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Scientific literacy of primary school teacher education students using RADEC based course materials on basic science concepts

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ABSTRACT

This study examined changes in scientific literacy among prospective primary school teachers following instruction using Read, Answer, Discuss, Explain, and Create (RADEC)-based course materials across three basic science topics. A one-group pretest–posttest design involved purposively selected third-semester teacher education students. Scientific literacy was assessed using ten essay questions addressing scientific inquiry, explanation of phenomena, and evidence use. Mean scores increased from 23.85 (SD = 7.20) to 67.92 (SD = 19.43). Normalized gains were moderate for matter and its changes (0.51), temperature and heat (0.64), and the circulatory system (0.56). Improvements were observed across scientific literacy competencies, although posttest scores showed substantial variability. RADEC-based materials were associated with improved scientific literacy across the three topics. However, the absence of a control group and variability in student performance limit causal interpretation and warrant further rigorous controlled investigations.



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Introduction

Scientific literacy constitutes a fundamental professional competence for prospective primary school teachers, enabling them to interpret scientific phenomena, evaluate empirical evidence, and communicate scientific concepts accurately within educational contexts. Beyond conceptual knowledge, scientific literacy encompasses the ability to formulate scientific questions, explain natural phenomena, and draw evidence-based conclusions, as emphasized in the Programme for International Student Assessment (PISA) framework (OECD, 2023; National Research Council, 2012). These competencies are particularly relevant to primary teacher education because prospective teachers must transform scientific knowledge into meaningful learning experiences appropriate to children's cognitive development. Scientific literacy also supports critical reasoning, problem-solving, and informed decision-making, which are essential for effective science instruction (Osborne, 2014; Turiman et al., 2012). Nevertheless, developing these competencies requires instructional approaches that integrate conceptual understanding with scientific inquiry and evidence-based reasoning rather than emphasizing factual knowledge alone (Bybee & Chair, 2009). Consequently, strengthening scientific literacy during initial teacher education represents an important foundation for improving prospective teachers' preparedness to facilitate meaningful science learning.

Despite its educational significance, empirical studies have identified persistent limitations in scientific literacy among prospective and practicing primary school teachers. Research in Indonesian teacher education contexts has reported inadequate scientific literacy achievement, particularly in competencies requiring scientific reasoning and the application of conceptual knowledge (Fazilla, 2016; Puspita R, 2021). Similarly, Juniarso (2019) found that prospective teachers predominantly demonstrated functional scientific literacy, suggesting limited progression toward more comprehensive scientific understanding. International investigations have also documented scientific literacy difficulties among teachers and teacher candidates, although differences in educational systems, participant characteristics, and assessment instruments limit direct comparisons with Indonesian primary teacher education students (Sülün et al., 2009; Akengin & Sirin, 2013). Collectively, these findings indicate that scientific literacy challenges extend beyond knowledge acquisition and involve the ability to interpret scientific information, construct explanations, and evaluate supporting evidence. However, existing studies provide insufficient evidence regarding how these specific competencies develop through structured science learning materials in Indonesian higher education contexts.

Several instructional and contextual factors may contribute to inadequate scientific literacy development, including limited contextualization of scientific concepts, insufficient opportunities for inquiry, and instructional materials that prioritize memorization over scientific reasoning. Previous investigations have identified difficulties in connecting theoretical science knowledge with everyday phenomena, potentially restricting students' ability to apply scientific concepts meaningfully (H. Lestari, 2020; I. Lestari, 2019). Additional research has highlighted challenges associated with literacy achievement, scientific misconceptions, teacher competence, and educational resources within Indonesian science education (Ratri, 2015; Yusmar & Fadilah, 2023). Fuadi et al. (2020) further identified instructional materials, reading proficiency, misconceptions, and limited contextual learning as factors associated with scientific literacy outcomes. Although misconceptions and scientific literacy are conceptually related, their relationship should not be interpreted as evidence that inadequate literacy among prospective teachers directly causes misconceptions in primary school pupils without longitudinal or classroom-based verification (Fazilla, 2016). These findings emphasize the importance of instructional materials that explicitly support scientific questioning, conceptual explanation, and evidence evaluation through structured learning activities.

