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Effectiveness of Project-Based Inquiry Learning in Developing HOTS-Based Scientific Literacy: Moderated by Science Process Skill

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Abstract: Effectiveness of Project-Based Inquiry Learning in Developing HOTS-Based Scientific Literacy: Moderated by Science Process Skill. Objectives: This study examines three core questions: (1) whether the Project-Based Inquiry (PBI) model improves students' HOTS scientific literacy, (2) whether students' initial Science Process Skills (SPS) influence their outcomes, and (3) whether there is an interaction between the two. These variables were selected because HOTS-based scientific literacy and SPS are essential competencies for prospective elementary teachers. **Methods:** A quasi-experimental design was used with two naturally formed groups. The experimental group learned through the project-based inquiry model, while the control group used guided inquiry. Data were collected using a project assessment sheet and the HOTS scientific literacy test, with identical pre- and post-tests administered. The data were analyzed using: 1) Normality and homogeneity test, 2) Paired sample t-test, 3) Independent sample t-test, and 4) Hypothesis testing was carried out using two-way ANOVA, where H€† was rejected if the significance value was <0.05. **Findings:** The analysis for the learning model factor yielded a highly significant result ($p = 0.000$; < 0.05). The results show that the learning model had a significant effect on HOTS scientific literacy, with the PBI model outperforming guided inquiry ($p = 0.000$). SPS level did not produce a significant independent effect ($p = 0.562$), and no interaction was found between the learning model and SPS. These findings indicate that the PBI model is the primary factor driving students' improvement. **Conclusion:** Overall, Project-Based Inquiry is an effective approach to strengthening HOTS scientific literacy among prospective elementary teachers. Although SPS levels did not independently influence outcomes, students across SPS levels still benefited from PBI. These findings offer theoretical insight into how inquiry–project learning supports higher-order reasoning and provide practical guidance for developing instructional designs that foster analytical and evidence-based thinking in teacher education programs.

Keywords: project-based inquiry, guided inquiry, science process skill, hots, scientific literacy, science education.

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INTRODUCTION

Science learning involves conceptual knowledge, science process skills, and scientific inquiry competencies, all of which are essential for real-world problem-solving (Lederman et al., 2013; Ritter et al., 2018; Smith & Wiser, 2015).

Furthermore, science learning presents diverse scientific concepts, many of which are relevant and found in everyday life (Ali & Jager, 2020). Because science is fundamentally concerned with systematically investigating natural phenomena, it is not merely a collection of reliable knowledge in the form of facts, concepts, or principles, but also includes scientific methods and attitudes (Bonney et al., 2016; Nuangchalerm & El Islami, 2018). Science learning activities are most effective when they provide opportunities for students to gain direct experience, focusing on mastering science process skills and fostering scientific attitudes (Prachagool et al., 2016; Ritter et al., 2018).

Science education globally is shifting toward student-centered learning that emphasizes inquiry, collaboration, and problem solving (Barron & Darling-Hammond, 2008; Hmelo-Silver et al., 2007). Inquiry-Based Learning (IBL) and Project-Based Learning (PBL) are widely acknowledged to promote student autonomy, scientific reasoning, and authentic engagement (Donohue et al., 2020; Ellwood & Abrams, 2018; Krajcik & Blumenfeld, 2006). A key method within SCL is knowledge discovery (inquiry learning) facilitated through project-based learning (PBL). The adoption of these learning models has become an international trend, compelling students to discover knowledge independently through PBL (Baran et al., 2018; Cairns & Areepattamannil, 2019; Donohue et al., 2020; Ellwood & Abrams, 2018; Erenler & Cetin, 2019; Hubber et al., 2017). Currently, the use of such learning models is also growing and gaining popularity in Indonesia (Artayasa et al., 2018; Darmuki et al., 2018; Dewi & Mashami, 2019; Effendi-Hasibuan et al., 2019; Gunawan et al., 2020). Students are now required to acquire their own knowledge and concepts by completing projects assigned by their lecturers. Skills like higher-order thinking, scientific literacy, and scientific inquiry are now seen as the heart of meaningful learning (Darling-Hammond et al., 2020; Fraser, 2021).

The problem facing lecturers in teaching science courses is the difficulty in utilizing engaging and varied learning models and methods (Suprihatin et al., 2023). Less engaging instruction often stems from the failure to implement diverse learning models (Affandi et al., 2022). In this context, lecturer creativity in using various models is essential to increase student engagement in directly studying problems and finding alternative solutions (Weng et al., 2022; Xu et al., 2020). Lecturers play a crucial role in maintaining continuous teaching and learning interactions: between learning resources and students, among students themselves, and between students and their learning environment (Munna & Kalam, 2021). Furthermore, lecturers must master various learning models to effectively achieve learning objectives (Supena et al., 2021). Lecturers are not only required to master these models; they are also expected to teach them. However, they must also be able to develop and integrate diverse learning models tailored to their students' specific needs and characteristics.

Although inquiry-based learning (IBL) and project-based learning (PBL) have each demonstrated strong effectiveness when implemented independently, theoretical perspectives in constructivist learning emphasize that these two models possess complementary strengths that make their integration pedagogically meaningful. IBL develops scientific reasoning through questioning, investigation, and evidence-based explanation, whereas PBL provides extended, authentic, and collaborative contexts in which inquiry processes can be meaningfully applied (Hmelo-Silver et al., 2007). Although IBL and PBL are well studied individually, few studies have examined their combined application. Systematic reviews indicate that integrated Project-Based Inquiry Learning (PBIL) remains rare globally (Strat et al., 2024; Urdanivia Alarcon et al., 2023). No existing research examines PBIL in Basic Concepts of Science courses for pre-service elementary teachers, creating a critical empirical and theoretical gap in science teacher preparation.

From a sociocultural and constructivist standpoint, the integration of IBL and PBL enables learners to engage in deep cognitive processing while simultaneously constructing knowledge through real-world problem solving, a synergy supported by prior research showing that project environments strengthen inquiry outcomes, and inquiry scaffolds improve the quality of project results (Krajcik & Blumenfeld, 2006). Thus, integrating PBL and IBL is not merely a practical response to the limitations of each model, but is theoretically grounded in the need to combine structured scientific reasoning with complex, meaningful tasks that foster higher-order thinking. Despite this theoretical rationale, systematic evidence on the combined application of PBL and IBL remains scarce. Scopus-indexed studies in Indonesia and internationally show that most research investigates IBL or PBL as standalone models, for example, IBL to strengthen scientific reasoning or conceptual mastery (Cairns & Areepattamannil, 2019), and PBL to enhance collaboration and problem-solving (Baran et al., 2018), but rarely as an integrated pedagogical approach. A major systematic review of inquiry-based science education in teacher education. Studies focusing on pre-service teachers predominantly examine inquiry-based learning alone, with minimal exploration of its integration with project-based learning (Strat et al., 2024). Likewise, a global systematic review reported that research on inquiry approaches remains dominated by single-model implementations, with very few studies combining inquiry and project frameworks into a unified model (Urdanivia Alarcon et al., 2023). In Indonesia, research integrating PBL and IBL for pre-service elementary teachers is especially limited, despite the unique student characteristics and learning culture that require contextualized instructional models. Therefore, a study that explicitly examines the integrated PBL–IBL approach in the context of Indonesian pre-service teacher education is both theoretically justified and urgently needed to fill this empirical gap.

The integration of IBL and PBL within PBIL provides a theoretically aligned solution to the limitations of inquiry alone. IBL strengthens scientific reasoning, while PBL situates learning in authentic, extended tasks that support sustained cognitive engagement. This combination enhances students' ability to build scientific explanations, evaluate evidence, and apply concepts in context, precisely the competencies where Indonesian PGSD students commonly struggle. PBIL's guided inquiry structure and long-term project orientation mitigate the challenges identified in prior inquiry research, offering a more robust pathway for developing HOTS and scientific literacy. However, data from international assessments like PISA and TIMSS indicate that Indonesian students still struggle to apply science concepts to real-world problems (Deratama et al., 2022; OECD, 2023). This disparity highlights a significant gap between the theoretical potential of these learning models and actual student achievement in local contexts. Specifically, no empirical research has tested the effect of implementing project-based inquiry learning (PBIL) in Basic Concepts of Science courses.

