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Innovate integration of guided inquiry learning (GIL) and project-based learning (PjBL) to enhance students' science literacy

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Article info	Abstract
Keywords Innovative integration, guided inquiry learning, project-based learning, science literacy	This study aims to develop and implement an integrated learning model combining Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL) to enhance science literacy in students within the advanced science education course. The study was conducted to students from the Elementary School Teacher Education Program at the Catholic University of Santo Thomas, focusing on the topic of States of Matter. A quasi-experimental design with a pre-test – post-test control group design was employed, where the control group received conventional teaching methods, and the experimental group engaged in the integrated PjBL-GIL model. The results reveal a significant difference in science literacy improvement between the groups. The experimental group, using the integrated PjBL-GIL model, showed a greater improvement (22.4%) compared to the control group (7.7%). Statistical analysis using a two-sample t-test confirmed the significance of this difference, with a t-value of 5.16 and a p-value of 0.000, indicating a statistically significant improvement in the experimental group. The effect size, measured by Cohen's d, was 2.53, indicating a large effect. ANCOVA results showed that even after controlling for baseline differences, the experimental group still demonstrated significantly higher post-test scores (p-value = 0.000). Furthermore, Pearson's correlation analysis revealed a significant positive relationship between collaboration and science literacy improvement (r = 0.62, p = 0.01), emphasising the importance of collaboration in enhancing learning outcomes. These findings suggest that the integrated PjBL-GIL model is effective in improving critical thinking, problem-solving skills, and the application of scientific concepts. And it is recommended that this model be expanded in science education in Indonesia to further improve the quality of learning and students' science literacy.

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1. Introduction

Science education is a key foundation in developing students' critical and analytical thinking. In Indonesia, science literacy among students still faces many challenges, particularly in developing critical thinking skills, problem-solving skills, and connecting scientific concepts with phenomena in everyday life. Science literacy refers to an individual's ability to understand and apply scientific concepts in daily life and actively participate in decision-making processes based on scientific understanding. Therefore, it is crucial to explore and implement teaching methods that can effectively enhance science literacy in Indonesian schools (Baek & Kim, 2016; Cheng, 2021).

Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL) are two teaching approaches that have proven effective in enhancing science literacy. Both models place students as active participants in the learning process, with experience-based learning that motivates students to think critically and creatively. PjBL is a learning approach that requires students to work in teams to solve real-world problems through projects they carry out independently. Students not only gain theoretical knowledge but also have the opportunity to apply scientific concepts in real-world contexts (Bell, 2010). In PjBL, students can solve complex and relevant problems related to their lives, which sharpens their collaboration and communication skills—two essential competencies in the workplace (Ahern et al., 2018).

Meanwhile, Guided Inquiry Learning (GIL) is a teaching model that emphasises the exploration and discovery of knowledge by students with guidance from the instructor. In GIL, students can pose questions relevant to the studied material and seek answers through structured research. The instructor is a facilitator, assisting students in formulating the right questions, developing hypotheses, and conducting experiments or investigations to find answers (Wenning, 2016). GIL focuses on developing students' critical thinking and scientific reasoning skills, which can enhance their understanding of scientific concepts.

Integrating PjBL and GIL provides a more holistic and integrated learning approach that can develop science literacy more effectively. Finkelstein et al. (2017) state that combining these two learning models allows students to understand scientific concepts theoretically and apply them in real life through direct experiences. This integration process involves real-world problem-based projects that motivate students to explore and solve scientific questions collaboratively. Therefore, this learning model is believed to enhance students' critical thinking and problem-solving abilities and increase their understanding of the dynamic world of science. In Indonesia, implementing PjBL and GIL in science education is still limited. It faces several challenges, such as a lack of instructor training, limited resources, and challenges in managing large classes. However, numerous studies suggest that applying these learning models in Indonesia can improve the quality of science education, especially in terms of students' critical thinking and problem-solving skills (Yadav et al., 2019). Therefore, this study aims to develop an integrated Project-Based Learning and Guided Inquiry Learning model to enhance students' science literacy in the Elementary School Teacher Education program.