The Read, Answer, Discuss, Explain, and Create (RADEC) model offers a potentially relevant instructional framework for addressing these competencies through sequential and collaborative learning activities. Originally introduced by Sopandi (2017), RADEC was subsequently proposed as an instructional approach compatible with Indonesian educational characteristics and learning requirements (Sopandi, 2019). Its instructional sequence provides opportunities for students to develop conceptual understanding through independent reading, articulate preliminary reasoning through written responses, and refine scientific explanations through collaborative discussion. The Explain stage encourages the communication and justification of scientific understanding, whereas the Create stage provides opportunities to apply acquired knowledge to meaningful problems. Conceptually, these activities correspond to scientific literacy competencies involving the identification of scientific questions, explanation of phenomena, and interpretation of scientific evidence (OECD, 2023; Agustin et al., 2021). Previous studies have reported favorable outcomes of RADEC implementation for prospective teachers' lesson-planning abilities and the development of broader twenty-first-century competencies (Handayani et al., 2019; Pratama et al., 2019). Nevertheless, these findings do not directly establish its contribution to measurable scientific literacy development, particularly across different science content domains.

Although inquiry-oriented instruction has demonstrated potential for strengthening scientific literacy, evidence concerning the specific contribution of RADEC-based course materials to prospective primary school teachers' scientific literacy remains insufficiently established. For example, Ristanto et al. (2017) reported improvements in scientific literacy through guided inquiry, supporting the broader relevance of active learning approaches without establishing the comparative superiority of RADEC. Existing RADEC investigations have primarily emphasized instructional processes, lesson planning, and general learning competencies rather than systematically examining changes across PISA-oriented scientific literacy indicators (Handayani et al., 2019; Pratama et al., 2019; Agustin et al., 2021). Furthermore, limited attention has been given to whether scientific literacy development differs across fundamental science topics requiring distinct forms of conceptual and evidence-based reasoning. Matter and its changes, temperature and heat, and the human circulatory system provide relevant contexts because they involve observable physical transformations, explanations of thermal phenomena, and biological system interactions, respectively. Examining these topics offers an opportunity to characterize scientific literacy development across multiple content domains while identifying variations in learning achievement.

Addressing these gaps, the present study examined changes in scientific literacy among prospective primary school teachers following instruction using RADEC-based course materials in the Basic Concepts of Natural Science course. Specifically, the investigation focused on three PISA-oriented competencies: identifying scientific questions, explaining phenomena scientifically, and using scientific evidence across matter and its changes, temperature and heat, and the human circulatory system (OECD, 2023). Using a one-group pretest–posttest design, the study evaluated overall changes in scientific literacy achievement and topic-specific learning gains following the instructional intervention. The study's contribution lies in providing competency-oriented and content-specific empirical evidence concerning scientific literacy development within RADEC-supported preservice teacher education, extending previous research primarily focused on instructional planning and broader learning competencies (Sopandi, 2017; Sopandi, 2019; Handayani et al., 2019; Pratama et al., 2019). Given the absence of a comparison group, the findings are interpreted as observed changes associated with the instructional implementation rather than definitive evidence of causal effectiveness. This investigation therefore provides a contextual foundation for refining RADEC-based science instruction and informing subsequent controlled research.

Method

Research Design

This study employed a quantitative approach using a pre-experimental one-group pretest–posttest design to examine changes in scientific literacy among prospective primary school teachers following instruction supported by Read, Answer, Discuss, Explain, and Create (RADEC)-based course materials. The research design involved measuring students' scientific literacy before and after the instructional intervention within the same participant group (Creswell, 2012). The pretest established baseline scientific literacy achievement, whereas the posttest assessed subsequent performance following the implementation of RADEC-based learning activities. The research design is represented as O_1-X-O_2 , where O_1 denotes the pretest, X represents the instructional intervention, and O_2 indicates the posttest. This design enabled the examination of within-group changes across scientific literacy competencies and basic science topics. However, because no comparison group was included, the observed changes cannot be attributed exclusively to the intervention.

Participants and Sampling

The study was conducted at Langlangbuana University, Bandung, Indonesia, involving third-semester students enrolled in the Primary School Teacher Education Program during the 2022 academic cohort. Participants were selected through purposive sampling, with Class A01 designated as the study group. The selection considered students' academic achievement, information obtained through interviews with the course lecturer, and existing classroom conditions. All selected participants received instruction using RADEC-based course materials within the Basic Concepts of Natural Science course. The study focused on prospective primary school teachers because scientific literacy constitutes an essential competence for understanding scientific concepts and facilitating evidence-based science instruction. The unit of analysis was the individual student, with scientific literacy performance assessed at two measurement points. The sampling procedure was nonrandom, and the findings were therefore interpreted within the characteristics of the participating class rather than generalized to the broader population of prospective teachers.