The consistent gap between Indonesian students' performance and expected inquiry competencies suggests a mismatch between current instructional practices and the skills required in modern science learning. PBIL provides a theoretically aligned solution by integrating structured inquiry (scientific reasoning) with authentic project tasks (application in real contexts), directly targeting the competencies where Indonesian learners struggle most (Hmelo-

Silver et al., 2007; Krajcik & Blumenfeld, 2006; Krajcik & Shin, 2014).

Inquiry-based learning strengthens students' abilities to reason scientifically through questioning, evaluating evidence, and explaining. In contrast, project-based learning provides extended, authentic problem-solving contexts in which these reasoning processes must be applied. The persistent difficulty of Indonesian students on PISA and TIMSS is particularly in tasks requiring the interpretation of data, the explanation of scientific phenomena, and the application of concepts to real-world situations. OECD indicates a deficiency not merely in content knowledge, but in the coordinated ability to connect inquiry processes with authentic problem contexts (OECD, 2023). International assessments such as PISA and TIMSS consistently show that Indonesian students underperform in tasks requiring scientific reasoning, data interpretation, and application of scientific concepts to real-world problems (Mullis et al., 2019; OECD, 2023). These findings indicate weaknesses not only in content mastery but also in integrated inquiry-process skills essential for authentic science learning (Cairns & Areepattamannil, 2019).

This type of deficit aligns logically with what PBIL is specifically designed to address: integrating structured inquiry with real-world projects that require students to investigate, design, test, evaluate, and communicate solutions. Therefore, the gap identified in international assessments provides a theoretically grounded rationale for PBIL as an intervention model, not as a coincidental association, because it targets the precise cognitive and applied competencies in which Indonesian students consistently underperform. However, despite this theoretical alignment, no empirical studies have examined PBIL in the Basic Concepts of Science course for pre-service elementary teachers in Indonesia. This absence creates both a theoretical and an empirical gap regarding the effectiveness of PBIL in developing HOTS scientific literacy in a context where these skills are demonstrably lacking.

International research demonstrates that although inquiry-based learning (IBL) has strong potential for developing scientific reasoning and HOTS, its effectiveness is inconsistent across contexts. Several studies show that unguided or minimally guided inquiry often leads to cognitive overload, fragmented understanding, and shallow reasoning, especially for learners with limited prior knowledge (Arsal, 2017; Furtak et al., 2012; Kirschner et al., 2006). Meta-analyses further indicate that inquiry becomes effective only when accompanied by structured scaffolding, explicit modeling, and opportunities to apply investigation processes in meaningful contexts (Alfieri et al., 2010; Lazonder & Harmsen, 2016). These findings reveal that the inconsistency stems from a systematic mismatch between the inquiry's cognitive demands and the instructional support available in real classrooms. This offers a strong theoretical rationale for integrating IBL with project-based learning (PBL), in which authentic, extended project cycles help stabilize inquiry steps, reduce fragmentation, and promote deeper conceptual coherence, forming the foundation of Project-Based Inquiry Learning (PBIL).

Research indicates that unguided inquiry often fails to improve higher-order thinking unless structured scaffolding is provided (Furtak et al., 2012; Kirschner et al., 2006). PBIL overcomes this limitation by combining guided inquiry with sustained project work, thereby enhancing authenticity and deeper cognitive engagement (Ölçer, 2025; Strat et al., 2024). Furthermore, this approach enables students to actively construct meaning and solve problems grounded in real-world phenomena, thereby strengthening the connection between science content and everyday life (Ölçer, 2025). Several recent studies advocate for integrating inquiry with project-based learning (PBL) models to address time constraints and enhance the authenticity of scientific experiences (Chen & Tippett, 2022). This integrated approach supports more meaningful, context-based learning by providing students with opportunities to apply scientific processes sustainably, thereby strengthening their mastery of Higher-Order Thinking Skills (HOTS) and scientific literacy.

Project-Based Inquiry Learning (PBIL) is grounded in sociocultural and constructivist theories emphasizing collaborative sense-making, contextual learning, and dialogic inquiry (Chatzipanteli et al., 2014; Johnson et al., 2019; Stacey, 2019). It supports metacognition, perspective-taking, and conceptual co-construction, key competencies for 21st-century scientific literacy. PBIL is supported by sociocultural and social constructivist theories, which emphasize that learning is socially, historically, and contextually situated. In this approach, children work collaboratively with their peers and teachers to research and find answers to their questions through dialogue, debate, and representation, thus co-constructing new understandings (Probine et al., 2023; Stacey, 2019). This process supports children in developing a deeper awareness of their individual and learner identities through metacognition, fostering an appreciation for different perspectives, and cultivating various attributes and dispositions considered essential for navigating life in the 21st century (Chatzipanteli et al., 2014; Johnson et al., 2019; Santín & Torruella, 2017).

Research that seeks to understand further how Project-Based Inquiry Learning (PBIL) has been contextualized in the education sector is valuable. This research benefits educators working within these specific contexts and all educators seeking to develop inquiry approaches that effectively respond to their unique settings. Such studies are particularly important for educators aiming to respect and integrate Indigenous perspectives, theories, and knowledge into their students' inquiries. It has also been shown that the quality of project outputs can be stronger when they result from an inquiry process focused on topics of personal interest to the learners (Chu et al., 2011; Learning, 2004).

That is why this study focuses on exploring how the Project-Based Inquiry (PBI) model affects students' science process skills and HOTS-based scientific literacy. The model used here follows six stages: (1) identifying problems, (2) forming questions and hypotheses, (3) designing projects, (4) carrying out projects, (5) presenting and communicating results, and (6) reflecting and evaluating. Each stage is designed to help students explore ideas, collaborate, and reflect on their own learning, a process that closely aligns with constructivist and experiential learning theories.

This study evaluates PBIL's effectiveness in improving HOTS and scientific literacy among pre-service elementary teachers, specifically in the Basic Concepts of Science course. This context has rarely been examined internationally, especially in developing countries, where constraints such as limited laboratories, teacher-centered norms, and inconsistent inquiry-readiness require contextual adaptation (Bank, 2020; Tatto, 2022). The novelty of this research stems from three key areas: the integration of learning models, its sharp focus on the local context (Indonesia), and its effort to address core challenges in science education through an innovative and contextually relevant approach. This study offers a novel contribution to the educational literature by advancing a contextually grounded integration of project-based and inquiry-based learning tailored specifically to the needs of pre-service elementary teachers in Indonesia. Unlike existing international PBIL research that predominantly focuses on K–12 students, STEM majors, or highly resourced learning environments, the integration developed in this study is conceptually adapted to the characteristics of Indonesian pre-service teachers who often enter Basic Science Concepts courses with limited scientific reasoning, fragmented conceptual understanding, and low confidence in teaching science. The PBIL design in this research incorporates culturally and contextually relevant project themes, structured inquiry scaffolds, and explicit connections to elementary curriculum demands, features rarely addressed in international PBIL studies that assume higher baseline competencies and more inquiry-supportive learning conditions. Furthermore, the study addresses specific local challenges, such as large class sizes, limited laboratory access, and pedagogical norms that remain predominantly teacher-centered. These conditions directly shape the PBIL structure, scaffolding intensity, and implementation strategy, thereby distinguishing it conceptually and practically from the PBIL frameworks reported in the global literature. Thus, the novelty of this study arises from both the contextual adaptation of PBIL for pre-service teacher preparation in Indonesia and the empirical evaluation of its effectiveness in strengthening pedagogical and professional competencies in science instruction.

METHOD

Participants

The study population consisted of all students enrolled in the Primary School Teacher Education (PGSD) program. The sample was selected using an intact-class sampling technique, in which two naturally existing classes at the same institution were chosen. The sample consisted of two classes, totaling 33 students in the experimental group and 35 in the control group, for a total of 68 students. The selection of two classes from a single institution was based on administrative feasibility, curricular alignment, and the need to control instructional variables (Creswell & Creswell, 2018). Nevertheless, selection bias is a potential concern in intact class sampling. To mitigate this possibility, both classes were taken from the same semester, had identical syllabi, and were provided a pretest measuring HOTS scientific literacy and science process skills prior to the intervention. An independent-samples t-test was used to assess baseline equivalence. The descriptive statistics and pretest equivalence results are presented in Table 1.

