Humanidades & Inovação

THE EFFECT OF PROJECT-BASED INQUIRY LEARNING ON STUDENTS' HIGHER ORDER THINKING AND SCIENCE LITERACY

O EFEITO DA APRENDIZAGEM POR INVESTIGAÇÃO BASEADA EM PROJETOS NO PENSAMENTO DE ORDEM SUPERIOR E NA ALFABETIZAÇÃO CIENTÍFICA DOS ALUNOS

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Abstract: *This study investigates the effectiveness of the Project-Based Inquiry Learning model in enhancing students' higher-order thinking skills (HOTS) and scientific literacy. Grounded in constructivist learning theory, the research adopted a quasi-experimental design with pretest–post-test control groups involving secondary school students. Standardised instruments assessed HOTS dimensions (analysis, evaluation, creation) and scientific literacy competencies (content, process, and context). Data were analysed using descriptive statistics, paired-samples tests, and ANOVA to determine significance and effect sizes. Findings revealed that students taught through the Project-Based Inquiry approach achieved significantly higher gains in HOTS and scientific literacy than peers in conventional instruction. The results suggest that integrating inquiry-driven projects fosters deeper engagement, critical reasoning, and application of scientific concepts to real-world contexts. These findings highlight the pedagogical potential of project-based inquiry learning as an innovative strategy for strengthening science education and preparing students for 21st-century challenges.*

Keywords: *Project-based learning. Higher-order thinking skills. Scientific literacy. Science education.*

Resumo: *Este estudo investiga a eficácia do modelo de Aprendizagem por Investigação Baseada em Projetos (AIB) no aprimoramento das habilidades de pensamento de ordem superior (HOTS) e da alfabetização científica dos alunos. Fundamentada na teoria construtivista da aprendizagem, a pesquisa adotou um delineamento quase-experimental com grupos de controle pré e pós-teste, envolvendo alunos do ensino fundamental II e médio. Instrumentos padronizados avaliaram as dimensões das HOTS (análise, avaliação e criação) e as competências de alfabetização científica (conteúdo, processo e contexto). Os dados foram analisados utilizando estatística descritiva, testes de amostras pareadas e ANOVA para determinar a significância e o tamanho do efeito. Os resultados revelaram que os alunos que aprenderam por meio da abordagem de AIB obtiveram ganhos significativamente maiores em HOTS e alfabetização científica do que seus pares no ensino convencional. Os resultados sugerem que a integração de projetos orientados à investigação promove um engajamento mais profundo, o raciocínio crítico e a aplicação de conceitos científicos a contextos do mundo real. Essas descobertas destacam o potencial pedagógico da aprendizagem por investigação baseada em projetos como uma estratégia inovadora para fortalecer o ensino de ciências e preparar os alunos para os desafios do século XXI.*

Palavras-chave: *Aprendizagem baseada em projetos. Desenvolvimento de habilidades de pensamento crítico. Alfabetização científica.*

Introduction

The evolving landscape of science education in the twenty-first century demands a concerted effort to foster higher-order thinking skills (HOTS) and scientific literacy among students. International assessments like the OECD's PISA highlight content mastery and the crucial importance of applying scientific understanding to real-world contexts, preparing learners for active citizenship and lifelong learning (Le et al., 2023). Critical thinking, a cornerstone of HOTS, encompasses abilities such as analysis, evaluation, and creation, which have significantly enhanced students' engagement with complex scientific problems (Vincent-Lancrin, 2023). However, despite the acknowledged need for these skills, educational research consistently reveals a troubling persistence of traditional pedagogies emphasising rote memorisation over inquiry-based approaches (Ilma et al., 2023). Large-scale assessments indicate that students often struggle with scientific literacy, failing to connect classroom learning and significant societal issues such as environmental challenges and technological advancements (Agustina et al., 2022). This disconnect is particularly stark in secondary education, where instructional practices remain teacher-centred, limiting students' opportunitieto engage in critical thinking and real-world problem-solving (Wijayanto et al., 2023).