Instructional Intervention

The instructional intervention integrated RADEC-based course materials into the Basic Concepts of Natural Science course, covering three scientific topics: matter and its changes, temperature and heat, and the human circulatory system. The intervention followed five sequential instructional stages: Read, Answer, Discuss, Explain, and Create. During the Read stage, students independently examined relevant scientific materials provided by the lecturer and consulted additional learning resources to develop preliminary conceptual understanding. In the Answer stage, students responded to pre-learning questions presented through structured learning worksheets. Subsequently, the Discuss stage involved collaborative activities in which students compared responses, clarified misconceptions, and developed scientific explanations through peer interaction. During the Explain stage, students presented their understanding and communicated scientific reasoning based on the learning materials and classroom discussions. Finally, the Create stage encouraged students to apply acquired knowledge by generating ideas or solutions related to the scientific concepts studied. These activities were implemented across the three science topics to provide structured opportunities for conceptual understanding, scientific reasoning, and evidence-based explanation.

Research Instruments and Data Collection

Scientific literacy was assessed using a learning achievement test consisting of ten open-ended essay questions developed around the scientific literacy competencies represented in the Programme for International Student Assessment framework. The assessment addressed three competencies: identifying scientific questions,

explaining phenomena scientifically, and using scientific evidence. These competencies were examined within the contexts of matter and its changes, temperature and heat, and the human circulatory system. The essay format was used to assess students' ability to articulate scientific understanding, construct explanations, and apply scientific reasoning rather than merely recognize factual information. Data collection was conducted at two stages. First, participants completed a pretest before receiving instruction using RADEC-based course materials. Following the instructional activities, participants completed a posttest to assess changes in scientific literacy achievement. The resulting scores provided the basis for evaluating overall performance, topic-specific achievement, and changes across scientific literacy competencies.

Statistical Analysis

Quantitative data were analyzed using IBM SPSS Statistics version 26. Descriptive statistics, including mean scores, standard deviations, minimum values, maximum values, and medians, were used to summarize students' scientific literacy achievement before and after the intervention. Differences between paired pretest and posttest scores were examined using the Wilcoxon signed-rank test, consistent with the nonparametric analysis reported in the study. Statistical significance was evaluated at the 0.05 level. In addition, normalized gain (N-gain) scores were used to describe the magnitude of learning improvement across the three science topics and scientific literacy competencies. Normalized gain was calculated as the difference between posttest and pretest scores divided by the difference between the maximum attainable score and the pretest score. N-gain values were interpreted using three categories: low ($g < 0.30$), moderate ($0.30 \leq g < 0.70$), and high ($g \geq 0.70$). The analyses focused on describing within-group changes in scientific literacy performance following RADEC-based instruction, without making causal comparisons with alternative instructional approaches.

Results and Discussions

The RADEC learning model was employed to conduct the course. This model comprises the stages of Read, Answer, Discuss, Explain, and Create. The "Read" stage takes place both prior to and during the lesson; students are required to read the material to be taught, utilizing sources provided by the lecturer, the internet, or other relevant materials. Following the "Read" stage, the "Answer" stage begins, wherein students are presented with pre-learning questions. Before answering these questions, participants are instructed to consult alternative reading materials. After completing the reading and answering stages, students proceed with classroom learning through the remaining three RADEC stages: Discuss, Explain, and Create.

The course begins with a pre-test, followed by instruction using the RADEC model covering the Read, Answer, Discuss, Explain, and Create stages. After the Read and Answer stages, the course addresses three key topics regarding basic science concepts: temperature and heat; matter and its changes; and the human circulatory system, utilizing prepared RADEC-based instructional materials. At the conclusion of the course following the "Create" stage students take a post-test to measure the scientific literacy achievement of the Primary School Teacher Education (PGSD) students. Pre-test and post-test scores are processed and analyzed using SPSS V.26. Descriptive data regarding the pre-test and post-test scores are presented in Table 1.

