

The Effect of the Flipped Classroom Model on Elementary Students' Science Literacy

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ABSTRACT

This study examines students' science literacy through the implementation of the flipped classroom model in an elementary school context. The research is grounded in the persistent challenge of low science literacy, often associated with limited student engagement and teacher-centered instructional practices. Positioned within a quantitative framework, this study employs a pre-experimental one-group pretest-posttest design to analyze changes in students' performance before and after the intervention. The participants consisted of 15 fifth-grade students at SDN 20 Tanjung Keramat, selected using a saturated sampling technique. Data were collected using a science literacy test adapted from PISA indicators and analyzed using descriptive statistics and the Wilcoxon Signed-Rank Test. The results indicate a consistent increase in students' scores, with all participants demonstrating improvement and no decline observed. Statistical analysis reveals a significant difference between pretest and posttest results, suggesting that the flipped classroom model is associated with enhanced science literacy. These findings highlight the potential of structured active learning environments in supporting deeper conceptual understanding. However, the use of a pre-experimental design and a small sample size limits the generalizability of the results. Future research is recommended to employ more rigorous designs and broader samples.

Penelitian ini bertujuan untuk menganalisis kemampuan literasi sains siswa melalui penerapan model pembelajaran flipped classroom pada konteks sekolah dasar. Penelitian ini dilatarbelakangi oleh rendahnya literasi sains siswa yang sering dikaitkan dengan rendahnya keterlibatan belajar serta dominasi pembelajaran berpusat pada guru. Penelitian ini menggunakan pendekatan kuantitatif dengan desain pre-experimental one-group pretest-posttest untuk mengidentifikasi perubahan kemampuan siswa sebelum dan sesudah perlakuan. Subjek penelitian berjumlah 15 siswa kelas V di SDN 20 Tanjung Keramat yang dipilih menggunakan teknik sampling jenuh. Data dikumpulkan melalui tes literasi sains yang disusun berdasarkan indikator PISA dan dianalisis menggunakan statistik deskriptif serta uji Wilcoxon Signed-Rank. Hasil penelitian menunjukkan adanya peningkatan skor pada seluruh siswa tanpa adanya penurunan nilai. Analisis statistik juga menunjukkan perbedaan yang signifikan antara hasil pretest dan posttest, yang mengindikasikan bahwa penerapan flipped classroom berkaitan dengan peningkatan literasi sains siswa. Temuan ini menunjukkan pentingnya pembelajaran aktif yang terstruktur dalam mendukung pemahaman konsep secara lebih mendalam. Namun demikian, penggunaan desain pre-experimental dan ukuran sampel yang terbatas menjadi keterbatasan dalam penelitian ini. Penelitian selanjutnya disarankan menggunakan desain yang lebih kuat dan cakupan sampel yang lebih luas.

Keywords: flipped classroom, science literacy, elementary education.

Introduction

Science literacy has increasingly been positioned as a fundamental competency in contemporary education, particularly in response to the growing complexity of the twenty-first century. In its broader conceptualization, science literacy extends beyond the acquisition of scientific knowledge to include the ability to interpret scientific phenomena, critically evaluate information, and apply evidence-based reasoning in addressing real-world problems (Poudel &



Sharma, 2025; Wright & Park, 2022). Within elementary education, the development of science literacy plays a crucial role in establishing foundational scientific thinking, fostering intellectual curiosity, and enabling students to engage meaningfully with their environment. Instructional approaches that emphasize active engagement and deeper cognitive processing are therefore essential in supporting the development of these competencies (Olana et al., 2026; Wright & Park, 2022).

Despite its recognized importance, international assessment results consistently indicate that students' science literacy in Indonesia remains relatively limited. Many students continue to experience difficulties in applying scientific concepts to real-life situations, suggesting that their understanding remains largely procedural rather than conceptual. This condition reflects a persistent gap between classroom practices and the broader objectives of science education, which emphasize higher-order thinking, contextual understanding, and problem-solving skills. In many instructional settings, learning remains predominantly teacher-centered, thereby restricting students' opportunities to actively construct knowledge and engage in reflective learning processes.