Integrating project-based learning (PjBL) offers a promising pathway to address these challenges. Research shows that PjBL enhances student engagement and directly contributes to improved outcomes in HOTS and scientific literacy (Suprojo et al., 2025). By framing learning within a project context, students are encouraged to apply theoretical knowledge to practical scenarios, thus reinforcing essential skills such as critical thinking and creativity (Krushelnycky & Karrow, 2025). Empirical studies suggest that when students are involved in hands-on, inquiry-based learning environments, their ability to analyse and synthesise information increases significantly (Riwayatiningsih et al., 2025).

Moreover, innovative pedagogies that intertwine STEM education with project-based methodologies have effectively nurtured scientific literacy across diverse learner populations (Lin & Li, 2025). For instance, utilising technology-enhanced learning strategies, like gamification combined with PjBL, further fosters motivation and deeper cognitive engagement (Ng et al., 2024). These methods encourage students to acquire knowledge and develop the competencies necessary to navigate and address contemporary global challenges in science and technology. Aligning science education with the demands of the twenty-first century requires a deliberate shift towards pedagogical frameworks that prioritise higher-order thinking and scientific literacy. As emphasised in current research, adopting student-centred, inquiry-based pedagogies can significantly enhance engagement, critical thinking, and the real-world applicability of scientific knowledge, ultimately preparing students not merely to know, but to think creatively and critically in an increasingly complex world (Quyen et al., 2025).

Implementing Project-Based Inquiry Learning (PjBIL) represents a promising pedagogical response to the ongoing challenges in science education. Specifically, PjBIL enhances traditional project-based learning by integrating inquiry-focused processes, positioning students as active participants in their educational journey rather than passive recipients of knowledge (Dema & Choden, 2024). This method encourages learners to engage in a cycle of questioning, planning, experimenting, and presenting solutions to authentic problems, cultivating higher-order thinking skills (HOTS) and enhancing scientific literacy (Prihatin et al., 2025).

Previous studies have separately documented the benefits of project-based and inquiry learning, showcasing improvements in student engagement and cognitive skills (Milner-Bolotin & Zazkis, 2025). However, a gap in the literature remains concerning the systematic examination of the combined effects of PjBIL on both HOTS and scientific literacy, particularly under controlled experimental conditions (Jailani et al., 2023). This study seeks to bridge that gap through a quasi-experimental design aimed at providing empirical evidence regarding the efficacy of the PjBIL model in enhancing secondary school students' abilities to analyse, evaluate, and create solutions while applying scientific knowledge across various contexts (Prihatin et al., 2025).

The significance of integrating PjBIL into the curriculum is underscored by evidence suggesting that such pedagogies foster not only a deeper understanding of scientific content but also its application to complex real-world issues relevant to today's rapidly evolving society

(Boon et al., 2022). Moreover, incorporating technology and blended learning elements into the PjBIL framework further enriches the educational experience, helping students transition into more innovative learning environments (Milner-Bolotin & Milner, 2025). The anticipated findings from this research aim to make a substantial contribution to the existing body of literature on innovative pedagogical strategies in science education. By systematically evaluating how PjBIL can enhance HOTS and scientific literacy, this study offers practical insights for educators and policymakers seeking to improve educational outcomes aligned with twenty-first-century skills (Suryanti et al., 2024). Integrating effective teaching methods is vital for preparing students to meet the challenges of the modern world, equipping them with the skills needed to become informed and active participants in society (Riwayatiningsih et al., 2025).

Methodology

Research Design

This study employed a quasi-experimental design with a pretest–post-test non-equivalent control group. This approach was chosen because it allows for evaluating the effects of a pedagogical intervention on targeted outcomes by comparing students taught using the Project-Based Inquiry Learning (PjBIL) model (experimental group) with those taught through conventional instruction (control group (Creswell, W. John & Creswell, 2018).

Participants

The participants comprised 72 secondary school students from an urban public school, divided into two intact classes: 36 students in the experimental group and 36 in the control group. The students were aged 14–16 years. A convenience sampling method was used based on class availability. Informed consent was obtained from students and their guardians in accordance with ethical guidelines for educational research (Mohammadi et al., 2022).

Instruments

Table 1 is two standardized instruments were used to measure students' higher-order thinking skills and scientific literacy.