An independent-samples t-test indicated that the difference in pretest scores between the two groups was not statistically significant, $t(66) = 1.71$, $p = 0.087$. Although the independent-samples t-test showed no statistically significant difference in the pretest scores between groups ($p = 0.087$), the nonsignificant result does not by itself guarantee practical equivalence. Because the p-value was close to the significance threshold and descriptive statistics indicated uneven distributions of scores, the groups were treated as comparable but not fully equivalent. Therefore, additional statistical control was required during the main analysis.

Table 1. Descriptive statistics of science process skills pretest scores

Group	N	Mean	SD	Min	Max
Experimental	33	76.35	7.58	57.14	86.30
Control	35	73.13	7.93	54.60	86.70

Research Design and Procedures

This study used a quasi-experimental design with a 2 × 2 factorial structure to compare the effects of PBIL and Guided Inquiry across two levels of science process skills (high and low). Quasi-experimental designs are widely applied in educational contexts where randomization is not feasible (Shadish et al., 2002). The experimental group received the specific treatment (the learning strategy whose effectivenes was being tested), while the control group utilized an existing, conventional learning strategy (Amelia et al., 2023). The research design is presented in Table 2.

The intervention lasted for eight weeks, with a total of 16 meetings, each lasting 150 minutes, and was applied equally to both groups. The PBIL (experiment) intervention followed the phases proposed by Krajcik & Blumenfeld (2006), and the control group was taught using the Guided Inquiry model based on the six phases recommended by Gibson & Chase (2002) and National Research Council (2000). The research steps are shown in Table 3.

Table 2. Two-Way ANOVA research design with 2 x 2 factorial

Models (A) / Science Process Skills (B)	Project-Based Inquiry (A_1)	*Guided Inquiry* (A_2)
High (B_1)	$\mu A_1 B_1$	$\mu A_2 B_1$
Low (B_2)	$\mu A_1 B_2$	$\mu A_2 B_2$

PBIL has been shown to effectively enhance scientific literacy and higher-order thinking by engaging learners in authentic inquiry (Kurt & Akoglu, 2023; Santosa et al., 2023). Guided Inquiry is supported by extensive research for improving conceptual understanding through structured exploration (Firman et al., 2019; Furtak et al., 2012; Pedaste et al., 2015). Both groups studied identical topics: properties and changes of matter, heat and heat transfer, light and optics, and fundamental science process

Table 3. Research steps

Component	Description
Experimental Group (PBIL)	1. Problem Identification: Students explore real-world scientific problems. 2. Question and Hypothesis Formulation: students pose research questions and develop hypotheses. 3. Project Design: students collaboratively plan project steps and determine required resources. 4. Project Implementation: students conduct experiments and collect empirical data. 5. Presentation and Communication: present project results in the form of reports, posters, or multimedia presentations 6. Reflection and Evaluation: students analyze findings and draw scientific conclusions.
Control Group (Guided Inquiry)	1. Orientation: introduction to scientific phenomena via demonstrations. 2. Problem Presentation: The lecturer provides a structured investigative problem. 3. Planning: students use guided worksheets to identify variables, procedures, and predictions. 4. Investigation: students conduct experiments with partial guidance. 5. Data Analysis & Explanation: analysis using tables, graphs, and guided questions. 6. Conclusion & Reflection: students summarize findings and connect them to scientific principles.

skills, to ensure internal validity (Cook & Cook, 2005).

Instruments of Data Collection

Two main instruments were used: the Science Process Skills (SPS) project assessment sheet dan the HOTS Scientific Literacy Test. To measure students' initial SPS, a project evaluation assessment sheet was used as the primary instrument. Although this assessment sheet is typically applied during the final stage of a project, in this study, the instrument was intentionally adapted for pre-test measurement using a simulated mini-task format rather than a complete project implementation.

The rationale for using the project evaluation sheet at the pre-test stage was to ensure that the SPS measured aligned precisely with the SPS indicators required during the intervention phase. Therefore, before the Project-Based Inquiry Learning model was implemented, students completed a brief structured inquiry task designed solely to elicit observable SPS behaviors. This mini-task required students to perform abbreviated scientific steps, observing, measuring, classifying, predicting, inferring, and communicating without constructing a full project product. Their performance during this preliminary activity was assessed using the same rubric applied during the treatment, allowing equivalent scoring criteria across phases.

Using the same rubric for both the pre-test and post-intervention ensured measurement consistency, minimized construct shift, and strengthened internal validity by providing comparable scoring dimensions. The assessment rubric consisted of a 1–4 Likert scale (1 = poor, 2 = adequate, 3 = good, 4 = very good) across three dimensions (process, product, and communication), with each mapped directly to six SPS competencies. The SPS rubric is shown in the following table.

Table 4. Rubric for SPS indicators

SPS Aspect	Product Assessment Indicators
Observing	1. The student records data/events accurately during the process. 2. The product demonstrates detail, precision, and alignment with data/facts. 3. The presentation reflects a thorough understanding of the project results.
Measuring	1. The student uses measuring tools/procedures according to standards throughout the process. 2. The product shows accuracy in measurements, proportions, or parameters based on proper procedures. 3. Data/measurement results are presented appropriately in tables or graphs.
Classifying	1. Data/work results are systematically categorized throughout the project. 2. Product components/elements are classified correctly according to scientific concepts. 3. Presentation materials are organized systematically (introduction, content, conclusion).
Predicting	1. The student formulates preliminary predictions based on collected data. 2. The product reflects logical initial predictions or hypotheses. 3. The student can explain potential developments or implications of the project results.
Concluding	1. The student draws conclusions at each stage of the project process. 2. The product contains findings that reflect accurate conclusions. 3. The presentation communicates final project conclusions accurately.
	1. The student documents the project process (notes, reports, graphics). 2. The product includes explanations/graphs/tables that facilitate

Communicating	comprehension. 3. The presentation is delivered in an organized, clear, engaging, and convincing manner.

The HOTS Scientific literacy essay test consisted of 25 items adapted from the PISA 2023 science framework (OECD, 2023). The test measured two domains: science knowledge (content, procedural, epistemic) and science competencies (explaining phenomena, interpreting data and evidence, evaluating scientific inquiry). The rubric for the HOTS scientific literacy essay is shown in the following table.

Table 5. Rubric for essay indicators

Aspect	Sub-Aspect	Cognitive Level
Science Knowledge	Content Knowledge	C4
	Procedural Knowledge	C5
	Epistemic Knowledge	C6
Science Competencies	Explaining Scientific Phenomena	C4
	Interpreting Data & Scientific Evidence	C5
	Evaluating Scientific Inquiry	C6

To evaluate the quality of student responses on the essay test, an analytic scoring rubric was employed. This rubric was designed to assess the level of conceptual understanding, scientific reasoning, and the accuracy of the supporting evidence used to answer the questions. The performance level descriptors are presented in Table 6 below:

Table 6. Rubric for essay score

Level	Descriptor
4	Complete, accurate reasoning with scientific evidence; coherent explanation
3	Mostly accurate reasoning with minor gaps
2	Partial understanding; simplistic or partially incorrect explanations
1	Incorrect, irrelevant, or missing explanation

Validity testing was conducted using the Pearson product–moment correlation technique (Arikunto, 2017). The significance of the correlation was then tested using the Student's *t*-distribution. The decision rule is that if rhitung > rtabel, the item is considered valid and statistically significant. The analysis of the validation results for this research instrument is presented in Table below. The reliability of the test was determined using Cronbach's Alpha. If r11 > rtabel '! the test is reliable, or if r11 d" rtabel '! the test is not reliable. Interpretation of Reliability Coefficients Interprestasi 5Ø_Ü11 is presented in Table 7 below:

Table 7. Interpretation of reliability coefficients

Reliability Coefficient (r_{11})	Interpretation
$r_{11} \leq 0.20$	Very Low
$0.20 < r_{11} \leq 0.40$	Low
$0.40 < r_{11} \leq 0.60$	Moderate

$0.60 < r_{11} \leq 0.80$	High
$0.80 < r_{11} \leq 1.00$	Very High

The data analysis of the validation and reliability test results conducted on this research instrument is presented in Table 8 below.