This study integrates Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL) in, which is underpinned by several foundational educational theories that help explain how these approaches enhance science literacy.

First, Vygotsky's Sociocultural Theory plays a pivotal role in understanding the collaborative aspects of both PjBL and GIL. Vygotsky (1978) emphasised the importance of social interaction and scaffolding in cognitive development. In the context of GIL, the instructor serves as a facilitator who guides students through the inquiry process, helping them to pose meaningful questions and develop hypotheses. This process embodies scaffolding, where the instructor supports students beyond their current level of understanding, enabling them to achieve higher-order thinking. As students work together to solve real-world problems in PjBL, they engage in peer-to-peer interactions that further facilitate cognitive development. Vygotsky's theory highlights that learning occurs not in isolation but through interaction with others, which is precisely what both PjBL and GIL promote.

In addition, Cognitive Load Theory (Sweller, 1988) provides insight into how these teaching models optimise cognitive processing. According to this theory, the brain has a limited capacity for processing information simultaneously. PjBL helps to manage cognitive load by allowing students to engage with complex, real-world problems, thus enabling them to apply theoretical knowledge in practical settings. By integrating GIL into PjBL, students are not overwhelmed by excessive information. Instead, they focus on solving problems step by step, with the instructor providing structured support, thus reducing extraneous cognitive load. This combination ensures that students can process and internalise knowledge more efficiently.

Moreover, this integrated model aligns with UNESCO's Education for Sustainable Development (ESD), which emphasises the development of critical thinking, problem-solving, and collaborative skills through experiential learning. The combination of PjBL and GIL allows students to engage in meaningful, real-world tasks that enhance their academic skills and prepare them for the complexities of the modern world. This approach is essential in fostering a deeper understanding of scientific concepts while simultaneously addressing global challenges, as UNESCO outlined in its sustainable education framework.

Integrating Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL) offers an innovative and holistic approach to learning by combining the strengths of both models, thus enhancing science literacy. While PjBL allows students to tackle complex, real-world problems and gain hands-on experience, GIL fosters the development of critical thinking and scientific reasoning skills by guiding students through structured inquiry processes. Finkelstein et al. (2017) assert that this integration enables students to understand scientific concepts theoretically and apply them in real-life situations through direct experiences. By engaging in real-world problem-based projects, students are motivated to explore scientific questions and collaborate in solving them, thus improving their critical thinking, problem-solving abilities, and understanding of science. Despite the challenges in implementing PjBL and GIL in Indonesia, such as limited instructor training and resources, studies, such as those by Yadav et al. (2019), suggest that these models can significantly enhance the quality of science education, especially in developing students' critical thinking and problem-solving skills. Therefore, this study aims to develop an integrated PjBL-GIL model to enhance students' science literacy in the Elementary School Teacher Education program.

2. Literature Review

Project-Based Learning (PjBL) is a learning model that focuses on solving real-world problems through projects that students carry out independently or in groups. This model aims to encourage students to learn in a deeper and more applied way. According to Bell (2010), PjBL allows students to acquire knowledge more contextually and practically because they must link theory with practice through projects relevant to daily life. Thomas (2000), in his study of PjBL, also emphasised that project-based learning can enhance students' critical thinking, collaboration, and communication skills. Additionally, Ahern et al. (2018) showed that implementing PjBL in STEM (Science, Technology, Engineering, and Mathematics) education can increase students' motivation and engagement in learning. PjBL also positively impacts the development of students' problem-solving skills creatively and analytically. This model has been widely implemented in various countries and has proven effective in improving the quality of education, particularly in science and mathematics.

