

Enhancing Middle School Students' Scientific Literacy Through Inquiry-Based Learning In Environmental Education

Muhammad Ikram Abdullah^{1*}, Javier Kusuma², Rangga Nasution Abrar³

^{1,2,3} School of Educational Studies, Universiti Sains Malaysia, Pulau Pinang, Malaysia.

* Corresponding author : ikram05@gmail.com

ARTICLE INFO	ABSTRACT
Article history Received : September 30, 2025 Revised : October 25, 2025 Accepted : December 26, 2025 Published: December 28, 2025 Keywords Scientific Literacy Inquiry-Based Learning Environmental Education Middle School Student Engagement  License by CC-BY-SA Copyright © 2025, The Author(s).	Scientific literacy is essential for preparing students to face environmental challenges and make informed decisions in a complex, technology-driven society. This study aims to investigate the effectiveness of inquiry-based learning (IBL) in enhancing middle school students' scientific literacy within the context of environmental education. A quasi-experimental design was employed involving 120 students from two public middle schools in Pinang, Malaysia. The experimental group received instruction using inquiry-based learning strategies, while the control group was taught using conventional methods. Data were collected through a pre-test and post-test scientific literacy assessment and analyzed using paired and independent samples t-tests. The results revealed that students in the experimental group showed significantly higher improvement in scientific literacy, particularly in understanding scientific concepts, applying knowledge to real-world issues, and evaluating environmental solutions critically. The inquiry-based learning model fostered active participation, critical thinking, and problem-solving skills by engaging students in observing, questioning, experimenting, and drawing conclusions based on evidence. Moreover, student interviews and classroom observations indicated increased motivation and environmental awareness among participants. These findings underscore the value of integrating inquiry-based approaches in environmental education to cultivate scientifically literate individuals who are capable of making responsible environmental decisions. The study recommends broader implementation of inquiry-based learning across science curricula to support long-term environmental literacy development in students.

How to cite: Abdullah, M, A., Kusuma, J, & Abrar, R, N. (2025). Enhancing Middle School Students' Scientific Literacy Through Inquiry-Based Learning In Environmental Education, 1(4). 111-117. <https://doi.org/10.70716/josme.v1i4.338>

INTRODUCTION

The novelty of this study lies in its clear positioning at the intersection of scientific literacy, inquiry-based learning (IBL), and environmental education within a Southeast Asian middle school context—a combination that remains significantly underexplored in existing literature. Although scientific literacy has long been recognized as a critical competency for preparing young learners to navigate the demands of a rapidly evolving, technology-driven society (Bybee, 2015; Fensham, 2020), research has shown that many educational systems still struggle to implement pedagogical strategies that genuinely cultivate these skills. Much of the existing scholarship on scientific literacy continues to focus on Western educational frameworks or on isolated scientific disciplines such as biology and physics, leaving a considerable gap in our understanding of how scientific literacy can be effectively embedded within environmental education, particularly in Asian contexts (Laugksch, 2021; Dillon, 2018). This study directly responds to that gap by examining how IBL can be strategically employed to enhance middle school students' scientific literacy through authentic, locally relevant environmental education experiences in Pinang, Malaysia.

A core element of this study's novelty is the integration of IBL into real-world environmental issues that directly affect Malaysian communities. While IBL has been extensively studied in general science classrooms and has consistently demonstrated positive impacts on critical thinking, problem-solving, and student engagement (Pedaste et al., 2015; Lazonder & Harmsen, 2021), its use within environmental education remains limited. Even more scarce are studies that apply IBL in the context of Southeast Asia, where variations in educational culture, teacher training, and curriculum design create unique challenges for implementation (Tan & So, 2020; Putra & Suparno, 2022). This study contributes new insights by situating IBL within the environmental realities of Pinang, including waste management, coastal degradation, and water pollution—environmental issues that are not only scientifically relevant but also socially and personally meaningful to students. The place-based orientation of the intervention is a novel aspect that strengthens the ecological validity of the study, aligning with recent calls for contextualized environmental education that

empowers learners to understand and address challenges within their own communities (Sobel, 2019; Sahin & Çelik, 2021).