Item difficulty refers to the probability that a student with a given ability level will answer an item correctly, typically expressed as an index ranging from 0.00 to 1.00. Difficulty levels are classified as follows: 0.00–0.30: Difficult;0.31–0.70: Moderate, and 0.71–1.00: Easy. The data analysis of the test difficulty level conducted on this research instrument is presented in Table 9 below.

Table 8. Validation and reliability test results

Description	Item Number	Total
Valid	1. 2. 3. 4. 5. 7. 8. 9. 10. 12. 13. 14. 15. 17. 18	15
Not Valid (Invalid)	6. 11. 16	3
Notes	$R_{count} = 0.751$ > $R_{table} = 0.334$	Reliable

Table 9. Analysis of the test difficulty level

Description	Item Number	Total
Easy	13	1
Moderate	1. 2. 3. 5. 6. 7. 8. 10. 11. 12. 15. 16. 18	13
Difficult (Hard)	4. 9. 14. 17	4

Data Analysis

Data were analyzed using quantitative procedures. Descriptive statistics (mean, standard deviation, minimum, maximum) were computed to summarize student performance. Normality was tested using the Shapiro–Wilk test, and homogeneity of variance was assessed through Levene's test. Baseline equivalence between groups was examined using an independent-samples t-test. Learning gains were calculated using normalized N-gain scores (Hake, 1999). To assess improvement from pretest to posttest. Science process skills were categorized into high and low using the mean ± 1 SD criterion. Inferential analyses included paired-samples t-tests, independent-samples t-tests, and two-way ANOVA to examine the effects of learning model and SPS level on HOTS scientific literacy. All hypothesis testing used a significance level of á = 0.05.

ANCOVA was considered an analytical option to statistically adjust for baseline variability. However, its use requires the homogeneity of regression slopes assumption, which was tested and not satisfied in this dataset. Because the interaction between pretest scores and treatment was not linear and varied across SPS levels, ANCOVA would have violated this assumption and risked producing biased effect estimates. Therefore, a Two-Way ANOVA with categorical SPS levels (via median split) was selected as a more appropriate and statistically valid approach aligned with the research objective of testing a moderation effect rather than covariate adjustment.

Thus, while the pretest comparisons ensured that the groups were not statistically different at baseline, the SPS categorization was applied to refine the analysis and examine potential moderation patterns rather than to correct inequivalence. This approach provides a more accurate testing structure consistent with the research questions.

Quantitative data were collected by administering identical pre- and post-tests to all participating students. Student improvement and the overall effectiveness of the Project-Based Inquiry (PBI) model were measured using normalized gain scores (N-gain), which compare student performance between the pre- and post-learning conditions. The gain score is used to assess the effectiveness of treatment from post-test results, which are classified into the following categories:

Table 10. Interpretation of normalized n-gain

Gain	Interpretation
$g > 0.7$	High
$0.3 < g \leq 0.7$	Middle
$g \leq 0.3$	Low

Students' science process skills were analyzed quantitatively using descriptive statistics (percentages) and subsequently categorized into high and low levels based on the standard deviation. The students' science process skills (SPS) were analyzed quantitatively using percentages. The categorization of SPS groups using a Two-Way ANOVA (2 × 2 factorial) design was based on the Median Split method. The purpose of this grouping was to reduce potential bias arising from variability in initial SPS levels, as identified from descriptive patterns. Despite nonsignificant baseline testing, the median split method was used to classify students into high and low SPS categories. This allowed the use of a factorial Two-Way ANOVA framework to examine whether SPS moderated treatment effects, rather than assuming full equivalence across groups. The Median Split method allowed participants to be classified into high- and low-ability categories based on the median, thereby enabling a more balanced and valid statistical analysis, as previously identified in Table 11.

Table 11. Interpretation of science process skill levels

Science Process Skills (B)	Median Split
High	If SPS *pre-test* >76.59%
Low	If SPS *pre-test* <76.59%

This grouping enabled a moderation hypothesis test: whether the effect of the Project-Based Inquiry Learning model on HOTS scientific literacy differed between students with High and Low initial SPS abilities. Next, the data were analyzed using: 1) Normality and homogeneity test, 2) Paired sample t-test, 3) Independent sample t-test, and 4) Hypothesis testing was carried out using two-way ANOVA, where H€ was rejected if the significance value was <0.05.

RESULT AND DISCUSSION

The analysis was conducted to compare the initial SPS abilities of students in the Experimental Group (who will receive IBP) and the Control Group (who will receive Guided Inquiry) before the treatment was implemented. The main objective was to ensure that the initial Science Process Skills (SPS) between the two groups were equivalent and that there were no significant differences, thereby enabling a valid comparison during the intervention. Therefore, data were adjusted using SPS categorization (Median Division) to apply a Two-Way ANOVA (2 x 2 Factorial Design). This step statistically controls for initial differences in ability by comparing the effect of the learning model only within homogeneous SPS subgroups (High SPS and Low SPS). The results of the analysis are presented in the table below:

The Science Process Skills (SPS) distribution table reveals a clear difference

Table 12. Interpretation science process skills data

Interpretation of SPS	Project-Based Inquiry		Guided Inquiry	
	F	**Fr (%)**	**F**	**Fr (%)**
High	21	63.63	18	51.42
Low	12	36.36	17	48.57

between the two groups. The majority of students in the experimental class fall into the high category, whereas the medium category primarily dominates the control class. The specific proportions are as follows: 1) Experimental Group: High (63,63%), Low (36,36%), 2) Control Group: High (51,42%), Low (48,57%). The following table presents the average achievement in six Science Process Skills (SPS) across the assessment aspects (Process, Product, Presentation).

The Experimental Group started with an advantage across all Science Process Skills (SPS). The most significant gaps were observed in communicating and Inferring skills. This higher initial SPS proficiency in the PBI group underscores their greater potential to benefit from learning interventions that demand independent investigation (such as Project-Based Inquiry) compared to the Control Group. Further details regarding this distribution are presented in the following Figure 1.

Table 13. Sub-Dimension analysis of science process skills (SPS)

Science Process Skills	Project-Based Inquiry	Guided Inquiry
Observing	77.62%	67.56%
Measuring	77.98%	67.35%
Classifying	78.49%	68.45%
Predicting	78.50%	69.17%
Inferring	78.69%	66.86%
Communicating	80.45%	70.26%

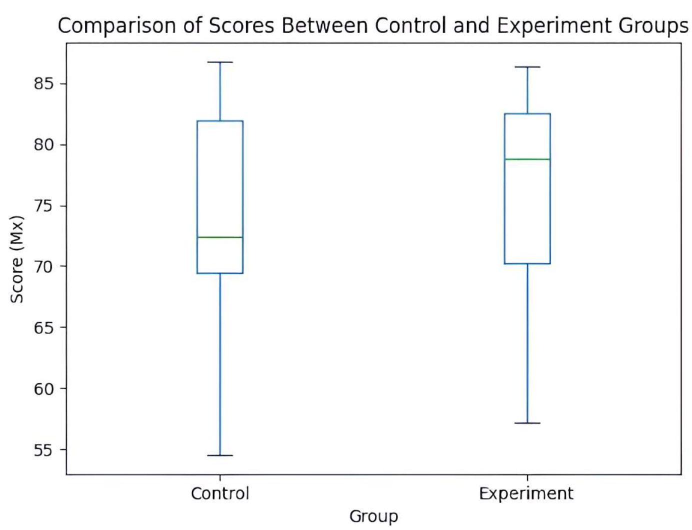

Figure 1. Science process skills percentage diagram

The box plot clearly shows that the Project-Based Inquiry method yielded higher, more consistent N-Gain scores than the Guided Inquiry method. For a more precise comparison, here are the key descriptive statistics (the five-number summary plus mean and standard deviation):

Table 14. Numerical descriptive statistics

Group	Count	Min	Q1 (25%)	Median (50%)	Q3 (75%)	Max	IQR	Std. Dev.
Project-Based Inquiry	33	68.25	77.78	81.75	84.72	88.89	6.94	76.59
Guided Inquiry	35	61.51	69.25	74.01	81.35	88.89	12.10	76.59

The Median and Q1 columns clearly show that the Experimental group had a higher initial SPS ability than the Control group (e.g., median 81.75% vs 74.01%). The IQR column shows that the Experimental group (6.94%) has a smaller score spread (more internally homogeneous) compared to the Control group (12.10%). This table serves as a concise and compact way to present the data use in Two-Way ANOVA.