Table 1. Research Instruments

Instrument	Construct Measured	Indicators / Domains	Item Type	Number of Items	Reliability (Cronbach's α)
Higher-Order Thinking Skills (HOTS) Test	Higher-order cognitive skills	Analysis, Evaluation, Creation	Multiple-choice and open-ended	15	0.82
Scientific Literacy Test	Scientific literacy ability	Content Knowledge, Scientific Processes, Contextual Applications	Multiple-choice and short response	20	0.79

Source: Author results

The HOTS test, based on Anderson and Krathwohl's revised taxonomy, assessed analysis, evaluation, and creation through multiple-choice and open-ended questions. The Scientific Literacy Test, adapted from the OECD PISA framework, measured content knowledge, scientific processes, and contextual application. Both instruments were validated by science education experts and showed acceptable reliability (α = 0.82 and 0.79).

Data Analysis

Data were analysed using SPSS 25.0. Descriptive statistics (mean, standard deviation, and normalised gain scores) were computed to provide an overview of performance. Inferential statistics included: 1) Shapiro–Wilk test for normality and Levene's test for homogeneity of variance; 2) Paired-sample t-tests to compare pretest and post-test scores within each group; 3) Independent-sample t-tests and one-way ANOVA to compare post-test scores between groups; and 3) Cohen's d to determine the effect size of the intervention. A significance level of $p < 0.05$ was adopted for all tests.

Results and discussion

Table 2 presents the pretest and post-test mean scores for higher-order thinking skills (HOTS) and scientific literacy for both groups. The experimental and control groups showed relatively similar mean scores at the pretest stage, indicating baseline equivalence. After the intervention, the experimental group demonstrated substantial improvements in HOTS and scientific literacy, whereas the control group showed only modest gains.

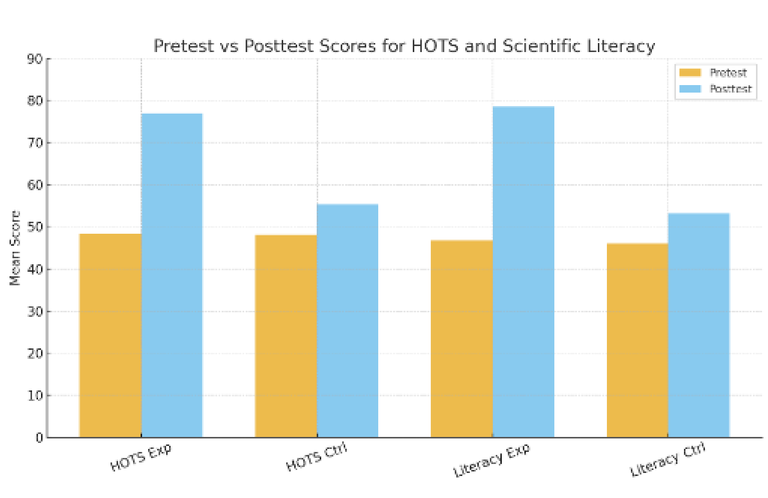
Table 2. Pretest and Post-test Scores for HOTS and Scientific Literacy

Variable	Group	Pretest Mean (SD)	Post-test Mean (SD)	Normalised Gain (g)
HOTS	Experimental	48.25 (6.41)	76.89 (7.05)	0.58
	Control	47.97 (7.02)	55.31 (6.87)	0.15
Scientific Literacy	Experimental	46.72 (5.88)	78.56 (6.44)	0.61
	Control	45.94 (6.33)	53.12 (7.15)	0.13

Source: Author results

Table 2 presents the mean pretest and post-test scores and normalized gain values for HOTS and scientific literacy. Both groups had similar pretest scores, indicating comparable initial abilities. After the intervention, the experimental group showed higher improvements (HOTS g = 0.58; literacy g = 0.61). In contrast, the control group showed only small gains (HOTS g = 0.15; literacy g = 0.13). These results indicate that the Project-Based Inquiry Learning model was more effective than conventional instruction.. The pre- and post-test results can be illustrated in graphs, as shown in Figure 1.