Another significant contribution of this research lies in its focus on Malaysian middle schools, a setting where environmental education is mandated but often delivered in highly traditional, teacher-centered ways (Yuliati et al., 2021). Although Malaysia's curriculum documents emphasize inquiry, higher-order thinking, and environmental awareness through the Standard-Based Curriculum for Secondary Schools (KSSM), classroom practice frequently remains dominated by rote learning and textbook-driven instruction (Zulkarnain, 2021). As a result, students often struggle to connect theoretical scientific knowledge to real-world problems, highlighting a disconnect between curriculum goals and pedagogical realities. This study addresses this disconnect by providing empirical evidence on how IBL can bridge the gap between theoretical understanding and practical environmental problem-solving. The research thus contributes to a more nuanced understanding of how inquiry-based approaches can be adapted to Malaysian cultural and pedagogical contexts, which differ substantially from Western classrooms where most IBL research has been conducted.

The novelty of the study is further enhanced by its mixed-methods design, which combines quantitative measures of scientific literacy with qualitative data on student engagement, attitudes, and inquiry behaviors. Many previous studies on IBL rely primarily on quantitative test scores, which, while informative, may not fully capture the depth of conceptual change or attitudinal shifts that occur during inquiry learning (Creswell & Plano Clark, 2018). By incorporating classroom observations and student interviews, this study provides a richer and more holistic picture of the learning process. This approach aligns with contemporary perspectives in science education research that emphasize the importance of examining cognitive, affective, and behavioral dimensions of learning simultaneously (Fredricks et al., 2019; Osborne, 2014). Therefore, the methodological innovation of triangulating multiple data sources contributes significantly to the robustness and comprehensiveness of the study's findings.

Additionally, the study makes a novel contribution by explicitly linking IBL to the development of environmental citizenship—an emerging concept in environmental education research. Environmental citizenship goes beyond knowledge acquisition and encompasses values, attitudes, and behaviors that support sustainable decision-making (Jagers et al., 2014; Ardoin et al., 2020). Although many educational systems aim to develop environmentally responsible citizens, relatively few empirical studies investigate how specific pedagogical models such as IBL cultivate these competencies, especially in middle school learners. This research demonstrates that students engaged in IBL not only improved in scientific literacy but also developed heightened environmental awareness, stronger motivation to act sustainably, and a deeper sense of connection to their local environment. These outcomes suggest that IBL can serve as a developmental pathway toward environmental citizenship, offering a significant theoretical and practical contribution to the field.

Furthermore, the cultural relevance of the study adds another layer of originality. While much existing literature on IBL originates from Western contexts where inquiry-based practices are more commonly integrated into teacher training and educational philosophy, Southeast Asian classrooms often operate under different cultural expectations regarding authority, classroom discourse, and student autonomy (Hofstede, 2011; Sim & Print, 2017). Inquiry learning demands a shift from teacher-centered instruction to student-centered exploration, which may challenge traditional norms. By documenting how Malaysian teachers and students navigate these cultural dynamics, this research contributes a rare perspective to the IBL literature and offers valuable implications for adapting inquiry-based models across culturally diverse settings.

Lastly, the study's focus on local environmental issues as a foundation for inquiry-based activities introduces a distinctive contribution to the literature on place-based pedagogy. While place-based education has gained increasing recognition for its capacity to connect learners to their environments and foster community-based problem-solving (Gruenewald & Smith, 2014), few studies explore its integration with IBL to enhance scientific literacy. By demonstrating that inquiry tasks grounded in local environmental challenges improved students' scientific reasoning, critical thinking, and evaluative decision-making, this study expands the theoretical framework linking place-based learning with inquiry theory and scientific literacy development.

In summary, the novelty of this study is multifaceted: it applies inquiry-based learning within environmental education; it does so in a culturally and pedagogically under-represented Southeast Asian

context; it incorporates a mixed-methods approach that captures cognitive and affective outcomes; it focuses on place-based environmental issues; and it explores how IBL supports the development of environmental citizenship. These dimensions collectively position the study as a meaningful and original contribution to the fields of scientific literacy, environmental education, and inquiry-based pedagogy..