A pretest-posttest design was used to determine students' Higher-Order Thinking Skills (HOTS) scientific literacy abilities before and after the treatment. The students' improvement and the model's effectiveness were subsequently measured using the normalized gain (N-gain) formula. The results of the N-gain calculation for students' HOTS scientific literacy abilities are presented in tabel 15 below:

Table 15. Summary of N-gain HOTS scientific literacy based on learning model

Statistic / Interpretation	Project-Based Inquiry (PBI)	Guided Inquiry (GI)
Sample Size (N)	33	35
Mean N-gain	0.558	0.304
Standard Deviation	0.207	0.282
Median (Q2)	0.579 (Medium - High)	0.250 (Low – Medium)
Q1 (25%)	0.429	0.097
Q3 (75%)	0.733	0.583
Interquartile Range (IQR)	0.304	0.486
Score Range (Min–Max)	-0.111 – 0.818	-0.200 – 0.781
N-gain Category Distribution (%)	High: 57.57% Medium: 39.39% Low: 3.04%	High: 34.28% Medium: 54.28% Low: 11.43%
Boxplot Characteristics	Scores are stable and concentrated in the High category, with minimal low outliers.	Scores are more widely spread, including several low outliers and values in the Low category.

The consolidated summary of N-gain performance presented in Table 15 provides a clear comparison of learning progress between the two instructional models. Overall, the Project-Based Inquiry (PBI) group demonstrated substantially greater improvement in HOTS Scientific Literacy than the Guided Inquiry (GI) group. This is evident from the notably higher mean N-gain score in the PBI condition ($M = 0.558$) compared with the GI condition ($M = 0.304$), indicating a greater learning gain among students exposed to PBI.

The median values align with this pattern: the PBI group's median score falls within the medium range. However, it approaches the high category, while the GI group's median remains in the low–medium range. This suggests that typical student performance under PBI was more consistently improved than under GI. Furthermore, the percentage distribution across N-gain categories reinforces this finding: more than half of the PBI students (57.57%) achieved significant improvement, whereas only 34.28% of the GI students did. Conversely, low improvement outcomes were rare in the PBI group (3.04%) but more prevalent in the GI group (11.43%).

Variability in performance also differed notably between groups. The PBI results showed a relatively narrow score distribution and minimal low outliers, indicating stability and consistency in learning outcomes. In contrast, the GI group exhibited wider score dispersion, a larger IQR, and several low-score outliers, suggesting less consistent progress and more uneven learner response to the instructional approach.

Taken together, these patterns demonstrate that Project-Based Inquiry not only leads to higher average learning gains but also produces more equitable and uniform outcomes across students. In comparison, Guided Inquiry appears less effective at promoting high-level improvement and may yield variable results depending on individual learner readiness.

This disparity suggests the effectiveness of implementing the Project-Based Inquiry (PBI) model in significantly improving HOTS scientific literacy, as it further examines HOTS scientific literacy at the sub-dimensional level, covering the following components, following Table 16 below:

Table 16. Sub-Dimension analysis of HOTS scientific literacy

Dimension	Sub-Dimension	HOTS Level	N-gain	
			Project-Based Inquiry	Guided Inquiry
Science Knowledge	Content Knowledge	C4	0.72	0.45
	Procedural Knowledge	C5	0.75	0.48
	Epistemic Knowledge	C6	0.68	0.32
Science Competencies	Explaining Scientific Phenomena	C4	0.71	0.46
	Interpreting Data & Scientific Evidence	C5	0.78	0.49
	Evaluating Scientific Inquiry	C6	0.7	0.35

A deeper sub-dimensional analysis revealed that the Project-Based Inquiry model produced the highest N-gain in procedural knowledge (C5) and data interpretation (C5), followed by strong gains in content (C4) and epistemic reasoning (C6). Item-level analysis also confirmed that PBI students outperformed the Guided Inquiry group across nearly all high-level tasks, especially those requiring evaluation of experimental methods and interpretation of scientific evidence. Qualitative analysis of essay responses further showed that PBI students demonstrated richer causal reasoning, more frequent use of evidence-based justification, and fewer misconceptions particularly in distinguishing variables, interpreting data trends, and evaluating experimental validity. In contrast, Guided Inquiry students tended to provide more descriptive and less analytical explanations. These findings emphasize that integrating inquiry and project cycles strengthens scientific reasoning by situating abstract procedures in authentic contexts. Overall, the additional analysis confirms that PBI's effectiveness is driven not only by overall gain scores but by substantial improvements in sub-dimensional HOTS scientific literacy components and reductions in common misconceptions.

In addition to the quantitative findings, the qualitative analysis of students' essay responses revealed noticeable differences in the quality of reasoning between the two instructional groups. Students in the Project-Based Inquiry (PBI) group demonstrated more elaborated causal reasoning supported by evidence and inference. Their responses typically included explanation chains and justification grounded in experimental observations. For example, one PBI student (Participant P12) wrote: "The temperature increased because the rate of molecular motion became faster. I concluded this after comparing the data from trials 1 and 2, in which higher heat led to a higher reaction rate. This pattern shows a direct correlation supported by the graph." (PBI Student, P12). Another PBI participant (P07) incorporated both conceptual reasoning and cross-referenced evidence: "The solution turned acidic because carbon dioxide dissolved in the water, forming carbonic acid. This was confirmed by the pH measurement, which dropped from 7 to 5 after the reaction. The color change in the indicator also supported this conclusion." (PBI Student, P07). In contrast, responses from Guided Inquiry (GI) students were generally shorter, more descriptive, and often relied on recall rather than interpretation of evidence. Several responses lacked explicit justification or inferential links. For instance, a GI student wrote: "The reaction is faster because the temperature is high." (GI Student, G14). Another GI response exemplified descriptive rather than analytical reasoning: "The indicator turned red because the solution became acidic." (GI Student, G22). These qualitative excerpts support the conclusion that PBI fostered deeper reasoning, data integration, and evidence-based justification, whereas GI responses tended to remain surface-level and descriptive.

To gain a more comprehensive understanding of variation in student abilities, the following is a box plot visualization. As further illustrated in the following Figure 2 below.

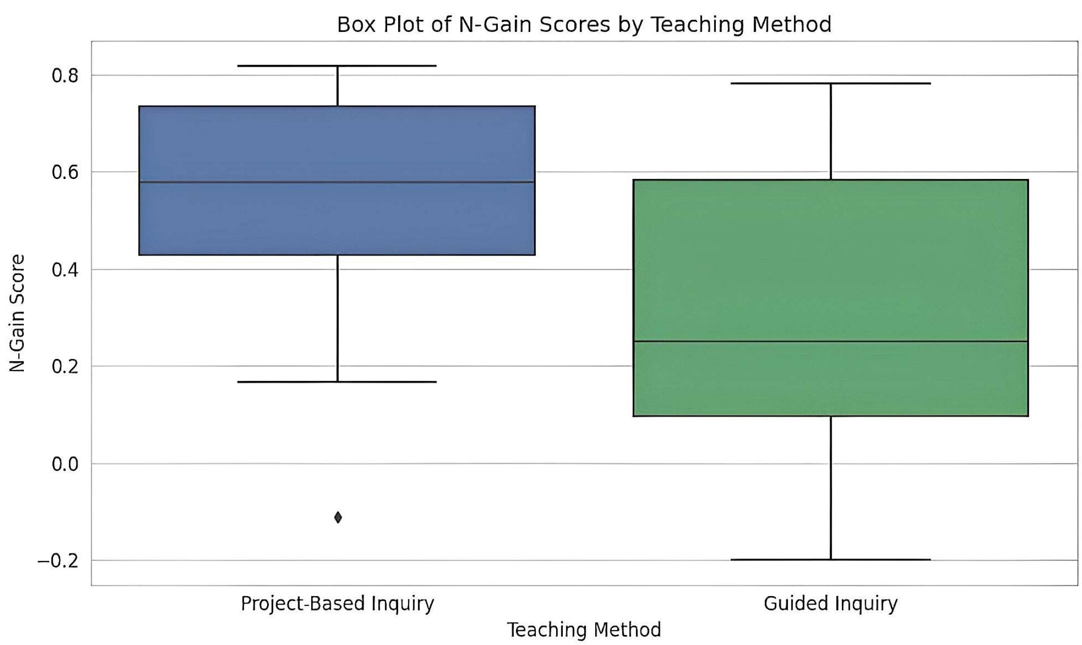

Figure 2. Comparison of average pretest and posttest scores

The Box Plot (Figure 2) provides a five-number summary statistic that shows a clear performance difference between the two groups. The box plot clearly shows that the Project-Based Inquiry method yielded higher, more consistent N-Gain scores than the Guided Inquiry method.