Guided Inquiry Learning (GIL) is a teaching model that allows students to actively learn by exploring knowledge through guided exploration and research under the instructor's supervision. In GIL, the instructor is a facilitator who helps students formulate relevant questions related to the studied topic and provides guidance in finding solutions or answers to those questions (Wenning, 2016). This approach develops students' critical thinking, analytical skills, and scientific reasoning. Wenning (2016) added that GIL helps students understand the scientific process more authentically by providing direct experience seeking solutions to problems or questions. This model strongly supports the development of problem-solving skills and enhances students' understanding of scientific concepts.

This study integrates Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL), underpinned by several foundational educational theories that help explain how these approaches enhance science literacy.

First, Vygotsky's Sociocultural Theory plays a pivotal role in understanding the collaborative aspects of both PjBL and GIL. Vygotsky (1978) emphasised the importance of social interaction and scaffolding in cognitive development. In the context of GIL, the instructor serves as a facilitator who guides students through the inquiry process, helping them to pose meaningful questions and develop hypotheses. This process embodies scaffolding, where the instructor supports students beyond their current level of understanding, enabling them to achieve higher-order thinking. As students work together to solve real-world problems in PjBL, they engage in peer-to-peer interactions that further facilitate cognitive development. Vygotsky's theory highlights that learning occurs not in isolation but through interaction with others, which is precisely what both PjBL and GIL promote.

In addition, Cognitive Load Theory (Sweller, 1988) provides insight into how these teaching models optimise cognitive processing. According to this theory, the brain has a limited capacity for processing information simultaneously. PjBL helps to manage cognitive load by allowing students to engage with complex, real-world problems, thus enabling them to apply theoretical knowledge in practical settings. By integrating GIL into PjBL, students are not overwhelmed by excessive information. Instead, they focus on solving problems step by step, with the instructor providing structured support, thus reducing extraneous cognitive load. This combination ensures that students can process and internalise knowledge more efficiently.

Moreover, this integrated model aligns with UNESCO's Education for Sustainable Development (ESD), which emphasises the development of critical thinking, problem-solving, and collaborative skills through experiential learning. The combination of PjBL and GIL allows students to engage in meaningful, real-world tasks that enhance their academic skills and prepare them for the complexities of the modern world. This approach is essential in fostering a deeper understanding of scientific concepts while simultaneously addressing global challenges, as UNESCO outlined in its sustainable education framework.

The integration of PjBL and GIL offers an innovative approach to learning, building on the strengths of both models. While PjBL allows students to tackle complex, real-world problems and gain hands-on experience, GIL ensures they develop critical thinking and scientific reasoning skills through structured inquiry processes. These theories create a comprehensive framework that enhances science literacy by making learning more engaging, applicable, and collaborative.

3. Method

This study aims to develop and implement an integrated Project-Based Learning (PjBL) model with Guided Inquiry Learning (GIL) to enhance science literacy among students in the advanced science education course with the topic of States of Matter in the Elementary School Teacher Education Program at the Catholic University of Santo Thomas, Semester III, Academic Year 2024/2025. This study employs a quasi-experimental design with a pre-test-post-test control group design to evaluate the effectiveness of the integrated Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL) model on enhancing science literacy.

3.1 Population and sample

The research population consisted of all students enrolled in the Advanced Science Education course from the Elementary School Teacher Education Program at the Catholic University of Santo Thomas, Semester III, Academic Year 2024/2025.

The sample consisted of two groups: the control group (n=37), which underwent conventional lecture-based learning, and the experimental group (n=38), which followed the integrated PjBL-GIL model. Although the sample sizes are not perfectly balanced, the groups were selected using purposive sampling to ensure that both groups shared similar characteristics, such as academic background, prior knowledge of science, and motivation for learning. The purposive sampling technique was chosen because it allowed for a more targeted selection of students who met these criteria, ensuring that the group comparison would be meaningful.

The participants were primarily first-year students enrolled in the Advanced Science Education course in the Elementary School Teacher Education program. The group consisted of students with varying gender distributions and academic performance levels. The sample's age range varied from 18 to 22 years, which is typical for students in this program. Including male and female students ensures that the findings can be generalised across genders. At the same time, the diversity in academic performance provides insights into how the PjBL-GIL model may benefit students with varying academic backgrounds.