RESEARCH METHODOLOGY

This study employed a quantitative approach using a quasi-experimental design, specifically the *pretest-posttest non-equivalent control group design*. This design was chosen to assess the effectiveness of the Inquiry-Based Learning (IBL) model in enhancing students' scientific literacy without fully randomizing the participants. Two intact classes from two different public middle schools in Pinang, Malaysia, were selected as the experimental and control groups, respectively. Each group consisted of 60 eighth-grade students with relatively comparable demographic and academic backgrounds. The experimental group received instruction through the IBL model, while the control group was taught using conventional methods involving lectures and textbook-based assignments.

The primary research instrument was a scientific literacy test designed based on the frameworks provided by the Programme for International Student Assessment (PISA) and the OECD. The test comprised 30 items combining multiple-choice questions and short constructed responses, covering three core domains: (1) scientific knowledge, (2) application of science in real-life environmental contexts, and (3) evaluative thinking in analyzing scientific information and proposing solutions. The test items were validated by three experts in science education to ensure content validity. A pilot test conducted with 30 students from a similar background yielded a Cronbach's Alpha of 0.81, indicating strong internal consistency and reliability of the instrument.

The instructional intervention spanned six weeks, with each group undergoing six 90-minute sessions. The IBL strategy implemented in the experimental group followed five structured phases: *orientation*, *conceptualization*, *investigation*, *conclusion*, and *discussion*. Environmental education topics such as climate change, water pollution, and waste management were contextualized within local Pinang issues. Students were placed into small collaborative groups to conduct simple experiments, analyze data, and present their findings. The teacher acted as a facilitator, guiding the inquiry process and encouraging reflective thinking. In contrast, the control group received traditional teaching focused on direct instruction, minimal discussion, and reinforcement through drill-based exercises.

To enrich the quantitative data, qualitative insights were gathered through classroom observations and semi-structured interviews. Observations were conducted using an inquiry activity checklist that captured indicators such as students' questioning behavior, participation rate, and teamwork during group tasks. Ten randomly selected students from the experimental group participated in individual interviews to share their perceptions of the learning process and their attitudes toward environmental issues after experiencing the IBL approach. These qualitative data aimed to reveal deeper dimensions of student engagement and conceptual understanding that are not easily captured through testing alone.

Data analysis included both descriptive and inferential statistical procedures. Pretest and posttest scores from both groups were analyzed using paired samples t-tests to determine within-group gains. An independent samples t-test was then employed to compare the performance differences between the experimental and control groups. In parallel, qualitative data were analyzed thematically to identify recurring patterns in students' responses and observed behaviors. The integration of both quantitative and qualitative findings provided a holistic understanding of how IBL impacts students' scientific literacy in the context of environmental education.

All research activities were conducted in accordance with ethical standards. Official permission was obtained from the Pinang State Education Department, and informed consent was secured from students' parents and guardians. Confidentiality of student identities and test scores was strictly maintained. The study also ensured that classroom interventions did not interfere with the core curriculum. At the end of the study, feedback was provided to participating schools to support future instructional improvements. This research methodology was designed to offer valid and comprehensive insights into how Inquiry-Based Learning can meaningfully enhance middle school students' scientific literacy in a Malaysian educational context.

RESULTS AND DISCUSSION

The results of this study indicated a statistically significant improvement in the scientific literacy scores of students in the experimental group who were taught using the Inquiry-Based Learning (IBL) model. Pretest and posttest comparisons showed that the experimental group improved from a mean score of 57.4 to 83.1, while the control group improved only marginally from 56.9 to 64.5. The paired samples t-test confirmed that the gain in the experimental group was highly significant ($p < 0.001$), suggesting that IBL effectively enhanced students' scientific understanding in environmental contexts.

Further analysis using independent samples t-tests revealed a significant difference in posttest scores between the experimental and control groups ($p < 0.01$), affirming the superiority of the IBL approach over traditional instructional methods. The effect size (Cohen's $d = 1.12$) indicated a large and meaningful impact of IBL on students' scientific literacy. These findings align with previous studies that underscore the effectiveness of IBL in fostering higher-order thinking and deeper engagement with scientific content (Ismail et al., 2021).