The effectiveness test was conducted on Primary School Teacher Education (PGSD) students from two groups: Class IV A, which received the Project-Based Inquiry treatment (experimental group), and Class IV B, which received the Guided Inquiry treatment (control group). This was subsequently followed by normality and homogeneity tests. The following presents the results of the residual normality test performed on the pretest and posttest, utilizing the One-Sample Kolmogorov-Smirnov Test:

Table 17. Normality of HOTS science literacy data

Class		***Kolmogorov-Smirnov*[a]**		
		Statistic	***df***	***Sig.***
Pre Test	Project-Based Inquiry	.126	33	.200
	Guided Inquiry	.133	35	.124
Post Test	Project-Based Inquiry	.155	33	.175
	Guided Inquiry	.140	35	.081

Based on the Kolmogorov-Smirnov test results presented in the table above, the significance (Sig.) value for all pretest and posttest data, across both the experimental and control classes, is greater than 0.05 (Sig. > 0.05). Therefore, it can be concluded that all data sets are normally distributed. A Levene's test for homogeneity of variances was conducted to assess whether the data originated from populations with equal variances. The results of the homogeneity test for HOTS scientific literacy scores are presented in Table 18 below.

Table 18. Homogeneity of HOTS science literacy data

		Levene Statistic	**df1**	**df2**	**Sig.**
Pre Test	Based on Mean	1.1051	1	66	.309
	Based on Median	.772	1	66	.383
	Based on Median and with adjusted df	.772	1	65.642	.383
	Based on the trimmed mean	1.020	1	66	.316
Post Test	Based on Mean	.514	1	66	.476
	Based on Median	.340	1	66	.562
	Based on Median and with adjusted df	.340	1	63.503	.562
	Based on the trimmed mean	.541	1	66	.465

Based on the Levene's Test results, the significance values for both the pretest and posttest data were all greater than 0.05. This finding indicates that the data exhibit homogeneity of variances, thereby fulfilling the assumption required for parametric analysis, specifically Two-Way ANOVA. Based on the research findings, the mean Higher-Order Thinking Skills (HOTS) scientific literacy scores, categorized by students' Science Process Skills (SPS) levels in both the experimental and control classes, are presented in Table 19 below:

The analysis of Science Process Skills (SPS) scores, categorized by initial proficiency level, reveals a significant divergence between the two groups following the intervention. Although the Control Group initially held a slight advantage in the High SPS category Pretest score (73.5

Table 19. Average HOTS scientific literacy based on science process skills

Science Process Skills (SPS)	Project-Based Inquiry		Guided Inquiry	
	Pretest	Postest	Pretest	Postest
High	66.1	87.5	73.5	78.6
Low	63.2	85.1	60.5	79.4

versus 66.1), the Experimental Group demonstrated a substantially higher and more uniform increase in Posttest scores, regardless of their initial proficiency. High SPS students in the Experimental Group achieved the highest Posttest score (87.5), representing a 21.4-point gain. Similarly, Low SPS students in this group also showed a large increase, scoring 85.1 (a 21.9-point gain).Conversely, the Control Group exhibited a highly uneven pattern of improvement. While their Low SPS students demonstrated a notable gain of 18.9 points, reaching a Posttest score of 79.4, their High SPS students showed only minimal improvement, with a gain of just 5.1 points, resulting in a Posttest score of 78.6. Consequently, the treatment administered to the Experimental Group (Project-Based Inquiry) proved highly effective in elevating students' SPS across all levels, resulting in significantly higher, more consistent overall Posttest scores than in the Control Group.

Hypothesis testing was performed using a Two-Way ANOVA to examine the effects of the learning models. Higher-Order Thinking Skills (HOTS) scientific literacy data were calculated as the mean for each group and subsequently compiled in the two-way ANOVA summary table presented below.

The statistical description of the ANOVA output for science process skills and HOTS (Higher-Order Thinking Skills) scientific literacy is shown in Table 21 below.

Table 20. HOTS data on science literacy factorial 2 x 2

Model / Science Process Skills (SPS)	Project-Based Inquiry (A_1)	Guided Inquiry (A_2)
High (B_1)	87.542	78.625
Low (B_2)	85.129	79.417

Table 21. Between-Subject factor

		Value Label	N
Model	1	Project-Based Inquiry (A1)	33
	2	Guided Inquiry (A2)	35
Science Process Skills (SPS)	1	High (B1)	31
	2	Low (B2)	37

Table 21 shows the number of students who have High Science Process Skills (SPS) (31 students) and Low SPS (37 students). The analysis continues with a Two-Way ANOVA hypothesis test within a Univariate General Linear Model. The complete test results are shown in Table 22 below.

The ANOVA results showed that the Learning Model factor had a highly significant main effect on students' Science Literacy HOTS, as indicated by 5Ø9Ü(1,64) = 81.765 and 5Ø]Ü = 0.000. This finding suggests a clear and meaningful difference in the average HOTS scores between students taught using Project-Based

Table 22. HOTS data on science literacy factorial 2 x 2

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Science_Process_Skills	10.476	1	10.476	1.004	.320
Learning_Model	852.973	1	852.973	81.765	.000
Science_Process_Skills * Learning_Model (Interaction)	40.969	1	40.969	3.927	.052

Inquiry and those taught with Guided Inquiry. Based on the group mean scores, the Project-Based Inquiry model consistently produced higher outcomes, 87.542 for students with high initial science process skills and 85.129 for those with low science process skills, compared to the Guided Inquiry model, which only reached 78.625 (high SPS) and 79.417 (low SPS). The superiority of the PBI model can be attributed to its characteristics, which require students to design, implement, and evaluate a project more independently. This process actively engages higher-order thinking skills and promotes deeper application of scientific literacy concepts.

The Science Process Skills (SPS) factor did not have a significant main effect on students' Science Literacy HOTS, as indicated by F(1, 64) = 1.004 and p = 0.320. This result suggests that, on average (when the effect of the learning model is not considered), the difference in HOTS scores between the High science process skills and Low science process skills groups is not large enough to be statistically significant. One possible explanation is that the intervention effect, namely, the learning model, had such a strong impact that it overshadowed the variability originating from students' initial science process skills levels when examined independently.

Based on the Two-Way ANOVA results presented in Table 22, the interaction between the Learning Model and Science Process Skills (SPS) was not statistically significant, with F(1.64) = 3.927 and p = 0.052. Since this value exceeds the commonly accepted significance threshold (á = 0.05), the result is still formally interpreted as failing to reject the Ho, indicating that no significant interaction effect was detected.

