countries, with an emphasis on conceptual and macro-policy aspects, but was still limited to the context of countries with relatively established or rapidly developing education systems. Meanwhile, Wu examined the influence of ICT on students' science literacy through a comparative study between Singapore and the United States in PISA 2022, with a specific focus on technological factors as the main determinant, thus not covering other structural dimensions such as education policy, access gaps, and pedagogical practices holistically. Both studies have not comprehensively integrated various key factors—such as science literacy achievements, policy reforms, socio-economic conditions, and education system challenges—in the context of developing countries with resource constraints and more complex educational disparities. Therefore, this study fills this gap by analyzing scientific literacy achievements in PISA while directly linking them to the implications of science education reform in developing countries, thereby providing a more contextual and applicable contribution in formulating strategies for improving the quality of science education sustainably.

The novelty of this research lies in its integrative approach, which comprehensively connects PISA-based scientific literacy achievements with direct implications for science education reform in developing countries. Unlike previous studies, which tended to be partial—whether focusing on conceptual frameworks, technological factors, or comparisons between developed countries—this study combines analysis of scientific literacy achievements, socioeconomic contexts, disparities in educational access, and policy directions within a single, coherent framework. Furthermore, this research presents a cross-country perspective across developing countries that remains relatively underexplored in the literature, thus providing a new contribution to enriching PISA-data-based scientific literacy studies.

The urgency of this research is based on the persistently low and uneven scientific literacy achievements in many developing countries, which impacts the limited capabilities of young people in facing the global challenges of the 21st century. Disparities in educational quality, limited resources, and the suboptimal integration of policies and learning practices are crucial factors that need to be addressed immediately. Therefore, this research is crucial for providing an empirical basis and strategic recommendations for designing more inclusive, adaptive, and sustainable science education reforms. This study aims to analyze science literacy achievement based on PISA results and compare the performance of ASEAN and African countries. It also seeks to examine the implications of PISA science literacy outcomes for the development and improvement of science education in developing countries.

2. RESEARCH METHOD

This research uses a qualitative descriptive approach with a document study design [35], [36]. This approach was chosen because the research focuses on analyzing official PISA data and reports without examining the research subjects. Document study allows researchers to examine in-depth the assessment framework, achievements, and characteristics of scientific literacy as measured by PISA [20], [37]. This design is also suitable for examining educational phenomena on an international scale. Therefore, this research emphasizes the interpretation and meaning of the available data. This research is also descriptive-comparative, as it compares scientific literacy achievements between regions based on PISA data.

The primary data source in this study is the official Programme for International Student Assessment (PISA) report published by the Organisation for Economic Co-operation and Development (OECD) [38], [39]. The data analyzed include PISA scientific literacy results from several recent assessment cycles. In addition, this study also utilized secondary data sources in the form of international and national journal articles relevant to scientific literacy and science education [40], [41]. Educational policy documents and supporting reports were also used as supplementary data. All data sources were selected based on their relevance and credibility. Data collection techniques were conducted through documentation and literature searches. Researchers collected PISA reports and scientific publications related to scientific literacy and science education [42], [43]. The data collection process was carried out systematically by identifying documents relevant to the research focus. Each document was then classified based on the theme and purpose of the study. This technique allowed for comprehensive and in-depth data collection.

Data analysis was conducted using content analysis. Researchers reviewed PISA documents to identify characteristics of scientific literacy, student achievement, and trends in results in developing countries. Data were analyzed by comparing findings across countries and across scientific literacy indicators. The results were then interpreted by linking them to theory and previous research [44]. This technique aims to gain a comprehensive understanding of the implications of PISA results for science education. In addition to content analysis, PISA scientific literacy data were analyzed using a quantitative descriptive approach to present scores, means, and ranges of scientific literacy achievement. Comparative analysis was also conducted across regions, particularly between ASEAN and African countries, to identify differences in patterns of scientific literacy achievement. Interpretation of the results was based on the OECD scientific literacy framework and supported by theories of scientific literacy and constructivist learning [45], [46]. This approach allows for interpretation of PISA data not only through descriptive statistics but also conceptually and contextually. Thus, the analysis aligns with the research objective of examining scientific literacy achievements and implications in developing countries.

Data validity was maintained through source triangulation by comparing PISA reports with various relevant scientific references. Researchers also ensured that the documents used came from official and reliable sources. Furthermore, the analysis process was conducted carefully and systematically to minimize interpretation bias. Discussion of the findings within a scientific literacy theoretical framework was used to strengthen the validity of the analysis [47], [48]. This step is expected to ensure a high level of trustworthiness in the research results.