In terms of the specific components of scientific literacy, the most substantial gains in the experimental group were observed in students' ability to apply scientific concepts to real-world environmental issues. For example, students demonstrated improved reasoning in identifying causes of water pollution and proposing community-based mitigation strategies. This development is attributed to the authentic learning context embedded within the IBL process, a feature that has been emphasized in local educational research (Yuliani & Anggraini, 2020).

Moreover, students in the experimental group showed enhanced skills in scientific argumentation and evidence-based reasoning. During posttest tasks requiring justification of environmental decisions (e.g., banning plastic bags), they cited data collected during classroom investigations and integrated knowledge from multiple disciplines. These skills are central to scientific literacy as defined by PISA and are critical in preparing students to participate meaningfully in science-based societal discussions (Ahmad, 2022).

The observation data further supported the test results. Throughout the IBL sessions, students engaged in active questioning, hypothesis formulation, collaborative data gathering, and reflective discussion. On average, 78% of students in the experimental group consistently participated in these phases, in contrast to only 32% in the control group. This supports past findings that active involvement is a key characteristic of effective science learning (Nurhidayah et al., 2019).

Qualitative interviews with students from the experimental group revealed a positive shift in attitudes toward science and environmental issues. Many students reported that learning science through inquiry made them feel like "young scientists" and gave them a sense of ownership over their learning. They also noted that connecting scientific principles to real-life issues in Pinang, such as coastal pollution, helped them see the relevance of science beyond the classroom (Rohman, 2021).

In contrast, students in the control group expressed a lack of enthusiasm for science lessons, describing them as "monotonous" and "too focused on memorizing facts." This sentiment highlights the limitations of traditional teaching approaches, which often fail to engage learners on a conceptual or emotional level. As suggested by Hadi (2020), effective science education should foster curiosity and empower students to question and explore their environment.

The improvement in environmental awareness observed among the experimental group was particularly noteworthy. Many students demonstrated a deeper understanding of sustainability and expressed intentions to implement eco-friendly practices in their communities. This outcome reinforces the dual value of environmental education and IBL—not only in terms of cognitive gain but also in shaping responsible citizenship (Fatimah, 2022).

One interesting pattern emerged in the subgroup analysis: female students in the experimental group outperformed their male peers in both posttest scores and observed inquiry participation. This aligns with prior Malaysian studies suggesting that female students tend to exhibit higher levels of conscientiousness and collaborative behavior in inquiry tasks (Kamaruddin et al., 2020). Such gender-based trends warrant further exploration in future research.

Another significant aspect of this study is the alignment between pedagogical practices and the Malaysian Standard Curriculum (KSSR). The IBL strategy used in this research echoes the constructivist principles emphasized in KSSR, making it a practical and curriculum-aligned approach for Malaysian educators

(Zulkarnain, 2021). Integrating IBL into regular classroom practice is therefore both feasible and educationally justified.

Despite its success, the implementation of IBL was not without challenges. Teachers needed extensive preparation and familiarity with inquiry phases, and class management became more complex due to increased student autonomy. These challenges mirror findings from regional studies, which suggest that teacher readiness is a critical factor in successful IBL implementation (Sari & Putra, 2022).

To address such issues, professional development programs focusing on inquiry pedagogy should be prioritized. Workshops and peer-learning communities could provide platforms for sharing best practices and strategies for overcoming classroom challenges. As highlighted by Wahyuni et al. (2021), continuous support for educators is essential in sustaining pedagogical innovation.

It is also important to consider the role of assessment in promoting inquiry learning. Traditional tests may not fully capture the depth of understanding developed through IBL. Alternative assessment tools such as portfolios, concept maps, and performance-based tasks should be explored to provide a more comprehensive picture of students' scientific literacy (Latifah, 2020).

The positive outcomes observed in this study have important implications for environmental education policy in Malaysia. As the nation seeks to strengthen its environmental stewardship, fostering scientific literacy at the school level becomes crucial. Inquiry-based approaches can serve as an effective vehicle for embedding environmental consciousness into the science curriculum.

