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# Moderation of Learning Motivation on the Effectiveness of Problem-Based Learning on Elementary School Students' Science Literacy: Quasi-Experimental Pretest–Posttest

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**Abstract:** This research is motivated by the importance of scientific literacy at the elementary school level and the need for an effective learning model to improve it, by considering students' psychological factors such as learning motivation. Objective: This study aims to investigate the effect of Problem-Based Learning (PBL) and learning motivation on elementary school students' scientific literacy, and to test the interaction between the two variables. Method: This study used a quasi-experimental design with a pretest–posttest nonequivalent control group. The sample consisted of 60 fourth-grade students at Mekar Bakti Public Elementary School, Indonesia, divided into two classes (n=30 each). Scientific literacy was measured using a PISA-oriented essay test (scale 0–100), while learning motivation was assessed with a 40-item Likert questionnaire ($\alpha$=0.884). Data were analyzed using a 2×2 factorial ANOVA and Tukey HSD follow-up test. The findings showed that: Students in the PBL class achieved higher scientific literacy than those in the conventional class (M=78.63 vs 68.57; p=0.001); Students with high motivation outperformed students with low motivation (M=76.67 vs 70.53; p=0.039); There was a significant interaction between PBL and learning motivation (F (1.56) =17.23; p<0.001); The post-hoc test results showed that the PBL-high motivation group performed significantly better than the other three groups. These findings indicate that the PBL model is most effective when student motivation is high.

**Keywords:** Elementary School; Learning motivation; Problem-Based Learning; Scientific literacy; Quasi-Experiment

## Introduction

Scientific literacy is a key 21st-century competency that enables students to understand phenomena, assess evidence-based information, and make decisions regarding science and technology issues in everyday life. The PISA framework defines scientific literacy as the ability to explain scientific phenomena, design and evaluate scientific investigations, and critically interpret data and evidence (Qiao et al., 2024). At the primary school level, scientific literacy instruction also needs to emphasize the functional side—the ability to use scientific knowledge in social and real-life contexts—and the integration of knowledge, scientific practice, and reasoning (Atias, 2026; Istyadji & Sauqina, 2023). In line with the challenges of scientific literacy achievement in various countries, the 2022 PISA report emphasizes the importance of learning that fosters active student engagement, learning resilience, and teacher support. Strengthening scientific literacy at the primary level needs to begin with meaningful, student-centered learning experiences that connect science to real-life contexts. The findings of a systematic review also emphasize the urgency of strengthening scientific literacy learning practices from an early age through consistent and measurable instructional design (Leonia et al., 2025; Roy et al., 2025). Problem-Based Learning (PBL) is a learning approach that positions contextual problems as the catalyst for learning activities, requiring students to ask questions, seek information, argue, and

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communicate solutions. Synthetic evidence shows that PBL has a positive impact on science learning outcomes (Koçoğlu & Kanadlı, 2025) and contributes to strengthening scientific literacy (Setyasih et al., 2022). In the Indonesian context, research in elementary schools reports that PBL can improve scientific literacy, including when enriched with media and local wisdom (Dina Restiani et al., 2024; Kristiantari et al., 2022; Lina, 2024). The systematic review also revealed variations in PBL implementation that influence its success in the classroom (Akcay & Benek, 2024).

However, the effectiveness of PBL is not uniform across all students. Self-determination theory-based motivation literature indicates that autonomous motivation, psychological need satisfaction (autonomy, competence, relatedness), and teacher support are associated with engagement, persistence, and learning outcomes (Bureau et al., 2022; Howard et al., 2021). Autonomy-supportive teaching practices have been shown to be scalable and provide broad benefits to student motivation and engagement (Reeve & Cheon, 2021), especially when combined with a clear learning structure (Patzak & Zhang, 2025). In the context of problem-based learning, meta-analyses indicate that problem-driven learning (including PBL) tends to increase motivation, but the magnitude of the effect is influenced by student characteristics and the quality of implementation (Gusti Alfiyanti & Erita, 2023; Wijnia et al., 2024). Based on these findings, this study focuses on examining the influence of PBL and learning motivation on scientific literacy, as well as examining their interaction in elementary school students. Interaction testing is important to determine whether PBL provides differential benefits for highly and low-motivated students, allowing for more precise learning implications (e.g., motivational support and scaffolding strategies during evidence-based discussions). Operationally, scientific literacy in this study was measured using a PISA-oriented essay test, while learning motivation was measured using a questionnaire that assessed students' internal and external drives to actively engage in learning.