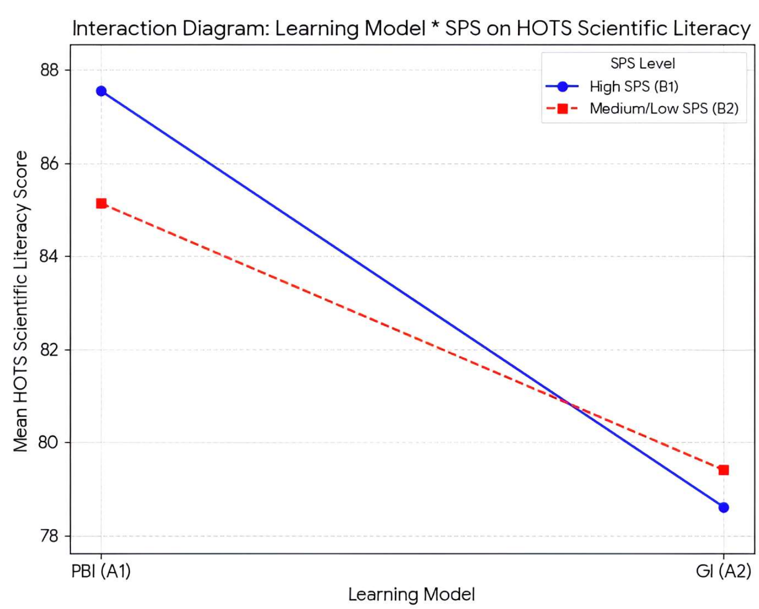

Figure 3. Interactions based on average data

Figure 3 presents the interaction plot illustrating the mean differences in Science Literacy HOTS scores across learning models and initial SPS levels. The visual trend in the plot supports the ANOVA findings, particularly the strong and statistically significant main effect of the Learning Model. The lines representing the High and Low SPS groups are consistently higher under the Project-Based Inquiry (PBI) condition compared to the Guided Inquiry (GI) condition, confirming PBI's overall advantage in improving students' HOTS performance.

In addition, the lines in the interaction plot are nearly parallel, consistent with the nonsignificant interaction effect observed in the statistical analysis ($p = 0.052$). This indicates that although the descriptive data show visible differences in SPS levels, the pattern does not provide sufficient evidence to conclude that the learning model's effectiveness depends on the initial SPS level. In other words, the benefit of the PBI model is relatively consistent across both High and Low SPS groups. The interaction plot shows parallel trends between SPS groups, supporting the nonsignificant interaction effect. The consistently higher mean scores under PBI demonstrate a strong main effect of the learning model, whereas SPS-level differences remain descriptive rather than statistically meaningful.

The two-way ANOVA results provide several important conclusions. First, the Learning Model shows a highly significant main effect ($p = 0.000$). This means that the Project-Based Inquiry (PBI) model is statistically more effective than the Guided Inquiry (GI) model in improving students' HOTS Scientific Literacy. This result is consistent with theory, as PBI requires students to plan, solve problems, and create products independently activities that naturally strengthen higher-order thinking.

Second, there is no significant interaction between the Learning Model and students' initial Science Process Skills (SPS) level ($p = 0.052$). Although the descriptive data show slightly higher gains for high-SPS students under PBI, this difference is not statistically meaningful. Therefore, PBI can be considered effective for all students, regardless of their initial SPS level. Finally, the SPS factor itself does not have a significant main effect on outcomes ($p = 0.320$). This suggests that the strong influence of the PBI instructional model ($F = 81.765$) outweighs any initial differences in SPS ($F = 1.004$).

In summary, the findings demonstrate that the choice of instructional model specifically, Project-Based Inquiry is the most influential factor in improving HOTS Scientific Literacy. As shown in Table 23, the Learning Model's significance value is 0.000 (< 0.05), so Ho is rejected, and Ha is accepted. This confirms that PBI produces significantly higher outcomes than GI. The results of further testing using Post Hoc LSD are presented in Table 23.

Table 23. Results of the post hoc least significant difference test

(I) Faktorial	(J) Faktorial	Mean Difference (I-J)	Std. Error	Sig.
A1B1	A1B2	2.4135*	1.13763	.038
	A2B1	8.9171*	1.19096	.000
	A2B2	8.1247*	1.00131	.000
A1B2	A1B1	-2.4135*	1.13763	.038
	A2B1	6.5036*	1.27062	.000
	A2B2	5.7112*	1.09486	.000
A2B1	A1B1	-8.9171*	1.19096	.000
	A1B2	-6.5036*	1.27062	.000
	A2B2	-.7924	1.15018	.493

A2B2	A1B1	-8.1247*	1.00131	.000
	A1B2	-5.7112*	1.09486	.000
	A2B1	.7924	1.15018	.493

The pairwise comparisons (Post-Hoc test) solidified the primary conclusion: the Project-Based Inquiry (PBI) model is significantly superior to Guided Inquiry (GI), and this dominance holds across all initial levels of Science Process Skills (SPS). As presented in Table 24 below.

The analysis showed that PBI consistently outperformed GI, regardless of whether students were categorized as having High SPS (A1B1 vs A2B1, $p = 0.000$) or medium SPS (A1B2 vs A2B2, p = 0.000). This robust finding underscores the PBI model's universal effectiveness. However, the Post-Hoc results also revealed an interesting internal pattern. When looking only at the PBI groups, the High SPS students significantly outperformed the Sedang/ Rendah SPS students (A1B1 vs A1B2, p=0.038). This suggests that while PBI works for everyone, students with stronger foundational skills (Higher SPS) can leverage the model's independence and complexity to reach even higher levels of HOTS Scientific Literacy. Conversely, within the GI group, there was no significant difference in HOTS scores between High SPS and Sedang/Rendah SPS students (A2B1 vs A2B2, p=0.493). This suggests that the GI model may not adequately challenge or facilitate maximum growth for students with high initial potential. In essence, PBI is the superior model, effectively boosting scores across the board, and it successfully differentiates student performance based on their initial ability, a sign of a truly effective, high-ceiling intervention.

Table 24. HOTS data on science literacy factorial 2 x 2

Comparison	Mean Difference (I-J)	Sig.	Statistical Conclusion (A1 vs. A2)
A1B1 vs. A2B1	8.9171	0.000	PBI is highly superior for High SPS students.
A1B2 vs. A2B2	5.7112	0.000	PBI is highly superior for Medium/Low SPS students.
A2B1 vs. A2B2	0.7924	0.493	No significant performance difference between High and Medium SPS groups under the GI model.

Interaction analysis indicates that students with High SPS derive the most significant benefits because they already possess an adequate cognitive infrastructure (basic SPS) to handle the ambiguity and open-ended demands of the PBI Model. They can directly allocate their cognitive energy to HOTS tasks (Analysis and Creation). At the same time, students with Low SPS may experience cognitive overload when simultaneously attempting to complete basic inquiry procedural steps and the demands of HOTS. This finding suggests the potential for a Matthew Effect in the implementation of PBIL, where the significantly steeper N-gain increase in the High SPS group potentially widens the relative achievement gap post-intervention (supported by the Post-Hoc LSD for A1B1 vs A1B2, p=0.038). This serves as a pedagogical warning: PBI, as a high-ceiling intervention, excels at maximizing potential but requires adaptation.

The study's results strongly indicate that the Project-Based Inquiry (PBI) model effectively enhanced students' HOTS scientific literacy skills. This success was clearly demonstrated by higher gain scores in the experimental class than in the control class, as well as the overwhelming percentage of experimental students (57.57%) in the high-gain category, compared to the control class (34.28%). Clearly, actively engaging students in scientific investigations and authentic projects strengthens both higher-order thinking skills and scientific literacy. A two-way ANOVA analysis confirmed a significant difference between groups ($p < 0.05$), indicating that PBI had a greater impact on improving HOTS scientific literacy than Guided Inquiry.

Although descriptive trends suggested that PBI may offer greater benefits for students with higher SPS, the interaction effect between the learning model and SPS was not statistically significant ($p = 0.052$). Therefore, this pattern cannot be interpreted as a confirmed moderation effect. Instead, it should be viewed as a potential emerging trend rather than conclusive evidence. Crucially, however, the model still improved learning outcomes for students with medium and low SPS overall. These findings resonate deeply with constructivism theory, which posits that knowledge is actively built through participation, reflection, and authentic experiences (Ertmer & Newby, 1993; Fosnot & Perry, 2013). By integrating inquiry and project processes, which inherently demand that students engage in higher-order cognitive processes such as Analysis (C4), Evaluation (C5), and Creation (C6), aligning perfectly with Bloom's revised taxonomy (Anderson et al., 2001).