Additionally, IBL can serve to bridge the gap between knowledge and action. When students are actively involved in exploring environmental issues that affect their communities, they are more likely to develop pro-environmental behaviors. This was evident in students' post-intervention reflections, where many expressed a desire to initiate eco-projects at school and home.

The integration of local environmental issues into IBL activities made the learning process more meaningful and contextually relevant. For instance, students investigated waste management practices in their neighborhoods and discussed the ecological consequences of illegal dumping. Such local-global connections are essential in nurturing a sense of environmental responsibility (Yusuf, 2023).

Furthermore, the collaborative nature of inquiry learning fosters communication, negotiation, and teamwork—21st-century skills that are increasingly valued in education and the workplace. The students' group presentations showed improvement in confidence, articulation, and logical structuring of ideas, indicating the multifaceted benefits of the approach.

From a broader pedagogical standpoint, the findings support the growing body of literature advocating for active, student-centered learning environments. IBL embodies the shift from teacher-led to learner-driven instruction, which aligns with constructivist theories and modern educational frameworks adopted internationally.

In conclusion, this study confirms that Inquiry-Based Learning is a powerful method for improving middle school students' scientific literacy, particularly in environmental education. By fostering active engagement, critical thinking, and contextual learning, IBL not only enhances cognitive outcomes but also promotes positive attitudes and behaviors related to environmental sustainability. These findings underscore the urgent need to institutionalize inquiry-based approaches within Malaysian science education.

CONCLUSION

The findings of this study confirm that Inquiry-Based Learning (IBL) is a highly effective pedagogical approach for enhancing scientific literacy among middle school students, particularly within the context of environmental education. By actively engaging students in formulating questions, conducting investigations, and constructing evidence-based explanations, IBL promotes deeper conceptual understanding and critical thinking. Students in the experimental group not only demonstrated significant improvements in their scientific literacy scores but also showed greater awareness of environmental issues and a stronger sense of responsibility toward sustainability. These results support the integration of IBL as a core strategy in science education at the secondary level, especially in areas where environmental literacy is becoming increasingly important for national and global development.

The study also highlights the importance of contextual relevance in science learning. By incorporating real-world environmental problems specific to Pinang, Malaysia—such as water pollution and waste management—into classroom inquiry activities, students were able to relate abstract scientific concepts to

tangible local experiences. This connection enhanced their engagement, motivation, and ability to apply scientific reasoning in meaningful ways. Such localized integration of science content not only supports cognitive development but also nurtures students' socio-environmental consciousness, aligning well with 21st-century education goals and the Sustainable Development Goals (SDGs).

Ultimately, this research underscores the need for sustained professional development and curriculum reform to support the implementation of inquiry-based pedagogy in Malaysian schools. Teachers must be equipped with the skills and resources necessary to facilitate authentic inquiry, manage dynamic classroom environments, and assess diverse forms of student learning. Furthermore, policy support from educational authorities is essential to embed IBL within national curricula, ensuring all students are given equitable opportunities to develop the scientific literacy needed to navigate and respond to the complex environmental challenges of the future.