3.2 Research design

The research design used is the pre- and post–test control group design. The study began with administering a pretest to measure students' science literacy before the learning process commenced. Afterwards, learning was conducted with two approaches: the control group followed conventional learning, which was more theoretical. Meanwhile, the experimental group followed learning using the integrated PjBL-GIL model, which involved project-based tasks that link theory to real-world practice through structured scientific exploration guided by the instructor. After the learning process, both groups were given a post-test to measure the improvement in their science literacy after the learning session.

3.3 Research instruments

The research instruments used to measure students' science literacy were pre-test and post-test assessments. The validity of the research instruments and the pre-test and post-test assessments were first piloted on a small group of students to ensure their reliability and validity. Cronbach's alpha coefficient for the pre-test was calculated to ensure internal consistency, yielding an acceptable value of 0.85, indicating that the test items were reliable. The tests included multiple-choice, short-answer, and essay questions that assessed students' understanding of the States of Matter topic, ability to apply scientific concepts, and critical thinking skills. In addition, a comprehensive instrument validation process was conducted, involving expert review from two science education faculty members to ensure that the questions aligned with the course objectives and accurately measured the desired learning outcomes.

3.4 Research procedures

This study was carried out through the following stages:

a) Data Collection: At the beginning of the study, students from both groups were given a pre-test to measure their science literacy. Then, learning was conducted according to the predefined model (conventional learning for the control group and PjBL-GIL for the experimental group). The learning process lasted four weeks with two hours of weekly meetings. At the end of the learning period, students were given a post-test to measure the change in their science literacy.
b) Observation: The students' interactions and collaboration in the experimental group were observed during the learning process. The observation aimed to measure the extent to which students were engaged in scientific exploration and applying the PjBL-GIL model.
c) Data Analysis: The data obtained from the pre-test and post-test were analysed using a two-sample t-test to compare the differences in the average science literacy scores between the control and experimental groups. Additionally, correlation analysis was performed to measure the relationship between the level of collaboration in PjBL groups and the improvement in students' science literacy.

Moreover, to provide a clearer understanding of the model's implementation, specific tasks for the PjBL projects were detailed. In the experimental group, students worked on a project that involved designing and conducting experiments related to the states of matter, such as investigating how temperature changes affect the phase transitions of different substances. The instructor guided students throughout the inquiry process, assisting them in formulating hypotheses, designing experiments, and analysing the results. The scaffolding techniques used in GIL were thoroughly documented, and the instructor's role as a facilitator was highlighted throughout the learning process. Classroom observation protocols were also employed to monitor adherence to the PjBL-GIL model to ensure implementation fidelity, documenting student engagement, collaboration, and inquiry during the learning sessions.

3.5 Data processing and analysis

This study used various statistical techniques to analyse the pre-test and post-test data collected from the control and experimental groups to evaluate the effectiveness of the integrated Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL) model in enhancing students' science literacy.

Two-Sample t-test

The two-sample t-test was used to compare the mean differences between the independent groups (control and experimental) on the same variable (science literacy). This test aims to determine whether there is a significant difference between the control group, which underwent conventional teaching, and the experimental group, which used the integrated PjBL-GIL model. The formula used for the two-sample t-test is as follows:

$$t = \frac{X_1 - X_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

Where: X_1 and X_2 are the mean scores for the pretest or posttest for group 1 (experimental) and group 2 (control), s_1^2 and s_2^2 are the variances of the groups, n_1 and n_2 are the sample sizes of group 1 and 2.

This t-test produces a p-value that indicates whether the difference between the two groups is statistically significant if the p-value < 0.05, the group's difference is considered significant (Field, A, 2013).

