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Science literacy competence of elementary school teachers: Bridging theory and practice

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Abstract

The quality of education is a key driver in the development of human resources, and teacher competence, particularly in scientific literacy, plays a central role in maintaining educational standards. This study aims to assess the quality of basic education by examining elementary school teachers' scientific literacy competence in relation to their teaching experience and age. Employing a descriptive quantitative approach with an experimental design, the study involved 87 elementary school teachers. Data were collected using pre-test and post-test instruments to measure changes in scientific literacy competence. The intervention included socialization and practical sessions designed to enhance teachers' understanding and application of scientific literacy. Descriptive statistical analysis revealed notable improvements in post-test performance, indicating that targeted interventions can effectively strengthen scientific literacy competence. These findings suggest that enhancing teachers' scientific literacy contributes significantly to improving the quality of basic education, reinforcing the importance of continuous professional development for educators.

***Keywords*:** Basic education; educational quality; scientific literacy; teacher competence; teacher development.

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1. INTRODUCTION

In the twenty-first century, global developments demand substantial transformation. These shifts are driven by rapid advancements in technology, significant progress in scientific and psychological research, and the ongoing evolution of cultural values (Mantri et al., 2019). Such transformations extend to the educational paradigm, particularly within science education (Amelia et al., 2021; Schreiter et al., 2024). The resulting paradigm shift emphasizes a transition from knowledge acquisition alone to a holistic framework incorporating skills development and value integration aimed at resolving real-life challenges. This comprehensive learning approach is conceptualized as scientific literacy, defined as the capacity to utilize scientific knowledge in identifying and addressing real-world issues. Proficiency in scientific literacy significantly influences educational quality (Muammar et al., 2023).

Educational quality constitutes a central component of the learning process. Quality reflects the comparative advantage of an institution relative to others (Madani, 2019). Efforts to enhance quality represent a continual pursuit of improvement across educational institutions. Accordingly, quality serves as a benchmark for assessing excellence, cognitive competence, and institutional effectiveness.

At all educational stages, instructional quality is considered the core of education (Mantri et al., 2019). Educational value, encompassing inputs, instructional processes, and learning outcomes, defines the overall quality of education (González García et al., 2020; Cottone et al., 2023). The formulation of educational quality and policy requires systemic improvements across all levels. Core educational objectives, such as enhancing primary education, advancing literacy, and developing competencies, are contingent on the quality of teaching and educator effectiveness (Snoek, 2021; Yun, 2025). The multifaceted nature of educational quality precludes a singular definition. Terms such as effectiveness, equity, efficiency, and quality are frequently used interchangeably (Mantri et al., 2019). Educational quality remains dynamic, influenced by intellectual, cultural, and technological advancements, thereby necessitating adaptability in response to ongoing educational evolution (Arifin & Setiawan, 2022).

Two key perspectives are critical. First, all educational systems must prioritize the cognitive development of both educators and learners (Snoek, 2021). Second, educators must facilitate the development of learners' values, attitudes, emotional intelligence, and creativity. The enhancement of elementary education quality is vital for human resource development, as this stage establishes foundational scientific understanding and supports optimal child development through teacher-guided learning (Feng & Sass, 2017). The primary objective of elementary education includes fostering personal development aligned with societal values, preparing learners for continued education, civic participation, and individual growth (Kalkan et al., 2020).

Scientific advancement and workforce demands necessitate the continuous improvement of teacher skills to elevate educational standards. Interdisciplinary integration serves as a strategic approach in achieving this objective. Scientific literacy represents a key competency for educators engaged in interdisciplinary teaching (Fitria et al., 2019). The Programme for International Student Assessment (PISA) 2018 highlights science as a critical component of daily life (Kalkan et al., 2020). Scientific literacy refers to the ability to engage with scientific issues and concepts. Science education should therefore emphasize inquiry and experimentation over passive knowledge acquisition (Cervetti et al., 2012). The PISA assessment evaluates the application of scientific knowledge in real-world contexts. Competency in scientific literacy is shaped by understanding scientific processes, scientific reasoning, and attitudes toward science (Al Sultan et al., 2021).