The use of clearly defined scientific literacy instruments is essential to ensure comparability of reported results across studies and support the accumulation of evidence (Gusmaweti et al., 2023; O'Donohoe et al., 2023). The research questions are: Are there differences in scientific literacy between students learning with PBL and conventional learning? Are there differences in scientific literacy between students with high and low learning motivation? and is there an interaction between the learning model (PBL vs. conventional) and learning motivation (high vs. low) on scientific literacy?. Hypotheses tested: H1: Students learning with PBL have higher scientific literacy than those learning with conventional learning; H2: scientific literacy of students with high learning motivation is higher than with low learning motivation; H3: there is an interaction between learning model × learning motivation on scientific literacy.

## Method

The research design used a quasi-experimental pretest–posttest nonequivalent control group in two existing classes (intact classes). The pretest was used to capture initial scientific literacy abilities and examine initial equivalence between groups before the treatment. After the treatment, the posttest was used as a measure of scientific literacy outcomes. Participants were 60 fourth-grade students at Mekar Bakti Public Elementary School, Panongan District, Tangerang Regency. Class IV-B (n=30) was designated as the experimental class receiving PBL, while class IV-C (n=30) was designated as the control class receiving conventional (teacher-centered) learning. Research permits included permission from the principal, the class teacher, and a letter of permission from the students' parents. Confidentiality of student identities was maintained throughout the data collection and reporting process. Procedure: The study was conducted in three sessions: administering the scientific literacy pretest, completing the learning motivation questionnaire, and implementing the learning according to the treatment (PBL or conventional) followed by the scientific literacy posttest.

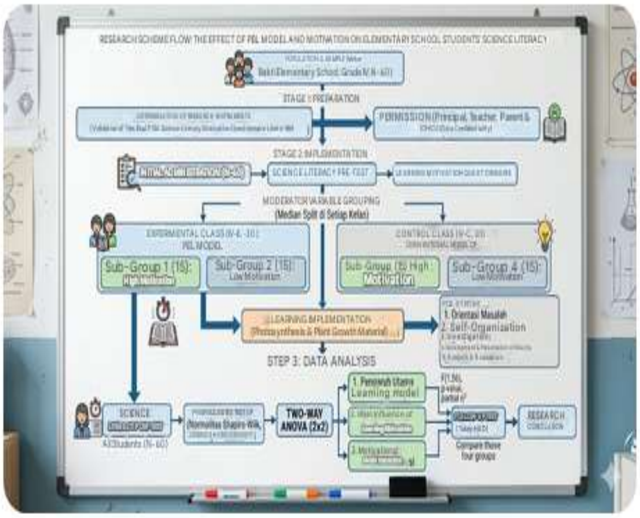

**Figure 1.** Research Scheme Flow

The science materials used covered the concept of photosynthesis and factors influencing plant growth (e.g., light and water requirements), in accordance with the learning outcomes for fourth grade. PBL Treatment. In the experimental class, PBL syntax was implemented through: contextual problem orientation, organizing students into small groups, investigation (seeking information), developing and presenting results, and analyzing and evaluating the problem-solving process. The teacher acted as a facilitator by providing prompting questions, scaffolding, and providing feedback. Instruments.

A science literacy test in the form of an essay with a scoring rubric (score 0–100) that mapped PISA-oriented science literacy indicators (explaining scientific phenomena, designing investigations, interpreting data/evidence); Learning motivation was measured using a 40-item Likert-scale questionnaire (1–5) covering indicators of need, persistence, self-confidence, and goal orientation; the questionnaire's internal reliability showed good consistency (α=0.884). Learning motivation grouping was conducted using a median split technique in each class (PBL class median = 79.25; conventional class median = 74.50), resulting in two motivation groups (high and low) each with n = 15. This approach was chosen for the needs of a 2×2 factorial design and was further interpreted as findings on the interaction of motivation level (high/low) with the learning model. Data analysis techniques included: descriptive statistics (mean and standard deviation) for the pretest, posttest, and learning motivation; prerequisite tests (Shapiro–Wilk normality and Levene homogeneity of variance); a two-way ANOVA (2×2) with learning model (PBL vs. conventional) and learning motivation (high vs. low) as factors on the science literacy posttest scores; reporting of effect sizes ($\eta p^2$) and a further Tukey HSD test to explore intergroup differences if the interaction was significant.