From a theoretical standpoint, enhancing science literacy requires instructional designs grounded in constructivist principles, which conceptualize learning as an active process of meaning-making shaped through interaction and experience (Poudel & Sharma, 2025; Wright & Park, 2022). This perspective is further supported by active learning and transformative learning frameworks, which highlight the importance of student engagement, collaboration, and the integration of technology in fostering deeper cognitive processing (Olana et al., 2026; Wright & Park, 2022; Yang & Valcke, 2026). Within this conceptual landscape, the flipped classroom model has emerged as a pedagogical innovation that reconfigures traditional instructional sequences by relocating initial content acquisition outside the classroom and utilizing in-class time for more interactive and student-centered learning activities.

In practice, flipped classroom is frequently implemented in combination with other student-centered pedagogical approaches. Empirical studies have shown that integrating flipped classroom with inquiry-based learning and problem-based learning enhances student engagement and promotes deeper conceptual understanding (Tsai et al., 2015; Wijayanti et al., 2025). Furthermore, its integration with computational thinking and differentiated multimedia design has been found to support the development of higher-order cognitive skills, including science literacy and spatial reasoning (Apriana et al., 2026). Methodologically, research over the past decade has predominantly employed quantitative or quasi-experimental designs, particularly pretest–posttest structures, supported by statistical analyses such as t-tests, Wilcoxon tests, and Mann–Whitney tests to evaluate instructional effectiveness (Apriana et al., 2026; Wibowo et al., 2023; Wijayanti et al., 2025).

Empirical evidence consistently demonstrates that flipped classroom contributes positively to science learning outcomes. The implementation of this model has been associated with improvements in conceptual understanding, academic achievement, and digital literacy compared to conventional instructional approaches (Kaya & Çebi, 2025; Tsai et al., 2015; Wijayanti et al., 2025; Zdravković et al., 2026). In addition to cognitive gains, flipped classroom has also been shown to enhance affective dimensions of learning, including students' motivation, engagement, and overall satisfaction, particularly when supported by interactive and flexible learning environments (Olana et al., 2026; Romero & Angeles, 2023; Wright & Park, 2022). Moreover, in certain contexts, the integration of flipped classroom with frameworks such as Technological Pedagogical Content Knowledge (TPACK), problem-based learning, and

culturally responsive approaches has been found to further strengthen science literacy while fostering critical and creative thinking skills (Mustadi, 2019; Ferdiansyah et al., 2025).

However, despite the growing body of research, several critical gaps remain insufficiently addressed. First, a substantial proportion of studies primarily focus on general academic performance and learning outcomes, with relatively limited attention given to science literacy as a distinct and explicitly measured construct (Apriana et al., 2026; Wijayanti et al., 2025). Second, research conducted at the elementary education level—particularly within the Indonesian context—remains comparatively scarce, limiting the generalizability of existing findings. Third, although many studies employ rigorous experimental designs involving control groups, fewer investigations explore simpler pre-experimental approaches that are often more feasible in authentic classroom settings. In addition, practical challenges such as unequal access to technology, variations in teacher readiness, and students' difficulties in managing self-directed learning continue to influence the implementation of flipped classroom (Mokhele-Ramulumo et al., 2024; Pilu et al., 2025). These gaps indicate the need for more context-sensitive and empirically grounded studies that explicitly examine science literacy within realistic instructional conditions.