Figure 1. Pretest and post-test scores for HOTS and scientific literacy



Source: Author results

Inferential Statistics

Before conducting hypothesis testing, the assumptions of normality and homogeneity were examined. The **Shapiro–Wilk test** indicated that the data were normally distributed, and the **Levene's test** confirmed homogeneity of variances across groups. These results validated the use of parametric tests for further analysis. **Table 3** presents the results of paired-sample t-tests within groups, independent-sample t-tests between groups, and effect sizes (Cohen's d).

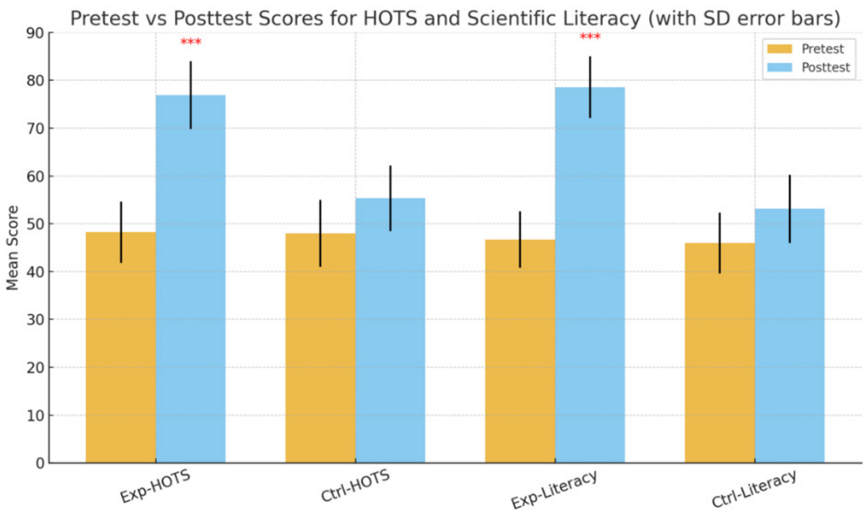
Table 3. Results of Paired-Sample and Independent-Sample t-Tests

Variable	Test	t-value	p-value	Effect Size (Cohen's d)
HOTS (Exp: Pre–Post)	Paired-sample t-test	14.82	< 0.001	–
Literacy (Exp: Pre–Post)	Paired-sample t-test	16.45	< 0.001	–
HOTS (Exp vs Ctrl Post)	Independent-sample t-test	9.37	< 0.001	1.52 (large)
Literacy (Exp vs Ctrl Post)	Independent-sample t-test	10.21	< 0.001	1.66 (large)

Source: Author results

Paired-samples t-tests showed that the experimental group had significant improvements in HOTS ($t = 14.82$, $p < 0.001$) and scientific literacy ($t = 16.45$, $p < 0.001$) after Project-Based Inquiry Learning. The control group showed only small, non-significant improvements. Independent-sample t-tests also showed that the experimental group scored significantly higher than the control group. Large effect sizes ($d = 1.52$ and 1.66) indicate that the intervention had a strong educational impact. Figure 2 visualises a single compact for the inferential results.

Figure 2 - Pretest and post-test scores for HOTS and scientific literacy



Source: Author results

The two bar charts with SD error bars: Pretest vs Post-test HOTS show a significant improvement in the experimental group, whereas the control group shows minimal change. Pretest vs Post-test Scientific Literacy highlights the substantial gains in the experimental group, while the control group indicates only slight progress. These results suggest that Project-Based Inquiry Learning strongly affected students' higher-order thinking and scientific literacy. The normalised gain values above 0.58 in the experimental group indicate medium-to-high learning effectiveness, while the control group's gains remained minimal.