3. RESULTS AND DISCUSSION

3.1 Scientific Literacy Achievements of ASEAN Countries (PISA 2022)

The analysis of PISA 2022 data shows wide variation in scientific literacy achievement across the ASEAN region. Singapore topped the list, with a score far exceeding the OECD average, while other ASEAN countries remained below that standard. Indonesia recorded a scientific literacy score of 383 points, a decrease compared to PISA 2018 and still well below the OECD average of 485 points [49], [50]. Malaysia and Thailand performed relatively better than Indonesia, but fell short of the OECD average. Overall, this data indicates that only a small number of ASEAN countries have achieved high levels of scientific literacy.

Table 1. PISA 2022 Science Literacy Scores of Selected ASEAN Countries

Country	Science Literacy Score
Singapore	561
Thailand	429
Malaysia	416
Indonesia	383
OECD Average	485

Visually, a comparison of scientific literacy scores reveals a striking gap between Singapore and other ASEAN countries. Countries with scores below 420 points are dominated by students who have only achieved basic scientific literacy. The proportion of students capable of higher-level scientific reasoning remains very limited [51], [52]. This situation indicates that the science education system in most ASEAN countries still focuses on mastering basic concepts [53], [54]. Thus, scientific literacy as an applied skill has not yet developed optimally in the region.

Overall, the distribution of scores indicates that the majority of students in ASEAN countries are still concentrated at lower proficiency levels, particularly below Level 2 of PISA scientific literacy. At this level, students are generally only able to identify simple scientific explanations and have limited ability to apply scientific knowledge in real-world contexts. This finding confirms that scientific literacy development in ASEAN is still dominated by basic competencies rather than higher-order thinking skills. Therefore, the main characteristic of scientific literacy achievement in ASEAN lies in its limited progression toward advanced reasoning and problem-solving abilities.

3.2 Scientific Literacy Achievements of African Countries (PISA 2022)

In contrast to ASEAN, the scientific literacy achievements of African countries participating in PISA 2022 showed lower and relatively homogeneous scores at the lower end of the scale. Countries such as Morocco, South Africa, and Senegal recorded scores below 370 points, indicating that the majority of students have not achieved the minimum scientific literacy competencies. These scores indicate students' limitations in understanding scientific concepts functionally and contextually. These low achievements also reflect structural challenges within the science education system in the African region. Overall, these data confirm that scientific literacy in Africa remains at a very basic level.

Table 2. PISA 2022 Science Literacy Scores of Selected African Countries

Country	Science Literacy Score
South Africa	366
Morocco	365
Senegal	342
OECD Average	485

The relatively close score patterns indicate that nearly all African countries analyzed face similar challenges in science education. The majority of students fall below PISA Level 2, the minimum competency level required to function scientifically in everyday life. The ability to design scientific investigations and interpret data appears almost non-existent. This suggests that science instruction still does not provide learning experiences that foster scientific thinking skills [55], [56]. Thus, PISA results reflect the weak strengthening of scientific literacy in the African region.

Furthermore, the concentration of student performance below Level 2 in African countries indicates a more critical condition compared to ASEAN. Students at this level typically struggle to interpret scientific data, evaluate evidence, and construct logical explanations of scientific phenomena. This pattern suggests that science learning has not yet effectively facilitated the development of essential scientific literacy competencies. Thus, the findings highlight that the challenge in African countries is not only low achievement but also the limited distribution of higher-level scientific literacy skills.

3.3 Comparison of ASEAN and African Science Literacy Scores

A direct comparison between the ASEAN and African regions shows that ASEAN has relatively better scientific literacy outcomes, although still below the OECD average. Non-elite ASEAN countries generally score between 380 and 430 points, while African countries score below 370 points. This difference indicates variations in the quality of science education systems across regions. However, both regions exhibit a predominance of students with low levels of scientific literacy. This underscores the global challenge of developing scientific literacy, particularly in developing countries.