Table 1. Descriptive Data

No	Descriptive Statistics	Pre-test	Post-test
1	Minimum Score	5,00	0,00
2	Maximum Score	33,00	85,00
3	Mean	23,85	67,92
4	Median	26,00	73,00
5	Standard Deviation	7,20	19,43

Based on Table 1, the mean pre-test and post-test scores show an increase; this indicates an upward trend in student scores following instruction that utilized RADEC-based learning materials for basic science concepts. The average pre-test and post-test scores for each topic are presented in Figure 1.

Based on Figure 2, the average pre-test and post-test scores for the topics of "Matter and Change," "Temperature and Heat," and the "Human Circulatory System" show an upward trend in scores. The differences between the pre-test and post-test scores across these three topics indicate that the implementation of the RADEC-based instructional materials can enhance students' scientific literacy in each of these subject areas.

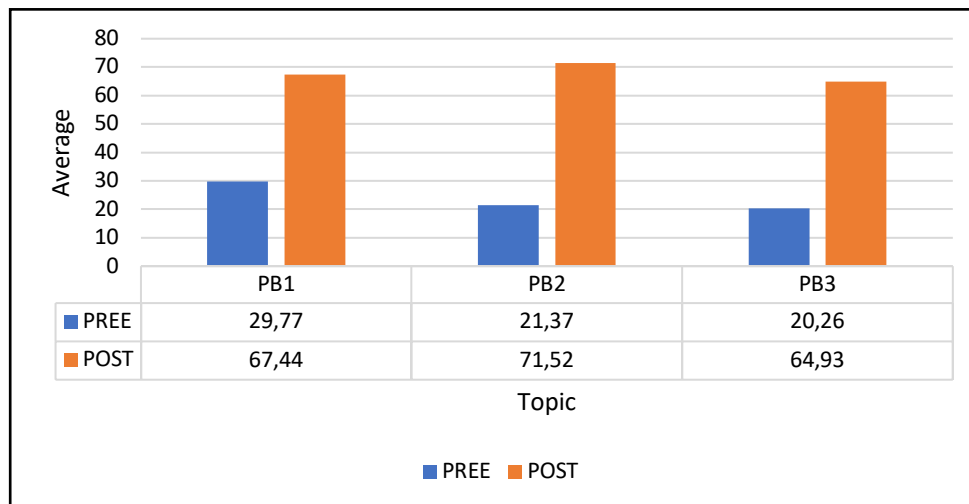


Figure 2. Average Pre-test and Post-test Scores for Each Topic

Note:

PB1 = Topic: Matter and its changes

PB2 = Topic: Temperature and heat

PB3 = Topic: Circulatory system

The improvement in scientific literacy skills is evident from the N-gain scores. The normalized N-gain scores for each topic are presented in Figure 3.

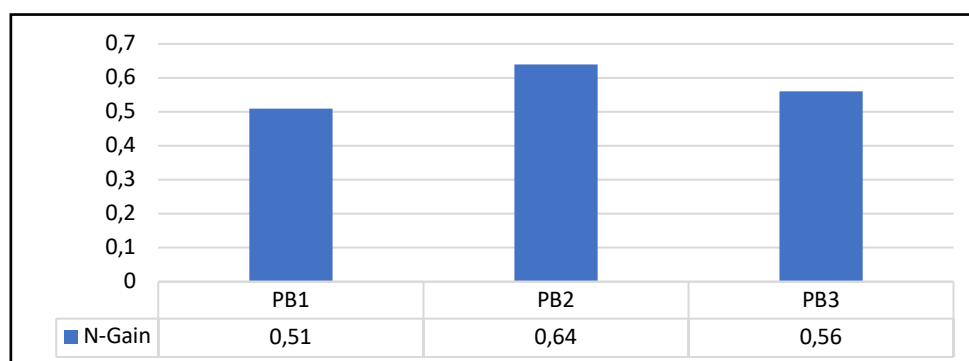


Figure 3. Normalized N-Gain values for each topic.

Based on Figure 3, the N-Gain values for the topics of "Matter and Change," "Temperature and Heat," and the "Human Circulatory System" fall into the medium category, as they range between 0.30 and 0.70. This medium classification is attributed to the fact that, during the implementation of the RADEC learning model, certain stages within its syntax were not fully executed effectively; nevertheless, the use of RADEC-based instructional materials can enhance students' understanding of science and improve their scientific knowledge at the university level. Figure 3 below illustrates the improvement in students' scientific literacy across each aspect of scientific literacy competence.