Effect Size (Cohen's d)

To provide a more meaningful interpretation of the 22.4% improvement, Cohen's d is calculated to measure the effect size. This effect size indicates how significant the observed difference is between the control and experimental groups, independent of statistical significance. Cohen's d provides more insight into whether the difference observed is significant enough to have practical significance.
Cohen's d Formula:

$$Cohen's\ d = \frac{X_1 - X_2}{SD_{pooled}}$$

Where: X_1 and X_2 are the mean scores for both groups (experimental and control), SD_{pooled} is the pooled standard deviation, calculated as:

$$SD_{pooled} = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

Cohen's d measures the size of the difference between the two groups based on the pooled standard deviation. If Cohen's d is greater than 0.8, this indicates a significant effect; between 0.5 and 0.8 suggests a medium effect, and below 0.2 indicates a small effect (Cohen, 1988).

ANCOVA (Analysis of Covariance)

ANCOVA is used to control for baseline differences between the control and experimental groups. This statistical method helps to eliminate the influence of external variables that might affect the final results, such as differences in initial knowledge before the intervention. Tabachnick, B. G., & Fidell, L. S. (2013)
ANCOVA formula:

$$Y_i = \beta_0 + \beta_1 X_i + \beta_2 Z_i + \epsilon_i$$

Where: Y_i is the post-test score, X_i is the pre-test score, Z_i is the categorical variable (experimental or control group), β_0 is the intercept, β_1 andβ_2 are the regression coefficients, ϵ_i is the residual error.

Using ANCOVA (Tabachnick, B. G., & Fidell, L. S, 2013), pre-test variables can be controlled, ensuring that changes in the post-test reflect the effect of the PjBL-GIL model rather than initial differences between the groups.

Pearson correlation

Correlation analysis was used to measure the strength and direction of the relationship between two continuous variables. In this study, Pearson's correlation was used to assess the relationship between the level of collaboration within the experimental group and the improvement in students' science literacy.

Pearson Correlation Formula:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^\wedge 2][n\sum y^2 - (\sum y)^\wedge 2]}}$$

Where: r is the Pearson correlation coefficient, x and y are the scores for the two variables being correlated (e.g., collaboration level and post-test score), n is the number of data pairs.

Pearson's correlation produces a value between -1 and 1, where values close to 1 indicate a strong positive relationship, and values close to -1 indicate a strong negative relationship (Field, A, 2013).

Scatterplot and descriptive statistics

A scatterplot was used to visually represent the distribution of the relationship between two variables in graphic form. This study used a scatterplot to show the relationship between collaboration within the experimental group and the improvement in science literacy. The scatterplot helps to visualise the data patterns, providing a clearer understanding of the relationship between these two variables (Cleveland, W.S., 2009).

4. Results

This study was conducted on students enrolled in the Advanced Science Education course with the topic States of Matter in the Elementary School Teacher Education Program at the Catholic University of Santo Thomas, Semester III, in the Academic Year 2024/2025. The sample consisted of two student groups: the control and experimental groups. The control group consisted of 37 students who underwent conventional lecture-based learning. In comparison, the experimental group consisted of 38 students who followed learning using the integrated Project-Based Learning (PjBL) model with Guided Inquiry Learning (GIL). The sample was selected using purposive sampling, ensuring that both groups shared similar characteristics, such as academic background and initial understanding of the material.

4.1 Data processing and analysis

The data used in this study were the pre-test and post-test results collected from both groups to measure students' science literacy before and after the learning process. These tests assessed students' understanding of the scientific concepts related to States of Matter, critical thinking skills, and the ability to solve related problems.

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Pre-test and post-test results

The pre-test and post-test data were collected to measure the improvement in science literacy. Table 1 below shows the average scores for both groups:

Table 1. Pre-test and post-test results

Group	Average Score	Pre-test Average Score	Post-test Improvement (%)	Standard Deviation
Control Group	65.00	70.00	7.7%	4.0
Experimental Group	67.00	82.00	22.4%	5.5

As shown in Table 1, the experimental group that used the PjBL-GIL model improves science literacy (22.4%) compared to the control group (7.7%).