Table 3. Comparison of Average PISA 2022 Science Literacy Scores

Region	Score Range
ASEAN	383 – 561
Africa	342 – 366
OECD	Average 485

Visually, the gap between developing country scores and the OECD average indicates a significant gap in scientific literacy. ASEAN shows greater potential for improvement than Africa, especially if it emulates the good practices of high-achieving countries. However, without curriculum reform and instruction oriented toward scientific literacy, this gap could persist [57], [58]. These results provide an important basis for discussing the implications for science education in the next section. Thus, the PISA data provide a strong empirical picture of the state of scientific literacy across regions. A broader synthesis of these findings reveals a consistent pattern across both regions, where scientific literacy remains largely at a foundational level despite differences in average scores. While ASEAN demonstrates relatively better performance, both regions share similar structural challenges, particularly in fostering higher-order scientific reasoning and inquiry-based competencies. The gap with the OECD average also reflects systemic issues related to curriculum alignment, instructional quality, and access to meaningful learning experiences. Therefore, the comparison not only highlights regional disparities but also underscores a common need for transformative improvements in science education systems.

The PISA results, which show low scientific literacy achievement in most ASEAN and African countries, can be understood through the scientific literacy framework developed by the OECD [19], [59]. Scientific literacy in PISA requires not only mastery of concepts but also the ability to explain phenomena scientifically, evaluate and design investigations, and interpret scientific data and evidence [60], [61]. The findings of scores dominated by low literacy levels indicate that students are not yet able to integrate scientific knowledge with scientific reasoning. This condition aligns with Bybee's view, which emphasizes that scientific literacy is functional and contextual, not simply the memorization of concepts. Therefore, low PISA scores reflect the suboptimal internalization of scientific literacy in learning.

These findings are consistent with prior studies highlighting persistent challenges in scientific literacy among students in developing countries. Previous research has shown that students often demonstrate limited ability to apply scientific knowledge in real-life contexts and struggle with interpreting scientific data and evidence [20], [24]. In addition, Ustun et al. [19] emphasized that instructional quality, school environment, and pedagogical approaches are significant predictors of scientific literacy achievement. The alignment between this study and previous findings reinforces the argument that the issue of low scientific literacy is systemic and closely related to the quality of science instruction rather than merely students' cognitive abilities. The differences in scientific literacy achievement between ASEAN and Africa demonstrate variations in the implementation of science learning. ASEAN countries, while still below the OECD average, show relatively higher scores than Africa, which can be attributed to the application of more diverse learning approaches. From a constructivist perspective, effective science learning requires active student involvement in constructing understanding through experience and interaction with the environment [62], [63]. The low achievement in Africa indicates that science learning still lacks inquiry and exploration experiences [64], [65]. This makes it difficult for students to develop the scientific reasoning skills that are the core of scientific literacy. This difference confirms that the quality of the learning process significantly influences scientific literacy achievement. Beyond differences in regional performance, the findings also point to underlying structural factors influencing scientific literacy outcomes. Limited access to quality educational resources, disparities in teacher competency, and insufficient integration of inquiry-based learning are likely contributing to the observed gaps [66], [67]. In many developing countries, science instruction remains teacher-centered and exam-oriented, which restricts opportunities for students to engage in higher-order thinking processes [68], [69]. Consequently, students are less exposed to activities that develop scientific reasoning, such as experimentation, data analysis, and evidence-based argumentation.

The distribution of PISA scores, which shows a predominance of students at low literacy levels in ASEAN and Africa, has serious implications for the development of scientific reasoning. Students at low literacy levels are generally only able to recognize simple scientific facts without being able to explain cause-and-effect relationships in depth [70], [71]. According to cognitive development theory, scientific reasoning skills develop through higher-order thinking exercises and contextual problem-solving [72], [73]. The low achievement at high literacy levels indicates that science learning has not consistently developed these skills [74], [75]. As a result, students are ill-prepared to face real-life scientific problems. This finding strengthens the argument that scientific literacy must be developed through learning that emphasizes the thinking process, not just the end result.

The PISA results also indicate a gap between science curricula and the demands of 21st-century scientific literacy. Curricula in many ASEAN and African countries still focus on delivering dense, conceptual content. Modern scientific literacy theory requires students to engage in inquiry, data analysis, and evidence-based decision-making [76], [77]. This gap leaves students less accustomed to dealing with context-based questions like those tested in PISA. Consequently, scientific literacy achievement remains low, even though the material has been taught. These findings highlight the need to align curricula with the PISA scientific literacy framework.