Based on Figure 4, it is evident that the average pre-test and post-test scores for each sub-aspect of competence across the respective topics showed improvement. This trend was observed in the sub-aspects of identifying scientific questions in scientific literacy, explaining phenomena scientifically, and using scientific evidence. The improvement in each scientific literacy competence aspect is reflected in the recorded N-gain values. The normalized N-gain values for each aspect of scientific literacy competence are presented in Figure 5.

Based on Figure 5, the N-gain values for the topics of "Matter and Change," "Temperature and Heat," and "Circulatory Systems"—across the competency aspects of identifying scientific questions, explaining phenomena scientifically, and using scientific evidence—fall into the medium category. This indicates that implementing RADEC-based course materials in the field-test class improved students' scientific literacy skills across these topics and competency aspects; however, the overall improvement in scientific literacy competency remains within the medium category. The categorization of the improvement in scientific literacy skills, based on the number of students, is presented in Table 2.

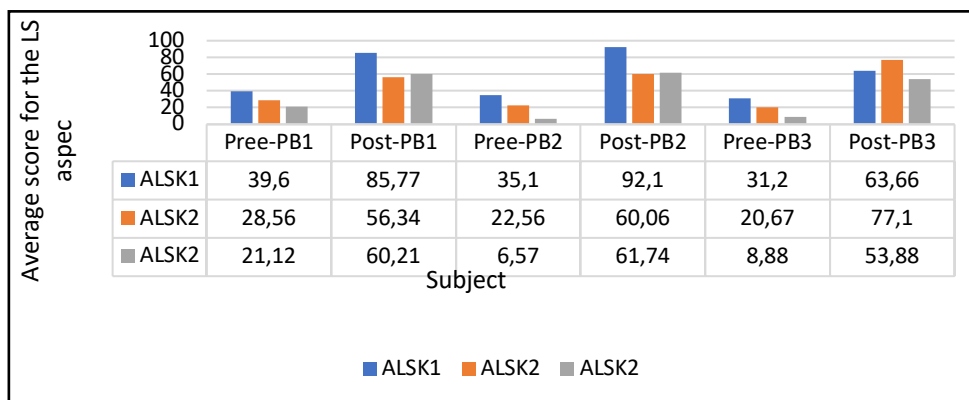


Figure 4. Mean pre-test and post-test scores of students for each aspect of scientific literacy competence.

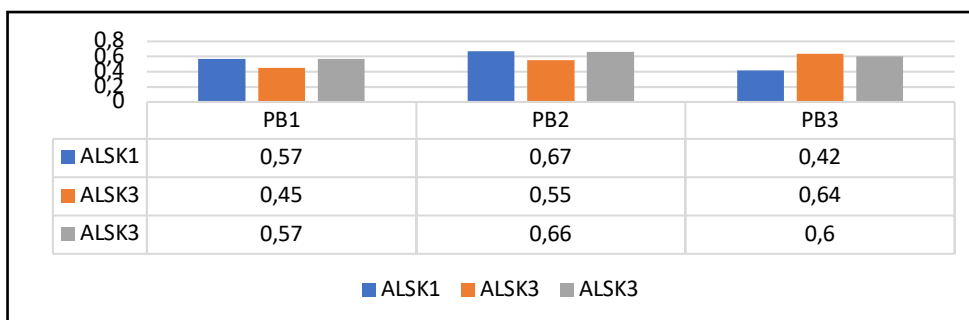


Figure 5. Interpretation of values for each aspect of scientific literacy competence.

ALSK1 = Scientific literacy competency aspect of identifying scientific questions.

ALSK2 = Scientific literacy competency aspect of explaining scientific phenomena.

ALSK3 = Scientific literacy competency aspect of using scientific evidence.

Table 2. Categories of Improvement in Scientific Literacy Skills Based on Subject Matter

No.	Category	PB1 Total	PB1 (%)	PB2 Total	PB2 (%)	PB3 Total	PB3 (%)
1	High	5	18	12	45	8	24
2	Medium	18	67	12	44	16	64
3	Low	4	15	3	11	3	12
Total		27	100	27	100	27	100

Based on Table 2 above, it is evident that the science literacy proficiency of the class across all topics predominantly falls into the "medium" category; indeed, nearly all results fall within this range. This indicates that while the use of RADEC-based instructional materials supports student science literacy, the resulting proficiency levels across the various topics remain within the medium category.