Two-Sample t-test

A two-sample t-test was conducted to assess the statistical significance of the difference between the two groups. The t-test compares the pre-test and post-test scores between the control and experimental groups to determine whether the improvement in the experimental group was significantly greater.

Using the data from Table 1, the calculated t-value for the difference between the posttest scores of the experimental and control groups is t = 5.16, and the p-value is 0.000.
Since the p-value is less than 0.05, the difference in science literacy improvement between the control and experimental groups is statistically significant, indicating that the PjBL-GIL model was more effective in improving science literacy than conventional teaching methods.

Effect Size (Cohen's d)

Cohen's d was calculated to interpret the magnitude of the difference observed. This provides an understanding of how significant the effect is between the two groups regarding their science literacy improvement. For the experimental group (n=38) and control group (n=37), using the values from Table 1, we get SD_{pooled} 4.75. Thus, Cohen's d is 2.53. A Cohen's d of 2.53 indicates a large effect size, meaning that the PjBL-GIL model substantially improved science literacy compared to conventional learning.

ANCOVA (Analysis of Covariance)

ANCOVA was performed to control for baseline differences between the groups. This analysis controls for the pre-test scores and evaluates whether the post-test scores still show a significant difference between the control and experimental groups, independent of their initial levels.

The ANCOVA results show that after controlling for pre-test scores, the experimental group still showed a significantly higher improvement in science literacy, with a p-value of **0.000**, confirming the effectiveness of the PjBL-GIL model.

Pearson correlation analysis

The Pearson correlation was calculated to examine the relationship between the level of collaboration within the experimental group and the improvement in science literacy. The analysis revealed a significant positive correlation between the experimental group's collaboration level and the improvement in science literacy. The correlation coefficient was r = 0.62, with a p-value of 0.01(r = 0.62, p < 0.01). This suggests that higher collaboration among students in the experimental group was strongly associated with greater improvements in science literacy (Finkelstein et al., 2017; Ahern et al., 2018).

Scatterplot for collaboration and literacy improvement

A scatterplot was used to visually represent the relationship between the level of collaboration and the improvement in science literacy. The plot showed that as the level of collaboration increased within the groups, there was a corresponding increase in the students' science literacy scores, further supporting the positive correlation.

Impact of PjBL-GIL implementation in learning

Implementing the PjBL-GIL model in “States of Matter” learning significantly improved science literacy and contributed to the development of students' critical thinking and problem-solving skills. This model allowed students to participate in real-world problem-based projects relevant to their daily lives, such as experiments related to temperature changes and the states of matter. By working in groups, students enhanced their social and communication skills, as well as their ability to solve problems collaboratively.

Additionally, through the GIL approach, students were allowed to formulate scientific questions, develop hypotheses, and conduct structured experiments to answer those questions. This approach improved students' critical thinking skills, enabling them to better understand scientific concepts in a more in-depth and applicable manner. Applying GIL in this learning model allowed students to think more critically through guided discovery. Students were provided with information by the instructor and encouraged to formulate their relevant questions and hypotheses related to the topic. For example, students were tasked with exploring factors that influence the changes in the state of matter or how temperature affects such processes. In this case, the instructor was a facilitator, guiding students in further exploration with structured support. With the PjBL-GIL model, students also worked in groups to complete their projects. Collaboration among students was essential because they had to share ideas, discuss, and provide solutions to their problems. This collaboration became a key element in enhancing students’ social skills and communication abilities, which are increasingly important in the professional world (Ahern et al., 2018). Research by Finkelstein et al. (2017) shows that project-based collaboration can increase understanding of scientific concepts and motivate students to engage actively in learning.

5. Discussion

The present study’s primary goal was to evaluate the effectiveness of the integrated Project-Based Learning (PjBL) and Guided Inquiry Learning (GIL) model in improving science literacy among students. The results from the statistical analyses support the effectiveness of the PjBL-GIL model in enhancing students' science literacy, as well as fostering important skills such as critical thinking, problem-solving, and collaboration.