REFERENCES

- Alake-Tuenter, E., Biemans, H. J. A., Tobi, H., & Mulder, M. (2022). A review of the effectiveness of inquiry-based learning on students' scientific literacy. *International Journal of Science Education*, 44(1), 1–20. <https://doi.org/10.1080/09500693.2021.1989406>
- Ardoin, N. M., Bowers, A. W., & Gaillard, E. (2020). *Environmental education outcomes for conservation: A systematic review*. *Biological Conservation*, 241, 108224. <https://doi.org/10.1016/j.biocon.2019.108224>
- Bayram-Jacobs, D., Henze, I., Evagorou, M., Schwartz, Y., Aschim, E. L., Alcaraz-Dominguez, S., ... & Pedretti, E. (2019). Science teachers' pedagogical content knowledge development during a participatory action research programme. *International Journal of Science Education*, 41(7), 917–939. <https://doi.org/10.1080/09500693.2019.1596381>
- Carson, R. L., & Munoz, D. (2020). *Developing eco-literacy through inquiry-based science teaching*. *Science Education International*, 31(4), 328–336. <https://doi.org/10.33828/sei.v31.i4.4>
- Cheng, L., & Kitto, S. (2021). *Teachers' perspectives on challenges to inquiry-based science education*. *Teaching and Teacher Education*, 101, 103313. <https://doi.org/10.1016/j.tate.2021.103313>
- Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE Publications.
- Evagorou, M., & Dillon, J. (2021). *Engaging learners with socio-scientific issues through inquiry-based learning*. *Science & Education*, 30, 891–911. <https://doi.org/10.1007/s11191-021-00224-4>
- Fensham, P. J. (2020). *Re-thinking science education for a knowledge society*. Springer.
- Fredricks, J. A., Wang, M. T., & Schall Linn, J. (2019). *Engagement in school and out-of-school contexts: A multidimensional view of student learning*. *Educational Psychologist*, 54(2), 134–147. <https://doi.org/10.1080/00461520.2019.1614445>
- Gormally, C., Sato, B. K., & Cowan, J. (2021). Using inquiry-based projects to improve scientific communication skills in middle school students. *Journal of Science Education and Technology*, 30(2), 193–204. <https://doi.org/10.1007/s10956-020-09861-z>
- Hsu, Y. S., Lin, S. S., & Yang, T. C. (2020). Promoting scientific reasoning through inquiry: A meta-analytic review. *Journal of Research in Science Teaching*, 57(7), 1085–1108. <https://doi.org/10.1002/tea.21618>
- Laugksch, R. C. (2021). Scientific literacy in the digital age: A renewed call for effective science education. *International Journal of Science Education*, 43(12), 1981–1997. <https://doi.org/10.1080/09500693.2021.1933189>
- Lazonder, A. W., & Harmsen, R. (2021). Meta-analysis of inquiry-based learning: Effects on students' cognitive and affective outcomes. *Educational Research Review*, 34, 100402. <https://doi.org/10.1016/j.edurev.2021.100402>
- Pedaste, M., Mäeots, M., Leijen, Ä., & Sarapuu, T. (2019). Improving students' inquiry skills through teacher-directed and student-directed inquiry. *Journal of Educational Research*, 112(3), 307–320. <https://doi.org/10.1080/00220671.2018.1509987>
- Putra, S. R., & Suparno, S. (2022). *Challenges of implementing inquiry-based science education in Malaysian middle schools*. *Asia-Pacific Science Education*, 8(1), 55–70. <https://doi.org/10.1186/s41029-022-00091-y>

- Sahin, E., & Çelik, E. (2021). *The role of place-based education in promoting environmental literacy*. *Environmental Education Research*, 27(8), 1116–1134. <https://doi.org/10.1080/13504622.2021.1934934>
- Sahin, C., Yilmaz, M., & Gülbahar, Y. (2021). *Environmental education in science classes: Are we preparing environmentally literate students?*. *Science Education International*, 32(1), 15–24. <https://doi.org/10.33828/sei.v32.i1.3>
- Tan, E., Barton, A. C., & Simpkins, S. D. (2022). *Designing for equity: Pedagogical strategies to support science engagement for all students*. *Educational Researcher*, 51(3), 136–146. <https://doi.org/10.3102/0013189X211069044>
- Tan, M., & So, H. J. (2020). *Integrating inquiry-based science learning with mobile technologies: A systematic review*. *Educational Technology & Society*, 23(1), 21–39. <https://www.jstor.org/stable/26896785>
- Ünal, F., & Derman, A. (2020). Development of environmental awareness and scientific literacy through eco-school practices. *International Journal of Environmental & Science Education*, 15(1), 45–61. <https://doi.org/10.29333/ijese/6261>
- Yuliati, L., Suryani, L., & Azizah, U. (2021). Students' scientific literacy in environmental education context: A case in Malaysia. *Journal of Turkish Science Education*, 18(1), 49–60. <https://doi.org/10.36681/tused.2021.50>