To assess the improvement in science literacy among Primary Teacher Education (PGSD) students—comparing levels before and after instruction using RADEC-based materials in the large-scale field test class—a paired-sample t-test was employed, preceded by prerequisite normality and homogeneity tests. The normality test utilized was the one-sample Kolmogorov-Smirnov test, conducted using SPSS version 26. The results of the normality test are presented in Table 3 below.

Table 3. Normality Test Results: Tests of Normality

Variable	Kolmogorov–Smirnov ^a Statistic	df	Sig.	Shapiro–Wilk Statistic	df	Sig.
Pretest LS	0.176	27	0.031	0.878	27	0.004
Posttest LS	0.213	27	0.003	0.726	27	0.000

^a Lilliefors Significance Correction. Source: SPSS output.

Based on Table 3 above, the normality test results are derived from the Shapiro-Wilk test (since $df < 50$), yielding significance values of 0.004 for the pre-test and 0.000 for the post-test—both below the 0.05 threshold. Since the significance values (Sig) for both the pre-test and post-test are less than 0.05, the data are not normally distributed. The second prerequisite test is the homogeneity test; the results of this test are presented in Table 4

below. Based on Table 4, the significance value (Sig.) based on the mean is 0.015; since this is less than 0.05, the data are not homogeneous, meaning

Table 4. Homogeneity Test Results

Variable	Method	Levene Statistic	df1	df2	Sig.
Kemampuan LS	Based on Mean	6.284	1	52	0.015
	Based on Median	4.961	1	52	0.030
	Based on Median and with adjusted df	4.961	1	32.117	0.033
	Based on Trimmed Mean	5.333	1	52	0.025

Interpretation: Levene's test based on the mean indicated a statistically significant difference in variances ($F(1, 52) = 6.284$, $p = 0.015$). Since $p < 0.05$, the assumption of homogeneity of variances was not satisfied.

The variances originate from unequal populations. Given that the data lack normality and homogeneity, subsequent analysis was conducted using non-parametric statistics—specifically the Wilcoxon test—with the aid of SPSS version 26 software. The results of the Wilcoxon test are presented in Table 5 below.

Table 5. Results of the Wilcoxon Class Test for Field Area Test Statistics

Test Statistics ^a	Posttest – Pretest
Z	-4.518 ^b
Asymp. Sig. (2-tailed)	0.000

^a Wilcoxon Signed Ranks Test. ^b Based on negative ranks. Source: SPSS output.

Based on Table 5, the Asymp. Sig. (2-tailed) value was found to be 0.000 (< 0.05); thus, the hypothesis is accepted. This indicates a significant difference between the pre-test and post-test scores in the large-scale field trial class, demonstrating the significant impact of using RADEC-based instructional materials on enhancing the scientific literacy of Primary Teacher Education (PGSD) students. By selecting appropriate instructional materials, lecturers can create learning experiences that effectively boost students' scientific literacy in large-scale field trial settings. These findings align with research results indicating that the developed instructional materials are effective and suitable for implementation in broader educational contexts, as they successfully improved scientific literacy among all participants in the field trial (Dini & Yunus, 2021).

The findings demonstrated a statistically significant improvement in scientific literacy among prospective primary school teachers following the implementation of RADEC-based course materials. The mean score increased from 23.85 in the pretest to 67.92 in the posttest, representing a substantial descriptive improvement of 44.07 points. The Wilcoxon signed-rank test confirmed a significant difference between the two measurements ($Z = -4.518$, $p < 0.001$). These findings suggest that the structured integration of reading, individual responses, collaborative discussion, scientific explanation, and creative application was associated with improved scientific literacy achievement. The observed improvement is consistent with the cognitive learning framework proposed by Krathwohl (2002), which emphasizes the progression from knowledge acquisition toward higher-order cognitive processes. Furthermore, the collaborative and explanatory components of RADEC correspond to Vygotsky's (1978) social constructivist perspective, which recognizes social interaction as an important mechanism for knowledge construction. Nevertheless, the absence of a control group prevents definitive attribution of these improvements exclusively to RADEC-based instruction.