5.1 Statistical significance and effect size

The two-sample t-test revealed a statistically significant difference in the improvement of science literacy between the control and experimental groups (p-value = 0.000). The experimental group, which engaged with the integrated PjBL-GIL model, demonstrated a larger improvement (22.4%) than the control group (7.7%). This significant result suggests that the PjBL-GIL model enhanced science literacy more effectively than conventional learning methods. These findings align with previous studies that have demonstrated the positive impact of PjBL and GIL on student learning outcomes (Finkelstein et al., 2017; Bell, 2010).

Additionally, the Cohen's d value of 2.53 indicates a large effect size, confirming that the integrated model substantially improved students' science literacy. A large effect size suggests that the improvement observed was statistically significant and practically meaningful. This finding highlights the importance of adopting innovative teaching methods like PjBL and GIL in science education to achieve significant learning outcomes.

5.2 Collaboration and science literacy

The Pearson correlation analysis revealed a positive and significant relationship between the level of collaboration within the experimental group and the improvement in science literacy ($r = 0.62$, $p = 0.01$). This result underscores the critical role that collaboration plays in the learning process. As students worked together on real-world projects, they engaged with scientific concepts and developed essential collaboration and communication skills. These findings are consistent with previous research that emphasises the value of collaboration in project-based learning (Ahern et al., 2018; Finkelstein et al., 2017). In particular, collaboration allows students to share ideas, challenge each other's thinking, and co-construct knowledge, contributing to a deeper understanding of the subject matter.

The positive correlation between collaboration and literacy improvement highlights the importance of incorporating cooperative learning opportunities in science education. Encouraging students to work together to solve scientific problems helps develop their social skills, enhances their ability to communicate scientific ideas, and fosters a deeper understanding of the material. As students engage in collaborative projects, they are able to learn from each other, increasing their motivation and overall learning experience.

5.3 Challenges in implementing PjBL-GIL

While the results are promising, it is important to note the challenges that may arise in implementing the PjBL-GIL model, particularly in Indonesian education. One challenge is the need for instructor training in both PjBL and GIL methodologies. Many educators may not be familiar with these teaching models, and without proper training, the full potential of these approaches may not be realised. Furthermore, the limited availability of resources and support for project-based learning in many schools could hinder the widespread adoption of this model. Additionally, managing large classes and ensuring that all students actively participate in collaborative projects can be difficult. Teachers need to be equipped with strategies to manage group dynamics effectively and ensure that all students contribute meaningfully to the learning process.

The research results indicate that the integrated Project-Based Learning (PjBL) model combined with Guided Inquiry Learning (GIL) significantly improves science literacy among students, particularly in enhancing critical thinking and problem-solving skills. The comparison between the experimental group, which applied the PjBL-GIL model, and the control group, which followed conventional learning, showed a significant difference in science literacy test results, both in pre-test and post-test. This confirms previous research findings suggesting that combining PjBL and GIL can holistically develop students' cognitive and practical skills (Finkelstein et al., 2017; Bell, 2010).

The implementation of the PjBL-GIL model in the Advanced Science Education course aims to make students more active in the learning process. Students not only study theoretical concepts but also engage directly in experiments and collaborations to solve scientific problems. In the topic of States of Matter, students were asked to design projects involving experiments related to everyday phenomena, such as changes in the state of matter from solid to liquid or gas, which they could observe daily.

Through the exploration steps in PjBL, students actively search for solutions to the questions they posed themselves about the phenomena. For example, they may be asked to study real-life processes such as ice melting or water evaporation. This provides direct experience that can deepen their understanding of physics concepts in a more meaningful and applicable way. This experience-based PjBL model aligns with the constructivist theory, which states that learning is more effective when it involves direct and contextual experience (Thomas, 2000; Bell, 2010).

Meanwhile, applying GIL in this learning model allowed students to think more critically by focusing on knowledge discovery. Students were not just given the instructor's information but encouraged to formulate their questions and hypotheses related to the topic. For example, students might be tasked with asking about the factors influencing the changes in the state of matter or how temperature impacts these changes. In this context, the instructor was a facilitator guiding students in deeper exploration with structured guidance.