In light of these limitations, the present study seeks to provide a more focused examination of science literacy by positioning it as the primary outcome of interest within an elementary school context. Unlike prior studies that predominantly emphasize general academic performance, this research explicitly investigates changes in students' science literacy through the implementation of the flipped classroom model using a quantitative pre-experimental approach. This design is intentionally selected to accommodate real classroom constraints while still enabling the systematic analysis of learning changes before and after the intervention. By situating the study within an underexplored context—namely elementary education with a specific emphasis on science literacy—this research aims to contribute empirical evidence that bridges the gap between pedagogical innovation and measurable literacy outcomes. Furthermore, the findings are expected to offer practical insights into how flipped classroom can be adapted as a contextually relevant instructional strategy, particularly in settings with limited resources, while also enriching the ongoing discourse on effective approaches to fostering science literacy in foundational education.

Methods

This study employed a quantitative approach using a pre-experimental design, specifically the one-group pretest–posttest design, to analyze changes in students' science literacy before and after the implementation of the flipped classroom model. This design is commonly used in educational research to examine learning changes under practical constraints, particularly when the establishment of a control group is not feasible (Creswell & Creswell, 2018; Fraenkel et al., 2011; Suhirman et al., 2026). Although it has limitations in controlling external variables, this design still provides empirical insights into students' learning progress through the comparison of pre-intervention and post-intervention scores. The study was conducted at SDN 20 Tanjung Keramat and involved all fifth-grade students, totaling 15 participants, consisting of 9 males and 6 females. A saturated sampling technique was applied, in which the entire population was used as the research sample (Sugiyono, 2023).

The research instrument consisted of a science literacy test in the form of 20 multiple-choice items. The instrument was developed based on science literacy competency indicators adapted from the Programme for International Student Assessment (PISA) framework, which

includes the ability to explain scientific phenomena, identify scientific questions, and use scientific evidence in decision-making (PISA, 2019). The instrument development process involved blueprint construction, item writing, and content validation by an expert to ensure alignment between indicators, content, and measurement objectives (Nasution, 2023; Suhirman et al., 2026). Reliability testing was conducted using Cronbach's Alpha coefficient to assess internal consistency, which is widely applied in quantitative educational research (Hamdi & Bahrudin, 2014). The detailed indicators of science literacy used in this study are presented in Table 1.

Table 1. Science Literacy Indicators

No	Science Literacy Indicator	Description	Number of Items
1	Explaining scientific phenomena	Ability to understand and explain scientific concepts in real-life contexts	7
2	Identifying scientific questions	Ability to formulate and recognize science-based problems	6
3	Using scientific evidence	Ability to analyze data and draw conclusions based on evidence	7

Data analysis was conducted in two stages. First, descriptive analysis was used to examine the distribution of pretest and posttest scores. This was followed by inferential analysis using the Wilcoxon Signed-Rank Test, a non-parametric statistical method appropriate for paired data with small sample sizes (Field, 2017; Suhirman et al., 2026). This test was employed to determine whether there were significant differences between pre-intervention and post-intervention scores. In addition to statistical significance, the interpretation of results also considered the direction of score changes to provide a more comprehensive understanding of students' improvement in science literacy following the implementation of the flipped classroom model.

Result

The results of this study are presented to examine the changes in students' science literacy before and after the implementation of the flipped classroom model. The analysis begins with descriptive statistics to provide an overview of the distribution and general trends of students' pretest and posttest scores.

Table 2. Descriptive Statistics of Pretest and Posttest Scores

Data	N	Mean	Min	Max
Pretest	15	55.06.00	45	70
Posttest	15	83.08.00	75	95

As shown in Table 2, the mean pretest score was 55.6, while the mean posttest score increased to 83.8, indicating a substantial improvement following the intervention. In addition, both the minimum and maximum scores shifted upward, suggesting that the improvement was not limited to specific individuals but occurred across the entire group of students. This pattern reflects a general enhancement in students' science literacy after the application of the flipped classroom model. To further examine whether the observed differences were statistically significant, a Wilcoxon Signed-Rank Test was conducted. The results of this analysis are presented in Table 3 and Table 4.