Promoting scientific literacy remains a primary objective of science education (Şentürk & Sari, 2018; Veziroglu-Celik et al., 2025). The American Association for the Advancement of Science (AAAS) provides a comprehensive definition, emphasizing the integration of mathematics, technology, and the natural and social sciences (Smith et al., 2012). According to Liu (2009), scientific literacy includes six core components: (a) understanding foundational scientific concepts, (b) comprehension of the nature of science, (c) adherence to scientific ethics, (d) analysis of science technology society interactions, (e) assessment of science environment relationships, and (f) differentiation between science and technology. Building on these dimensions, Romel et al. (2021) categorize scientific literacy into three domains: (a) practical, applying scientific expertise to real-

world issues, (b) civic, enabling participation in science-related discourse, and (c) cultural, recognizing science as a valuable cultural and intellectual tradition.

Teachers across all age groups contribute to technological progress through varying levels of scientific literacy. Core attributes of scientific literacy include the application of scientific knowledge, recognition of science characteristics, and evaluation of scientific benefits and risks (Aberšek, 2008). These attributes inform the development of analytical indicators for assessing scientific literacy. From the perspective of Bloom's taxonomy, scientific literacy involves higher-order thinking skills, such as creating, analyzing, and evaluating. Classroom implementation of scientific literacy fosters critical and creative thinking among educators. High-level skills developed through scientific literacy include the application of scientific concepts, technological categorization for problem solving, differentiation between credible and noncredible sources, explanation of phenomena, and conceptual analysis (Holbrook & Rannikmae, 2009).

Global competition demands high competence in all fields. The capacity to enhance knowledge and skills is essential for educational success in a rapidly changing world (Effendi et al., 2021). Scientific literacy encompasses the imaginative and responsible use of evidence-based scientific knowledge in addressing real-world problems (Indriayu, 2018). Teachers are expected to possess critical thinking abilities, enabling them to evaluate scientific knowledge and make informed decisions (Islami & Zaky, 2020).

Scientific literacy is vital for making informed decisions about environmental and societal issues. It involves applying scientific information, formulating questions, and drawing conclusions based on empirical evidence (Holbrook & Rannikmae, 2009). Countries such as the United States and Australia have recognized the importance of scientific literacy by establishing national benchmarks and curricular goals (Goodstein, 1992). These frameworks emphasize student competencies in scientific reasoning and inquiry. Scientifically literate individuals are characterized by their ability to apply scientific knowledge, engage in scientific practices, and appreciate science as a societal asset (Baker, 2004). Core principles of scientific literacy include contextual relevance, alignment with social and national needs, conformity with twenty-first-century learning standards, integration with other forms of literacy, and collaborative participation (Smith et al., 2012). The National Science Education Standards also define scientific literacy as the capacity to ask and answer questions derived from daily experiences (Kalkan et al., 2020).

The enhancement of scientific literacy among teachers is facilitated through the application of process skills, which are essential for scientific inquiry and personal development (Suryanti et al., 2018). These skills contribute to problem-solving and decision-making in both educational and everyday contexts. Scientific literacy has emerged as a critical attribute for modern citizens and a primary objective of science education (Rubini et al., 2019). Engagement in scientific inquiry fosters curiosity, information gathering, idea testing, application of learning, self-confidence, communication skills, and environmental awareness (Sülün et al., 2009).

Educators play a fundamental role in fostering scientific literacy across all educational levels. Scientific literacy competence increases through professional development and self-directed learning (Flores, 2019). This competency is indispensable in addressing twenty-first-century educational challenges (Anyanwu & Grange, 2017). Educators are increasingly expected to produce globally competitive graduates. However, findings from Alhashem and Al Jafar (2015, 2017) reveal a limited understanding of scientific literacy among educators. A teacher's comprehension of scientific literacy significantly influences classroom instruction and pedagogical effectiveness (Sharon & Baram-Tsabari, 2020).