Improvements in scientific literacy were observed across all three science topics, although their magnitude varied. The normalized gain values were 0.51 for matter and its changes, 0.64 for temperature and heat, and 0.56 for the human circulatory system, indicating moderate improvement across the investigated content domains. The highest gain in temperature and heat suggests that students may have benefited particularly from instructional activities connecting observable physical phenomena with scientific explanations. Meanwhile, the relatively lower gain in matter and its changes may reflect differences in conceptual complexity, prior knowledge, or students' engagement with the instructional materials. However, these potential explanations require further empirical investigation. The moderate gains also indicate that improvements were meaningful but had not reached the highest achievement category. This interpretation is consistent with Sopandi (2017), who emphasized the importance of implementing the RADEC instructional stages coherently to facilitate critical and creative thinking. Accordingly, the findings highlight the importance of instructional quality and the need to strengthen conceptual scaffolding throughout the learning process.

Regarding scientific literacy competencies, the findings revealed improvements in identifying scientific questions, explaining phenomena scientifically, and using scientific evidence. These competencies represent essential dimensions of scientific literacy because they enable learners to formulate investigable problems,

interpret scientific phenomena, and construct conclusions supported by empirical information (OECD, 2019). The RADEC instructional sequence provides a theoretically relevant framework for developing these competencies through interconnected learning activities. Specifically, the Read and Answer stages support initial conceptual engagement, whereas the Discuss and Explain stages create opportunities for scientific argumentation, clarification, and evidence-based reasoning. The Create stage further encourages students to apply scientific understanding to contextual problems. These findings are consistent with Dini Yunus (2021), who reported that innovative instructional materials could support scientific literacy development. Moreover, the emphasis on contextual application corresponds with Bybee's (2013) perspective that meaningful scientific literacy requires learners to connect scientific understanding with authentic situations. Nevertheless, improvements across competency indicators should be interpreted as changes in assessed performance rather than definitive evidence of equivalent development in all underlying scientific reasoning processes.

Despite the statistically significant improvement, the predominance of moderate N-gain values indicates opportunities for further instructional refinement. One possible explanation is that students experienced difficulties completing higher-order learning activities, particularly during the Create stage, which requires the integration of scientific concepts, analytical reasoning, and creative problem-solving. However, because the present study did not systematically measure implementation fidelity or stage-specific learning difficulties, this explanation remains tentative. Future instructional implementation should therefore emphasize the quality and accessibility of reading materials, structured questioning, collaborative scaffolding, and authentic scientific problem-solving tasks. These recommendations are consistent with Sopandi's (2017) emphasis on the sequential implementation of RADEC and Bybee's (2013) argument that scientific literacy develops through meaningful engagement with scientific practices. Furthermore, the considerable variability in posttest achievement ($SD = 19.43$), compared with pretest performance ($SD = 7.20$), suggests that students may have benefited differently from the instructional activities. This variability warrants further investigation into individual learning characteristics, prior scientific knowledge, and differences in participation.

The present study contributes to science teacher education by providing empirical evidence of changes in scientific literacy across multiple science topics and competency indicators following RADEC-based instruction. Its findings extend previous discussions of instructional innovation by demonstrating how a structured learning sequence may support prospective teachers' engagement with scientific concepts, reasoning, and evidence-based explanation. Nevertheless, several methodological limitations should be acknowledged. The one-group pretest–posttest design restricts causal inference because maturation, testing effects, and other uncontrolled influences cannot be excluded. Additionally, purposive sampling from a single class of 27 students limits the generalizability of the findings, while the absence of reported instrument reliability estimates and implementation fidelity measures constrains the interpretation of measurement quality and instructional consistency. Future research should employ controlled or randomized designs, larger and more diverse samples, validated scientific literacy instruments, and longitudinal assessments to establish the robustness and sustainability of learning improvements. Overall, RADEC-based course materials represent a promising instructional approach for supporting scientific literacy development among prospective primary school teachers, although stronger experimental evidence is necessary to determine their comparative effectiveness and broader educational applicability.

Conclusions

This study concludes that the implementation of RADEC-based course materials was associated with improved scientific literacy among prospective primary school teachers across basic science concepts. Improvements were observed in students' abilities to identify scientific questions, explain scientific phenomena, and use scientific evidence. These findings suggest that RADEC-based instruction represents a promising approach to supporting scientific literacy development in primary teacher education.

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