The present study demonstrates the significant impact of Project-Based Inquiry Learning (PjBIL) on enhancing students' higher-order thinking skills (HOTS) and scientific literacy. The empirical evidence gathered from the quasi-experimental design indicates that the experimental group engaged in the PjBIL achieved substantial improvements in both outcomes compared to the control group, with large effect sizes acknowledged in the relevant literature . These findings underscore the efficacy of active, student-centred pedagogies, which foster deeper engagement with learning materials and cultivate essential competencies for the twenty-first century (Dragnić-Cindrić & Anderson, 2025). The theoretical underpinnings of constructivist learning support the observed enhancements in HOTS, as articulated by Anderson and Krathwohl (Anderson, L.W. & Krathwohl, 2001). According to their framework, learners construct knowledge actively through investigation and problem-solving rather than rote memorisation. By participating in PjBIL, students engaged in project cycles that involved questioning, investigating, and presenting findings, thereby creating an environment conducive to the essential cognitive processes of analysis, evaluation, and creation, core components of HOTS (Rahmayanti et al., 2022). This aligns with the views of Shin (Shin et al., 2021) application of knowledge.

Furthermore, this study's results contribute to the existing literature highlighting the effectiveness of project-based and inquiry-focused methodologies in promoting HOTS and scientific literacy (Sholahuddin et al., 2023). Integrating these approaches enhances students' competencies and enables them to apply their scientific knowledge to real-world issues, reinforcing the importance of education in addressing contemporary challenges. While previous studies have established the individual effectiveness of either project-based learning or inquiry-based approaches, the systematic examination of their combined effects, as presented in this research, fills a critical gap in the literature (Ndiung & Menggo, 2024). The findings from this study reinforce the notion that innovative pedagogical methods, such as PjBIL, hold significant promise for transforming science education by equipping students with the skills to navigate and respond to the complexities of the modern world. The results provide insights for educational practitioners and policymakers and suggest a need for future research exploring the potential of integrated instructional models to enhance learning outcomes (Evens et al., 2015).

The marked gains in scientific literacy observed in this study underscore the effectiveness of Project-Based Inquiry Learning (PjBIL) in enhancing cognitive skills and equipping students to navigate and apply scientific knowledge to real-world problems. Students in the experimental group engaged with authentic issues, such as water quality and alternative energy, necessitating a synthesis of content knowledge, process skills, and contextual understanding. This aligns with (Hao et al., 2024), who posited that effective project-based learning significantly improves students' scientific literacy skills, preparing them for real-world challenges. In contrast, the control group showed limited improvement, highlighting the inherent limitations of traditional teacher-centred instruction, which often emphasises content transmission rather than critical engagement. Conventional pedagogical methods, as seen in lecture-dominated classrooms, frequently fail to cultivate vital skills such as analytical reasoning and problem-solving.

Practical Implications

For teachers, adopting PjBIL implies rethinking classroom practices toward more student-centred, collaborative, and problem-driven activities. For policymakers, the evidence underscores the need to embed inquiry-oriented projects within national science curricula to prepare learners for complex societal and technological challenges.

Conclusion

This study examined the effect of the Project-Based Inquiry Learning (PjBIL) model on secondary school students' higher-order thinking skills (HOTS) and scientific literacy. The findings clearly demonstrate that students who engaged in inquiry-driven projects achieved significantly greater gains in cognitive and scientific competencies than peers taught through traditional methods. Large effect sizes indicate that the intervention was statistically significant and educationally meaningful.

The results highlight the pedagogical value of combining project-based and inquiry-oriented approaches. While project-based learning situates knowledge in authentic contexts, inquiry ensures that students engage in systematic reasoning and evidence-based exploration. Together, these features create a powerful learning environment that fosters analysis, evaluation, creation, and the capacity to apply scientific knowledge to real-world problems. Beyond its theoretical contribution, the study carries practical implications for science educators and policymakers. Teachers are encouraged to adopt inquiry-driven projects to enhance students' engagement and deepen learning outcomes. Curriculum designers and decision-makers should consider embedding PjBIL models into science education policies to ensure that learners acquire the competencies required to address twenty-first-century challenges.

Nevertheless, the study has limitations. The relatively small sample and single-school context restrict the generalizability of the findings. Future research should involve larger and more diverse populations, examine long-term retention effects, and explore the role of teacher training in scaling up PjBIL implementation. Project-Based Inquiry Learning emerges as a promising pedagogical model that bridges the gap between content mastery and critical competencies. Nurturing higher-order thinking and scientific literacy can prepare students for active citizenship, informed decision-making, and participation in a knowledge-based society.

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Recebido em 26 de agosto de 2026
Aceito em 25 de fevereiro de 2026