This claim is powerfully substantiated by the N-gain data for HOTS Scientific Literacy sub-dimensions (Table 16). PBI consistently generated substantially higher N-gain scores across all HOTS levels, with the most profound impact observed at the highest tiers. For Creation (C6), PBI achieved an N-gain of approximately 0.69 (including Epistemic Knowledge and Evaluating Scientific Inquiry), significantly surpassing the Guided Inquiry group (0.335). This evidence firmly establishes PBI as a superior catalyst for deep, high-level thinking. Crucially, this quantitative boost is supported by qualitative evidence of the thinking process in the Basic Concepts of Science classroom. For Analysis (C4), observational notes confirmed students actively deconstructed complex, real-world phenomena into testable scientific variables, rather than merely memorizing facts. Furthermore, the high N-gain of 0.78 in Interpreting Data & Scientific Evidence (Evaluation/C5) is validated by observing students frequently engaging in critical debate and data justification when comparing their prototype's performance against expected scientific principles. The pinnacle of this deep engagement is evident in the project artifacts (simple working models of the human respiratory system and homemade solar-powered water purifiers), which serve as tangible proof of their ability to synthesize foundational scientific concepts into original, practical solutions (Creation/C6). Thus, PBI's effectiveness is empirically linked to its capacity to nurture and reward deep, high-level cognitive engagement.

The findings of this study align with a substantial body of research demonstrating that Project-Based Inquiry (PBI) and related inquiry-oriented pedagogies enhance scientific literacy, higher-order thinking, and problem-solving skills (Chu et al., 2011; de Jong et al., 2024; Prayogi et al., 2018). Prior work also shows that project-driven learning environments promote deeper engagement and improved HOTS (Jeffery et al., 2016), while the effectiveness of inquiry consistently depends on the scaffolding structures embedded in instruction (Hmelo-Silver et al., 2007; Lazonder & Harmsen, 2016).

Several influential studies argue that PBL/IBL is not universally effective, especially for learners with low prior knowledge or weak initial skills. (Kirschner et al., 2006) contend that minimally guided inquiry can result in cognitive overload, limiting conceptual understanding and, in some cases, leading to lower learning outcomes. Mayer (2004) and Alfieri et al. (2011) similarly report that unguided discovery approaches tend to be ineffective, particularly for low-ability learners (Alfieri et al., 2010; Corno & Winne, 2006). Systematic reviews and meta-analytic evidence show substantial variability in inquiry-based outcomes, with several studies finding no advantage over more direct instructional methods for low-performing groups (Furtak et al., 2012; Minner et al., 2010). In the context of PBL, another study highlights inconsistent effect sizes across studies (Walker & Leary, 2009), and Alromaih et al. (2022) report that low-ability students may even perform worse under PBL than under direct instruction.

Recent research reinforces the claim that inquiry learning is highly sensitive to the presence of structured guidance (Asma & Dallel, 2020; Kalyuga, 2007; Kirschner & Sweller, 2018; Meissner & Bogner, 2013; Schleinschok et al., 2017). These studies demonstrate that without sufficient procedural scaffolding, such as worked examples, task prompts, and milestone guidance, learners with lower initial competence are at significant risk of experiencing learning failure. This argument resonates with the Antonio & Effects (2024), Jong et al. (2023), and Sinha & Kapur (2021) productive failure framework, which posits that complex inquiry tasks disproportionately benefit high-performing learners while often hindering those with limited prerequisite knowledge.

The results of the present study play an important role in reconciling these divergent perspectives. On one hand, the observed Matthew Effect, where high-SPS students achieved significantly greater gains (Post Hoc $p = 0.038$), supports the contention that inquiry-rich environments tend to favor learners with stronger cognitive resources. This finding aligns with arguments from cognitive load theory and prior-knowledge literature. On the other hand, a critical aspect of the findings challenges the assumption that PBL/IBL inherently disadvantages low-ability students: PBI remained more effective than Guided Inquiry, even within the Low-SPS subgroup. This suggests that the PBI design implemented in this study, featuring clear project goals, structured task sequences, collaborative roles, and an explicit final product, served as both a motivational and a procedural scaffold, enabling low-SPS learners to remain engaged and succeed despite the cognitive demands.

Taken together, these results show that while PBI offers a “high ceiling” that strongly benefits high-SPS learners, it does not automatically widen achievement gaps. The key moderating factor is the intentional integration of scaffolding within the project structure. The present study extends prior literature by demonstrating that a well-designed PBI model can transform cognitive challenges into equitable learning opportunities, thereby countering concerns raised in studies of minimally guided inquiry.

Therefore, implementing the PBI strategy must be accompanied by a focus on structured scaffolding, particularly for students with lower Science Process Skills (SPS). Based on our findings, practical implications must be highly specific. First, to effectively familiarize students with SPS before project initiation, we recommend that lecturers dedicate the first two sessions to a Guided Mini-Inquiry. This explicitly trains 2-3 basic SPS skills (e.g., observing, measuring, and simple data interpretation) using highly structured, relevant phenomena from Basic Concepts of Science. Second, the specific scaffolding required for Medium/Low SPS students should focus on Procedural and Conceptual Scaffolding during the complex Analysis and Evaluation phases of the project. We recommend using Structured Procedural Templates, which include: a) A mandatory experimental checklist, and b) Guided Data Analysis Tables equipped with key questions to explicitly compel students to interpret their project findings and connect them back to the basic scientific concepts. This support must be gradually faded as students demonstrate competency in subsequent project cycles.

In conclusion, this research provides strong evidence that PBI can be an effective approach in teacher education programs for developing essential HOTS and 21st-century scientific literacy. Moving forward, the generalizability of these promising findings should be tested, but the most pressing research agenda is one driven by our specific data. Future research should specifically investigate the effectiveness of targeted scaffolding interventions for the Medium/ Low Science Process Skills (SPS) group within a PBIL environment. Specifically, experimental studies are needed to compare the impact of Procedural Scaffolding (e.g., highly structured project templates and checklists) versus Conceptual Scaffolding (e.g., guided questions focusing on data interpretation and connecting to core scientific concepts) to identify the optimal method for closing the HOTS performance gap. Furthermore, to validate PBI as a strategy for long-term cognitive change, longitudinal studies are highly recommended to determine whether the significant gains in HOTS Scientific Literacy achieved in the Basic Concepts of Science course are sustained for 6 to 12 months after the intervention concludes.

■ CONCLUSION

The findings of this study demonstrate that the Project-Based Inquiry (PBI) learning model effectively enhances the Higher Order Thinking Skills (HOTS) and science literacy of prospective elementary school teachers. The two-way ANOVA results showed a significant main effect of the learning model, indicating that PBI consistently produced higher HOTS science literacy scores than the Guided Inquiry model. While science process skills (SPS) alone did not yield a significant independent effect, descriptive differences suggested that students with higher SPS may benefit slightly more from PBI; however, the interaction effect between the learning model and SPS was not statistically significant. Thus, the effectiveness of PBI can be considered consistent across SPS levels rather than dependent on them. Accordingly, any interpretation suggesting differential benefits based on SPS level should be treated cautiously and may warrant further investigation in future studies with larger samples. This pattern supports theoretical perspectives that assert that inquiry-based pedagogies are most powerful when learner characteristics align with task demands, underscoring the importance of metacognitive and procedural skills in complex learning environments. Collectively, these results contribute meaningfully to the field of science education for teacher preparation programs by demonstrating that PBI is a robust pedagogical approach capable of cultivating analytical reasoning, data interpretation, and scientific argumentation competencies essential for 21st-century teaching.

The implications of this research extend to both theory and practice. Theoretically, the observed interaction aligns with Aptitude–Treatment Interaction (ATI) frameworks, which argue that the effectiveness of instructional methods depends on learner aptitudes. The finding that PBI works best for students with stronger SPS reinforces the view that inquiry-based models require certain cognitive and procedural readiness to be fully effective. Practically, these results suggest the need for preparatory scaffolding in SPS before implementing PBI broadly in teacher education programs. This study's quasi-experimental design, limited sample size, and reliance on instruments that warrant further validation constitute important limitations and should be acknowledged when generalizing the results. Future research should explore multi-site replications, longitudinal designs, and differentiated scaffolding strategies to understand better how PBI can equitably benefit students with varying initial SPS levels. Nonetheless, this study offers nuanced evidence that PBI is a promising, though not universally optimal, model whose effectiveness depends on thoughtful alignment between pedagogical design and learner characteristics. Consequently, the PBI model exhibits strong theoretical, functional, and empirical suitability for application in the specific learning context of prospective elementary school teachers.

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