## Result and Discussion

Descriptive statistics. Table 1 presents a descriptive summary of initial abilities (pretest), final results (posttest), and learning motivation in both groups. Analysis prerequisites. The Shapiro–Wilk normality test on posttest scores per cell showed normally distributed data (PBL–high motivation p=0.108; PBL–low motivation p=0.684; conventional–high motivation p=0.479; conventional–low motivation p=0.104). The homogeneity of variance (Levene) test was also met (p=0.641). Descriptively, the pretest means of both classes were relatively equivalent (Table 1), so changes in scores were primarily interpreted as the impact of the treatment and differences in learning motivation characteristics. Main analysis (two-way ANOVA).

**Table. 1** Group Descriptive Statistics

| Group | n | Pretest (Average) | Pretest (SD) | Posttest (Average) | Posttest (SD) | Motivation (Average) | Motivation (SD) | Gain (Average) | Gain (SD) |
|---|---|---|---|---|---|---|---|---|---|
| Conventional | 30 | 47.89 | 15.671 | 68.57 | 12.361 | 73.17 | 10.365 | 20.68 | — |
| PBL | 30 | 47.67 | 13.149 | 78.63 | 13.665 | 74.68 | 10.631 | 30.96 | — |

**Table 2.** Summary of Two-Way ANOVA (2×2) on Science Literacy Posttest Scores

| Source | JK (SS) | dk | F | p | ηp² |
|---|---|---|---|---|---|
| Learning models (A) | 1519.56 | 1 | 11.99 | 0.00 | 0.17 |
| learning motivation (B) | 564.57 | 1 | 4.45 | 0.03 | 0.07 |
| Interaction A×B | 2183.46 | 1 | 17.23 | <0.00 | 0.23 |
| Error | 7098.05 | 56 | — | — | — |

Table 2 shows the results of a 2×2 ANOVA to test the effect of learning model (PBL vs conventional), learning motivation (high vs low), and the interaction between the two on the science literacy posttest scores.

The ANOVA results showed a significant main effect of learning model: students in the PBL class obtained higher scientific literacy scores than those in the conventional class (M=78.63 vs. 68.57; F (1.56) =11.99; p=0.001; $\eta p^2=0.17$). The main effect of learning motivation was also significant: highly motivated students scored higher than those with low motivation (M=76.67 vs. 70.53; F (1.56) =4.45; p=0.03; $\eta p^2=0.07$). In addition, there was a significant and moderate interaction between learning model × learning motivation (F (1.56) =17.23; p<0.001; $\eta p^2=0.23$), indicating that the effect of PBL on scientific literacy depends on the level of learning motivation. To explore interaction patterns, a Tukey HSD follow-up test was conducted on four group combinations (PBL–high, PBL–low, conventional–high, conventional–low). A summary of the follow-up test results is presented in Table 3.

Further testing showed that the PBL–high motivation group (M=87.73) differed significantly from the PBL–low motivation group (M=69.53), conventional–high motivation group (M=65.60), and conventional–low motivation group (M=71.53). Meanwhile, the differences between the three groups other than PBL–high motivation were not significant.

This pattern confirms that the advantages of PBL primarily emerge when students' learning motivation is high. The superiority of PBL in scientific literacy is consistent with synthetic evidence showing that PBL improves science learning outcomes through problem-solving activities, evidence-based argumentation, and the integration of concepts with real-world contexts (Rehman et al., 2024; Torres-Peña et al., 2025). A meta-analysis in the context of scientific literacy also reported that PBL effectively strengthens the ability to interpret evidence and apply scientific concepts (Lu et al., 2025; Smith et al., 2022).