Table 3. Wilcoxon Signed-Rank Test Results

Category	N	Mean Rank	Sum of Ranks
Negative Ranks	0	00.00	00.00
Positive Ranks	15	08.00	120.00.00
Ties	0	-	-

As presented in Table 3, there were no negative ranks, indicating that none of the students experienced a decline in scores after the intervention. All observations were categorized as positive ranks, meaning that every student demonstrated improvement. The mean rank of 8.00 and the total sum of ranks of 120.00 further indicate a consistent direction of change toward higher scores across all participants.

Table 4. Wilcoxon Test Statistics

Statistic	Value
Z	-3.415
Asymp. Sig (2-tailed)	0.001

The statistical test results, as shown in Table 4, revealed a significance value of 0.001, which is lower than the established significance level ($\alpha = 0.05$). This finding indicates that there is a statistically significant difference between the pretest and posttest scores. Therefore, the implementation of the flipped classroom model is associated with an improvement in students' science literacy. Overall, the findings demonstrate that students' science literacy improved after the application of the flipped classroom model, as evidenced by both descriptive and inferential analyses. The improvement is reflected not only in the increase in average scores but also in the consistent upward trend observed across all students, suggesting that the instructional approach contributed positively to students' ability to understand and apply scientific concepts.

Discussion

The findings of this study indicate that the implementation of the flipped classroom model is associated with an improvement in students' science literacy, as reflected in the increase from pretest to posttest scores and the absence of any score decline among all participants. This consistent pattern of improvement suggests that the observed changes are not incidental but represent a uniform trend across the entire group. Such findings align with a substantial body of prior research highlighting the effectiveness of flipped classroom in enhancing learning outcomes. Meta-analytical evidence reported by Hew & Lo (2018) and Van Alten (2019) demonstrates that flipped classroom yields statistically significant positive effects on students' academic performance. Similarly, studies by Zainuddin & Halili (2016) and Lo & Hew (2017) emphasize its role in fostering student engagement and strengthening conceptual understanding. Within the Indonesian context, comparable findings have been documented by Putri et al. (2020) and Rahmawati (2019), who reported notable improvements in science literacy following the adoption of flipped classroom. Furthermore, the uniform improvement observed in all students in this study resonates with the findings of Sari & Wahyuni (2021), which indicate that learning gains can be experienced collectively rather than selectively.

Nevertheless, the effectiveness of flipped classroom is not universally consistent across all contexts. Several studies have reported mixed or non-significant results. For instance,

Stratton et al. (2019) and Jensen et al. (2015) found no statistically significant differences between flipped classroom and conventional or active learning approaches. Similarly, Bossaer et al. (2016) reported that improvements in academic performance were not consistently evident. Other studies, such as those by Cabi (2018) and Gren (2019), suggest that the effectiveness of flipped classroom is highly contingent upon instructional design quality and implementation context. Moreover, Karjanto & Acelajado (2022) argue that flipped classroom does not inherently outperform traditional methods. In the Indonesian setting, additional constraints such as technological readiness, teacher preparedness, and students' ability to manage independent learning have been identified as critical factors influencing its effectiveness (Darobi, 2023; Hamna, 2023). These variations highlight that the success of flipped classroom is context-dependent and cannot be generalized without considering situational factors.

The observed improvement in science literacy within this study can be interpreted through several complementary theoretical mechanisms. First, flipped classroom facilitates the implementation of active learning, in which students engage directly in discussion, problem-solving, and collaborative activities rather than passively receiving information. This approach aligns with empirical findings by Freeman et al. (2014) and Prince (2004), which demonstrate that active learning significantly enhances student achievement compared to traditional lecture-based instruction. By reallocating instructional time, flipped classroom enables deeper cognitive engagement and supports higher-order thinking processes essential for science literacy development. *Second*, from the perspective of cognitive load theory, flipped classroom contributes to a more balanced distribution of cognitive demands across different learning phases. Students are introduced to foundational content independently prior to classroom interaction, allowing them to process initial information at their own pace without immediate time pressure (Abeysekera & Dawson, 2015; Sweller, 1988, 2011). Consequently, classroom time can be devoted to elaboration, clarification, and application, which are critical for strengthening conceptual understanding and scientific reasoning.