Teacher professionalism develops incrementally through experience and participation in training programs (Wallace & Coffey, 2019). Professional growth requires mastery of competencies related to scientific literacy, which will be essential in future educational systems (Snoek, 2021). Scientific literacy must be prioritized to drive educational improvement.

Literatus, which means marked with letters, literate, or educated, and scientific, which means knowing, are two Latin terms that are combined to form the term "scientific literacy" (Nomxolisi et al., 2021). Scientific literacy is the ability to recognize questions, gain new knowledge, explain scientific phenomena, and draw

conclusions based on facts. It also includes understanding the characteristics of science, being aware of how science and technology influence the physical, intellectual, and cultural environments, and having the desire to participate in and care about issues relating to science (Gursesa et al., 2015).

Scientific literacy is the knowledge of science and comprehension of scientific ideas and procedures that enables a person to make decisions based on the information they have and to participate in societal, cultural, and economic development issues, taking into account their unique skills. Understanding science and how it applies to societal demands is one definition of scientific literacy (Babaci-wilhite, 2017). To transform the definition of scientific literacy into an assessment of scientific literacy, the scientific method, scientific substance, and scientific context are the three main aspects of scientific literacy that PISA highlights (Smith et al., 2012). The term "scientific process" refers to the thought processes involved in responding to a query or resolving an issue, such as recognizing and analyzing data and providing explanations for conclusions (Şentürk & Sari, 2018).

By the definition of scientific literacy, the characteristics of scientific literacy consist of 4 (four) components that are interrelated with one another. Each of these components can be described as follows:

a. Context, or being aware of real-world instances involving science and technology. The personal, social, and global contexts of science include things like health, resources, the environment, natural disasters, and the application of science and technology.

b. Knowledge, namely the ability to comprehend nature based on scientific knowledge, which comprises knowledge of both science and nature. Aspects of knowledge consist of physical systems (matter systems, chemical changes, chemical reactions, motion and power, energy), living systems (humans, animals, and plants, ecosystems, biosphere), and earth and space systems (earth and space). technology systems (science and technology).

c. Competence, namely using scientific evidence, detecting scientific problems, and describing scientific phenomena, are an examples of scientific competency.

d. Attitudes, namely interest in science, support for scientific research, and drive to act properly toward, for instance, the environment and natural resources (Holbrook & Rannikmae, 2009).

To meet the demands of science education, improvements are required in teacher training systems, especially for elementary educators. These include curriculum development, organizational reform, and enhancement of pedagogical practices (Lamanauskas, 2012). Multiple studies have demonstrated that elementary teachers often lack sufficient scientific literacy and relevant technical skills (Amiruddin et al., 2021). Challenges in developing scientific literacy include limited engagement with higher-order thinking, insufficient comprehension of academic literature, and difficulty articulating complex ideas (Feinstein, 2011). Therefore, educators must exhibit exemplary competencies throughout teacher preparation and professional practice (Aberšek, 2008). Elevated scientific literacy among teachers is associated with improved educational outcomes. Science literacy education plays an essential role in developing educators capable of critical, creative, and rational thought (Allen et al., 2013).

In the Indonesian context, scientific literacy has gained increasing attention from policymakers and science education practitioners. Although not explicitly referenced in the 2013 Curriculum, core competencies and learning objectives reflect an implicit emphasis on scientific literacy (Al Sultan et al., 2021). PISA findings highlight key factors affecting scientific literacy, including reading comprehension, mathematical ability, and the availability of educational resources (Chiang & Tzou, 2018). Hernandez underscores the importance of developing scientific literacy to enhance understanding of scientific knowledge, science communication skills, and the relationship between science, technology, and society (Moore-Hart et al., 2004). Consequently, scientific literacy competence among educators is essential for advancing educational quality.

1.1. Purpose of study

This study aims to evaluate the scientific literacy competence of elementary school teachers and examine its relationship with their age and teaching experience. By implementing targeted interventions such as

socialization and practical sessions, the study seeks to determine the effectiveness of professional development in enhancing teachers' scientific literacy, which is essential for improving the overall quality of basic education.