**Table 3.** Tukey HSD Follow-up Test on Group Combinations (Learning Model X Motivation)

| Pair comparison | Difference (I−J) | P | Significant (α=0.05) | Note | Group I | Group J |
|---|---|---|---|---|---|---|
| High-PBL vs Low-PBL | 18.20 | 0.001 | Yes | PBL is effective when motivation is high | A1B1 | A1B2 |
| High-PBL vs High Conventional | 14.00 | 0.014 | Yes | PBL–high superiority | A1B1 | A2B1 |
| High-PBL vs Low Conventional | 13.47 | 0.019 | Yes | PBL–high superiority | A1B1 | A2B2 |
| Low-PBL vs High Conventional | 4.20 | 0.188 | No | The difference is not significant | A1B2 | A2B1 |
| Low-PBL vs Low Conventional | 4.73 | 0.522 | No | The difference is not significant | A1B2 | A2B2 |
| High Conventional vs Low Conventional | 0.53 | 0.999 | No | The difference is not significant | A2B1 | A2B2 |

In the context of Indonesian elementary schools, similar findings were reported when PBL was enriched with media and local contexts, making problems more meaningful to students (Adah Miller & Li, 2025; Al-Thani & Ahmad, 2025). The finding that motivation is associated with scientific literacy aligns with meta-analyses of self-determination theory, which confirm the relationship between autonomous motivation and performance, persistence, and learning well-being (Grenier et al., 2024; Wijsman et al., 2018). A significant interaction indicates that PBL is most beneficial for highly motivated students. This makes sense, as PBL demands persistence, self-regulation, and a willingness to engage in challenging discussions (Almulla, 2020; Arani, 2025; Bendeliani & Torstensdotter, 2026). A recent meta-analysis showed that problem-driven learning tends to increase motivation, but the effect varies depending on student characteristics and implementation conditions (Abdurahman et al., 2023; Ackermans et al., 2025). For low-motivated students, the quality of teacher support is crucial: autonomy-supportive teaching practices have been shown to be trainable and impact engagement, especially when accompanied by clear structures (Kamberi, 2025; Kubsch et al., 2023).

Therefore, implementing PBL in heterogeneous classrooms requires the addition of goal scaffolding, role assignment, formative feedback, and facilitation of teacher-student interactions to ensure that low-motivated students can still participate meaningfully (Damayanti et al., 2026; Samsudin et al., 2023). First, PBL can be used as a strategy to strengthen scientific literacy, but teachers need to design motivational support (e.g., strengthening autonomy, competence, and connectedness) and structure (clear objectives, rubrics, and discussion flow) to ensure the benefits of PBL are shared equitably. Second, the interaction results suggest differentiation: for low-motivated students, teachers can strengthen their facilitation role, model evidence-finding strategies, and provide prompt questions to guide argumentation (Samsudin et al., 2023); . Third, monitoring motivation and engagement during PBL can serve as process indicators to ensure learning is progressing according to objectives (Lee, 2025; Wu, 2024).

The intervention was relatively short-lived, so the observed effects were short-term. Furthermore, grouping motivation using a median split facilitates factorial analysis, but potentially reduces information about variation in motivation as a continuous construct. From a measurement perspective, using pretests and posttests with similar formats can create a testing effect that contributes to improved scores (Pan & Carpenter, 2023; Pan & Sana, 2021). Further research is recommended using longer intervention durations, process measurements (implementation fidelity), and equivalent test formats to minimize the effect of item repetition.

## Conclusion

This study shows that PBL improves elementary school students' scientific literacy compared to conventional learning, and learning motivation is positively associated with scientific literacy. There is an interaction between learning model and learning motivation, so that the strongest advantage of PBL appears in students with high learning motivation ($\eta p^2$ interaction = 0.23). Practical implications: Teachers need to combine PBL with motivational support (autonomy support, competency feedback, and relatedness reinforcement) and a clear task structure to keep low-motivation students engaged. Future research is recommended to use longer intervention durations, measure implementation fidelity, and use equivalent tests to minimize repetition effects.

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**Conflicts of Interest**
The authors declare no conflict of interest.

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