Third, the flexibility inherent in flipped classroom promotes self-paced learning, enabling students to regulate their own learning processes according to their individual needs. This flexibility helps explain the absence of negative ranks in this study, as all students were afforded sufficient time and opportunity to grasp foundational concepts before engaging in more complex learning tasks (Tune et al., 2013). Furthermore, from a social constructivist perspective, classroom interactions provide opportunities for students to co-construct knowledge through dialogue and collaboration, which plays a crucial role in reinforcing science literacy (Piaget, 1970; Vygotsky, 1978). *Fourth*, increased student engagement and motivation constitute another important mechanism underlying the findings. Flipped classroom encourages active participation not only cognitively but also emotionally and socially, thereby enhancing students' overall learning experience (Albar et al., 2021; Fredricks et al., 2004; Zainuddin, 2018). The interactive and flexible nature of the learning environment fosters deeper involvement, which in turn contributes to improved understanding and application of scientific concepts.

From a theoretical standpoint, the findings of this study reinforce the integration of social constructivism, active learning principles, and cognitive load theory in explaining the effectiveness of flipped classroom. Rather than functioning merely as an instructional technique, flipped classroom can be conceptualized as a comprehensive pedagogical framework that supports structured and active knowledge construction. This interpretation is

consistent with Bishop & Verleger (2013), who conceptualize flipped classroom as a combination of direct instruction and active learning. Furthermore, the observed improvement in science literacy aligns with the frameworks proposed by OECD (2019) and Bybee (2013), which emphasize the importance of understanding, applying, and evaluating scientific knowledge in real-world contexts.

From a practical perspective, the findings offer important implications for educators and practitioners. Flipped classroom can serve as an effective alternative instructional strategy for enhancing science literacy, provided that it is implemented through careful and systematic instructional design. Teachers need to optimize the pre-class phase by providing clear and structured instructional materials, particularly in the form of video-based content, while utilizing classroom time for interactive activities such as discussion and problem-solving (Bergmann & Sams, 2012). In addition, the success of this model is influenced by technological readiness and students' capacity for self-directed learning (Zainuddin & Halili, 2016). The inherent flexibility of flipped classroom also allows for differentiated instruction tailored to students' diverse learning needs (Tomlinson, 2014), thereby supporting more equitable learning outcomes across heterogeneous classrooms.

Conclusion

This study demonstrates that the implementation of the flipped classroom model is associated with an improvement in students' science literacy, as indicated by the differences between pretest and posttest scores and the consistent upward trend observed across all participants. These findings suggest that structuring learning through a combination of independent pre-class activities and interactive in-class engagement provides students with greater opportunities to process, internalize, and apply scientific concepts. In this regard, the flipped classroom model can be considered a promising instructional approach for supporting the development of science literacy at the elementary level, particularly in learning environments that emphasize active participation and deeper cognitive engagement.

More broadly, the findings of this study offer both theoretical and practical implications. From a theoretical perspective, the results reinforce the relevance of integrating active learning, constructivist principles, and cognitive load management in explaining improvements in science literacy. From a practical standpoint, the study highlights the importance of carefully designing flipped classroom implementation by considering students' readiness, the availability of instructional media, and the quality of classroom interaction. However, this study is limited by the use of a pre-experimental design and a relatively small sample size, which restricts the generalizability of the findings. Therefore, future research is recommended to employ more rigorous research designs, involve larger and more diverse samples, and develop more comprehensive instruments for measuring science literacy in order to provide a deeper understanding of the effectiveness of flipped classroom across different educational contexts.

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