2. METHOD AND MATERIALS

2.1. Data collection tool

The primary data collection tool used in this study was a scientific literacy test structured around the concept of Higher Order Thinking Skills (HOTS). The test consisted of 25 questions designed to assess teachers' competence in scientific literacy before and after the intervention. These questions were developed to integrate critical thinking and problem-solving skills relevant to scientific literacy.

2.2. Participants

The participants in this study were 87 primary school teachers from the city of Padang. These teachers were selected to represent a sample of educators involved in basic education within the region.

2.3. Data analysis technique

This study employed an experimental method using a one-group pre-test post-test design alongside a quantitative descriptive approach. Data from the pre-test and post-test were analyzed to determine changes in scientific literacy competence among teachers. The comparative analysis of pre-test and post-test results allowed the researchers to assess the effectiveness of the intervention, which included periodic socialization and scientific literacy practice sessions.

3. RESULTS

To see the scientific literacy competence of elementary school teachers, this study uses two categories of sample grouping, namely, based on length of teaching and age. The following table 1 presents data about the characteristics of research respondents.

Table 1

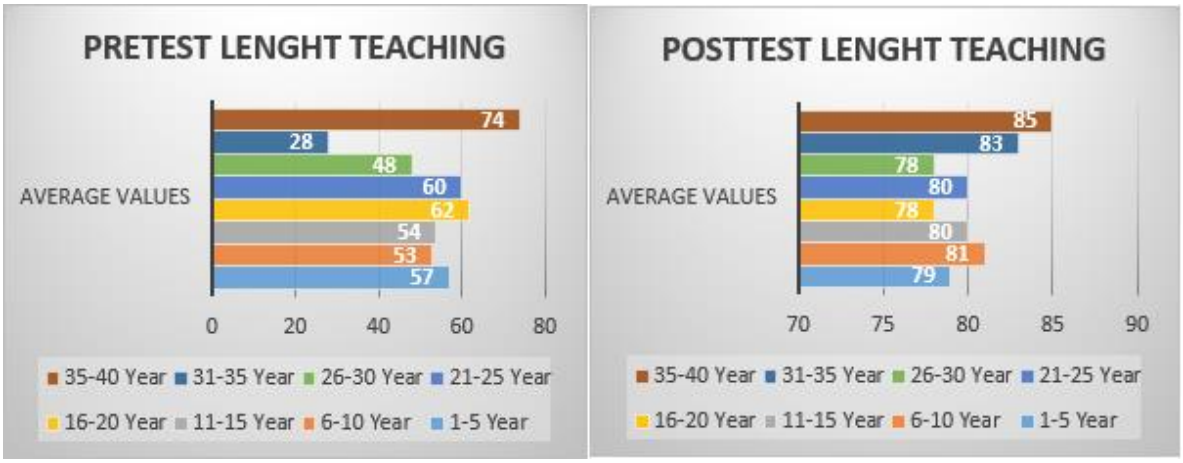
Categories of research respondents

Variable	Category	**n**	Percentage **(%)**
Long Teaching	0 – 5 Years	23	26,44 **%**
	6 – 10 Years	18	20,69 **%**
	11 – 15 Years	19	21,84 **%**
	16 – 20 Years	15	17,24 **%**
	21 – 25 Years	3	3,45 **%**
	26 – 30 Years	6	6,90 **%**
Age	31 - 35 Years	1	1,15 **%**
	36 – 40 Years	2	2,30
	21 – 25 Years	9	10,34 **%**
	26 – 30 Years	15	17,24 **%**
	31-35 Years	15	17,24 **%**
	36 – 40 Years	23	26,44 **%**
	41 – 45 Years	8	9,20 **%**
	46 – 50 Years	4	4,60 **%**
	51 – 55 Years	7	8,05 **%**
	56 – 60 Years	6	6,90 **%**

After the categorization is complete, the next step is to look at the teacher's scientific literacy competence. The results obtained are as follows:

Figure 1

Description of the average pre-test and post-test values of teachers' scientific literacy competencies based on the category of teaching duration



Based on the picture above, it is found that the average pre-test and post-test scores of teachers with 35-40 years of teaching experience have the highest average scores, namely 74 and 85. This can be influenced by the amount of experience and knowledge gained during teaching in elementary schools. It can be seen that after being given treatment, the average value of the teacher's scientific literacy competence increased.