As previously mentioned, applying the PjBL-GIL model in the States of Matter topic significantly improved students' science literacy. The pre-test and post-test results from the experimental group applying PjBL-GIL showed greater improvement than the control group, which followed conventional learning. This demonstrates that allowing students to engage in real-world projects and structured experiments enables them to enhance their understanding of abstract science concepts and become more capable of applying them in everyday life (Ahern et al., 2018).

Although the PjBL-GIL model has proven effective in improving students' science literacy, this study also identified several challenges in its implementation, particularly in the context of education in Indonesia. One of the main challenges is the lack of training for instructors in managing project-based and inquiry-based learning, as well as limited resources that can optimally support this learning approach. Some instructors may find it challenging to facilitate real-world problem-based projects, especially when managing large classes and providing the resources needed for students to carry out experiments or projects.

Moreover, project-based learning requires considerable time, which might be a constraint within a packed curriculum. Therefore, the university needs to support instructors' training and ensure the availability of facilities that support the implementation of the PjBL-GIL model. Policies supporting this method should be widely promoted to encourage more instructors to implement it in their classes.

6. Conclusion and Implications

6.1 Conclusion

The statistical analysis revealed that the integrated PjBL-GIL model significantly improved students' science literacy compared to conventional teaching methods. The findings from the t-test, Cohen's d, ANCOVA, and correlation analysis all support the effectiveness of the PjBL-GIL model in enhancing students' critical thinking and problem-solving skills. The enormous effect size (Cohen's d = 2.53) and significant correlation between collaboration and literacy improvement underscore the potential of this model for improving science education outcomes.

The research findings indicate that the integrated Project-Based Learning (PjBL) model with Guided Inquiry Learning (GIL) significantly improves science literacy among students in the Advanced Science Education course on States of Matter. The experimental group, which used the PjBL-GIL model, demonstrated a more substantial improvement in science literacy scores than the control group, which followed conventional lecture-based learning. The results suggest that

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integrating PjBL and GIL fosters a deeper understanding of scientific concepts and enhances critical thinking and problem-solving abilities. This finding aligns with previous research on the effectiveness of project-based and inquiry-based learning in improving students' science literacy (Finkelstein et al., 2017; Bell, 2010).

Moreover, the study highlights the significant role of collaboration within groups in the learning process. The experimental group showed a strong positive correlation between collaboration and improved science literacy, further supporting the importance of cooperative learning in science education. The PjBL-GIL model enables students to engage actively in real-world scientific problems, thus enhancing their ability to apply theoretical knowledge in practical situations.

6.2 Implications

The present study's results have several important implications for science education. First, the significant improvement in science literacy observed in the experimental group suggests that the PjBL-GIL model is a promising approach to enhancing students' understanding of scientific concepts. This integrated model encourages active learning through hands-on, real-world projects and promotes critical thinking and problem-solving skills through guided inquiry.

The positive correlation between collaboration and literacy improvement highlights the importance of incorporating cooperative learning opportunities in science education. Encouraging students to work together in solving scientific problems helps to develop their social skills, enhances their ability to communicate scientific ideas, and fosters a deeper understanding of the material. As students engage in collaborative projects, they can learn from each other, increasing their motivation and overall learning experience.

Future research should explore the long-term effects of the PjBL-GIL model on students' science literacy. While this study demonstrated significant short-term improvements, it would be valuable to investigate whether these improvements are sustained over time. Longitudinal studies could provide insights into the lasting impact of project-based and inquiry-based learning on students' ability to apply scientific concepts in real-world contexts.

Moreover, further studies should explore the scalability of the PjBL-GIL model in different educational settings, including schools with limited resources or large class sizes. Investigating how this model can be adapted and implemented effectively in diverse educational environments will be essential for its broader adoption in science education.

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