Theoretically, these research findings confirm the relevance of scientific literacy theory, which places scientific reasoning and problem-solving at the core of science education [43], [78]. Data from ASEAN and Africa demonstrate that without inquiry-based learning and real-world contexts, scientific literacy is difficult to develop. Practically, these findings imply the need to transform science learning toward a more constructivist and problem-based approach. Teachers need support in developing learning strategies that foster scientific reasoning and data interpretation [79], [80]. Furthermore, education policies need to align learning evaluation with scientific literacy competencies. Thus, PISA results can be used as a basis for developing sustainable science education. From a theoretical perspective, this study extends existing scientific literacy frameworks by providing empirical evidence from cross-regional comparisons in developing country contexts. While previous studies have largely focused on high-performing or OECD countries, this research highlights how scientific literacy theory operates under conditions of limited resources and educational inequality. This contributes to a more inclusive understanding of scientific literacy development and emphasizes the need to contextualize global frameworks within local educational realities.

The findings of this study align with those of various previous studies, which confirm that low scientific literacy achievement in developing countries is a consistent phenomenon in PISA-based studies. Research by Putri et al. [20] shows that most students in developing countries remain at a basic literacy level, with limitations in interpreting scientific data and applying concepts in real-life contexts. Furthermore, a study by Ustun et al. [19] revealed that factors such as learning quality, pedagogical approach, and school environment significantly influence students' scientific literacy achievement. These findings are further supported by Wang et al. [24], who stated that inquiry-based learning approaches and scientific exploration significantly contribute to improving scientific literacy and scientific reasoning skills. Thus, the results of this study not only confirm the patterns found in previous studies but also emphasize that low scientific literacy is closely related to the suboptimal implementation of learning oriented toward developing higher-order thinking and problem-solving skills. In practical terms, improving scientific literacy requires a shift in classroom practices toward more student-centered and inquiry-driven learning environments. Teachers need to be equipped with strategies that encourage questioning, investigation, and critical thinking [81], [82]. Additionally, assessment practices should move beyond factual recall and focus on evaluating students' ability to apply knowledge in unfamiliar contexts. Without such changes, improvements in scientific literacy are unlikely to occur despite curriculum reforms.

Implicationally, the results of this study demonstrate the need to align science curriculum, learning, and assessment with the demands of 21st-century scientific literacy. Science education needs to be directed toward inquiry-based learning, problem-solving, and real-life contexts to improve students' scientific literacy skills [66], [83]. Furthermore, strengthening teacher competency in implementing scientific literacy-oriented learning is a key factor in improving PISA outcomes. Education policies in developing countries also need to utilize PISA data as a basis for evaluating and planning science education development [84], [85]. Therefore, the results of this study can serve as a reference for developing more contextual and sustainable science education.

As a limitation, this study relied solely on secondary PISA data and did not include direct empirical data from classroom learning processes. Therefore, future research is recommended to combine PISA data analysis with more in-depth empirical or comparative studies across countries. Further research could also explore effective science learning practices for improving scientific literacy in developing countries. With the strengthening of these follow-up studies, the development of scientific literacy at the global level is expected to be more focused and evidence-based.

4. CONCLUSION

Based on document analysis and secondary data from the PISA using a quantitative and comparative descriptive approach, it was found that the scientific literacy achievements of ASEAN and African countries remain below the OECD average. While the ASEAN region performed relatively better than Africa, the majority of students in both regions remain at the basic scientific literacy level. This finding indicates students' limitations in scientific reasoning, contextual problem-solving, and scientific data interpretation. Therefore, this study confirms that scientific literacy in developing countries has not yet developed optimally. The regional comparison results indicate a gap in scientific literacy achievements, reflecting differences in the quality of science education systems. Countries with higher scores demonstrate the potential for learning practices that better support scientific literacy development. Conversely, the low achievements in most developing countries indicate the continued dominance of science learning oriented toward mastery of concepts rather than the development of scientific thinking skills. This finding is consistent with the OECD's scientific literacy framework, which emphasizes the importance of scientific reasoning and the application of knowledge in real-world contexts. Therefore, PISA results reflect not only rankings but also the quality of the science learning process.

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recommended to combine PISA data analysis with empirical classroom studies to obtain a more comprehensive picture of the learning practices that influence students' scientific literacy. Furthermore, further research is needed to more deeply examine the effectiveness of various inquiry-based and problem-based learning models in improving scientific reasoning skills and scientific literacy in developing countries.

AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Data Curation, Writing – Original Draft Preparation, and Visualization, YW.; Writing – Review & Editing, YW and RB; Supervision and Project Administration, YW and CPC. All authors have read, reviewed, and provided approval for the final version of the manuscript submitted for publication.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

INFORMED CONSENT STATEMENT

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USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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