Table 2

The results of the pre-test and post-test of teachers' Science Literacy Competence based on the Category of Teaching Length

		Mean	N	Std. Deviation	Std. Error Mean
Long Teaching	Pre-test	56,18	87	15,078	1,617
	Post-test	79,77	87	6,749	0,724

The calculation in the table above shows that the average pre-test score is 56.18, while the post-test score is 79.77, which means that there is an increase in the teacher's scientific literacy competence after being given treatment.

Table 4

Results of Paired Sample Correlations of Teachers' Science Literacy Competencies by Category of Teaching Length

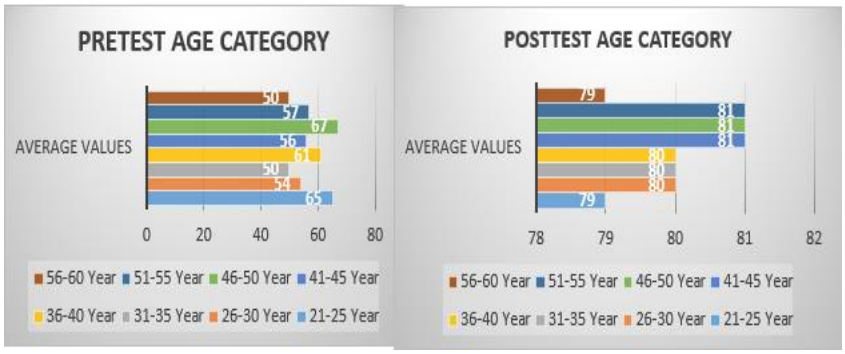
		Paired Differences			
		Mean	Std. Deviation	t	Sig.
Long Teaching	Pre Post	-23,586	17,756	-12.390	0,000

From the calculation results, the difference between the average pre-test and post-test values is -23,586, being higher than the pre-test average value. The standard deviation obtained is 17.756, which means that the scientific literacy competency data in the category of teaching duration is spread out, or the data distribution is 17.756. Then obtained significance value < 0.05 or 0.000 < 0.05. Thus, it can be said that the scientific literacy competence of elementary school teachers based on the category of teaching length before and after being given treatment has a significant difference.

Next, the pre-test and post-test scores of teachers' scientific literacy competencies were calculated based on age categories. The results obtained are as follows:

Figure 2

Description of the average pre-test and post-test values of teachers' scientific literacy competence by age category



Based on the picture above, it was found that the average pre-test score of teachers aged 46-50 was the highest average score at 67. The teacher's post-test average value increased as seen from three age classes having the same value, namely ages 51-55. , 46–50 and 41–45 years were 87 and were the highest average scores.

Table 5

The results of the pre-test and post-test of teachers' scientific literacy competence by age category

		Mean	N	Std. Deviation	Std. Error Mean
AGE	Pre-test	67,18	87	13,156	1,023
	Post-test	80,45	87	5,439	0,540

The calculation in the table above shows that the average pre-test score is 67.18, while the post-test score is 80.45, which means that there is an increase in the teacher's scientific literacy competence after being given treatment.

Table 6

Results of paired sample correlations of teacher science literacy competencies by age category

		Paired Differences			
		Mean	Std. Deviation	t	Sig.
AGE	Pre-Post	-23,678	17,756	-13.696	,000

From the calculation results, the difference between the average pre-test and post-test values was 78, with the post-test average value being higher than the pre-test average value. The standard deviation obtained is 16.126, which means that the scientific literacy competency data in this age category is spread out, or the data distribution is 16.126. Then obtained significance value < 0.05 or 0.000 < 0.05. Thus, it can be said that the scientific literacy competence of elementary school teachers based on the age category before and after being treated has a significant difference.

4. DISCUSSION

The findings of this study indicate a significant increase in scientific literacy competence among elementary school teachers, both about teaching experience and age. These results suggest that extended exposure to instructional practices and maturity contribute positively to the development of scientific understanding and application. These findings corroborate those of Haryanto et al. (2022), who emphasized that educators' comprehension of scientific literacy, reading theory, and literary theory is essential for improving overall literacy skills and, by extension, the quality of education. The present study reinforces the argument that scientific literacy is not static but develops progressively through sustained engagement in teaching and professional growth.

This finding aligns with the perspective of Holbrook and Rannikmae (2009), who highlighted the central role of scientific literacy in enhancing decision making, problem-solving, and critical thinking in educational

contexts. According to their study, scientific literacy is foundational to attaining twenty-first-century competencies. Therefore, the increase in teachers' scientific literacy, as revealed in the current study, represents not only a personal professional development but also a critical mechanism for improving the overall quality of basic education.

In terms of its broader implications, the present study supports the notion that teachers' competence in scientific literacy is essential in addressing the increasing demand for twenty-first-century skills. This reflects the arguments presented by Selanik-Ay and Duban (2018), who identified learning and innovation skills, as well as competencies in information, media, and technology, as key components of modern science learning. The National Association of Science Teachers, as cited by Selanik-Ay and Duban (2018), emphasizes the strategic role of science education in cultivating these essential skills. The findings of the present study further strengthen this assertion by demonstrating that teachers with higher literacy competence are more capable of integrating science-based pedagogies that reflect contemporary learning demands.

While the current study aligns with previous literature in recognizing the importance of teachers' scientific literacy, it adds empirical evidence regarding the influence of age and teaching experience—variables that are not always explored in detail. This differentiates the current research from prior studies by offering a more nuanced understanding of the demographic factors influencing literacy competence. Although the studies by Haryanto et al. (2022) and Holbrook and Rannikmae (2009) emphasize the importance of literacy understanding, they do not explicitly examine how professional longevity or age categories relate to competence levels, which the present findings now address.

Overall, the results underscore the necessity for sustained professional development and institutional support to cultivate teachers' scientific literacy. Increased literacy competence is not only beneficial to individual educators but is also crucial for maintaining the quality of foundational education. As highlighted in Haryanto et al. (2022), this development must be grounded in solid theoretical knowledge encompassing scientific, reading, and literary frameworks to ensure that teachers are equipped to meet evolving educational challenges.

4. CONCLUSION

Based on the results of this study, it can be concluded that the quality of basic education in the city of Padang has improved through the enhancement of teachers' scientific literacy competence following the implementation of targeted interventions. These interventions, conducted in the form of socialization activities and scientific literacy practice, served as structured efforts to develop educators' understanding and application of scientific concepts. The positive outcome of this treatment underscores the significance of systematic professional development in fostering competencies aligned with contemporary educational demands. Enhanced scientific literacy among teachers is closely associated with their ability to deliver high-quality science education, which in turn supports the broader goal of improving foundational educational outcomes. The findings provide empirical support for the argument that teacher quality, particularly in scientific literacy, plays a critical role in driving educational advancement at the primary level.

The observed increase in scientific literacy competence was categorized according to two variables: length of teaching experience and teacher age. Quantitative analysis revealed a statistically significant improvement in both categories, indicating that the intervention had a widespread and consistent impact across demographic groups. This suggests that scientific literacy development is not limited to early career educators but remains responsive to targeted training across various stages of a teaching career. These findings reinforce the notion that continuous professional development must be an integral component of teacher education systems. Moreover, the demonstrated improvement in literacy competence has the potential to positively influence instructional quality, curriculum delivery, and ultimately student learning outcomes. Therefore, sustained efforts to integrate scientific literacy into teacher training and in-service education are essential for ensuring the long-term quality and relevance of basic education.

Conflict of interest: No potential conflict of interest was reported by the authors.

Ethical Approval: The study adheres to the ethical guidelines for conducting research.

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