



Implementation of the IPBA-Ecolisa Module to Improve Logical and Critical Thinking Skills

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Abstract: This study examines the effectiveness of Earth and Space Science modules integrated with eco-pedagogy and science literacy (IPBA-EcoLisa) in improving students' logical and critical thinking skills. A pre-test-post-test design was employed with 43 prospective physics teacher students. Data were collected using validated instruments measuring logical and critical thinking abilities and analyzed using N-Gain scores. The results indicate a moderate improvement in logical thinking skills (N-Gain = 0.36), particularly in students' ability to apply patterns and rules to predict Earth and Space Science issues. Critical thinking skills demonstrated a significant improvement (N-Gain = 0.52), with the most notable gains observed in the Basic Support and Basic Clarification indicators. These findings suggest that integrating eco-pedagogy and science literacy within IPBA learning effectively strengthens higher-order thinking skills while fostering environmental awareness. In conclusion, the IPBA-EcoLisa module represents a promising instructional approach for supporting sustainable science education and enhancing essential cognitive competencies in physics education students.

Keywords: Critical thinking; Eco-pedagogy; IPBA; Logical thinking; Science literacy

Introduction

Education and science play a fundamental role in improving key environmental-related competencies, including logical thinking, critical thinking, science literacy, and environmental literacy, which are crucial for understanding and responding to complex environmental challenges (Edsand & Broich, 2020; Marwa et al., 2024; Napitupulu & Walanda, 2024; Napitupulu et al., 2022; Nudiati, 2020; Sanjiartha et al., 2024; Syahgiah et al., 2023; Yang et al., 2021). These competencies enable learners to interpret scientific information, evaluate evidence, and make informed decisions related to sustainability and environmental responsibility. Prior studies indicate that communicative and experiential learning strategies, particularly those involving real-world exploration, are effective in strengthening science literacy and fostering environmentally responsible reasoning (Amaliati et al., 2024; Napitupulu, 2022; Wisnu et al., 2021). However,

many science learning practices remain content-centered and insufficiently oriented toward higher-order thinking and ecological awareness.

Earth and Space Science (Ilmu Pengetahuan Bumi Antariksa/IPBA) is a dynamic scientific domain closely connected to real-world environmental phenomena and global sustainability issues (Napitupulu et al., 2025; Nuril et al., 2021). Due to its interdisciplinary and evolving nature, IPBA learning requires pedagogical approaches that not only convey scientific concepts but also cultivate students' reasoning abilities and environmental consciousness. Eco-pedagogy offers a relevant framework by integrating scientific understanding with ethical and ecological perspectives, encouraging learners to critically reflect on the relationship between science, society, and the environment (Johan et al., 2021; Korsant, 2022; Napitupulu et al., 2025; Ratnasari et al., 2024). Despite its theoretical relevance, empirical studies that integrate eco-pedagogy with structured science literacy

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frameworks in IPBA learning, particularly at the higher education level, remain limited.

From a global perspective, the IPBA aligns more closely with science literacy (Amin & Maritasari, 2023). This science plays a pivotal role in understanding natural phenomena, space exploration, and critical environmental issues (Sukmawati et al., 2025). Science literacy enables individuals to think critically, comprehend scientific concepts, and make informed, evidence-based decisions in their daily lives (Apriliansa & Anggrella, 2024; Howell & Brossard, 2021; Fiordelli & Diviani, 2023; Almeida et al., 2022).

This study addresses this gap by implementing the IPBA-EcoLisa module, which systematically integrates eco-pedagogy principles with science literacy-oriented learning activities to enhance students' logical and critical thinking skills. The novelty of this research lies in the development and empirical testing of an IPBA learning module that simultaneously targets higher-order cognitive skills and environmental awareness through an integrated instructional design, rather than treating these outcomes separately. Investigating the effectiveness of the IPBA-EcoLisa module is important because logical and critical thinking are foundational competencies for future science educators who are expected to address environmental and sustainability issues through informed, evidence-based instruction. Therefore, this study provides empirical evidence to

support innovative IPBA learning models that align cognitive skill development with the goals of sustainable science environmental education.

Method

This research is a type of research and development (R&D) using a 4-D model (Aisy & Dwiningsih, 2024; Napitupulu et al., 2025). This research was conducted within the Physics Education Study Program. The subjects of this research were 43 students enrolled in the Physics Education program who were going to take Earth and Space Science (IPBA) courses. The data analyzed in this research were obtained through the implementation of the developed and validated ESS-based science literacy oriented towards eco-pedagogy (IPBA-EcoLisa) modules. This was obtained through the administration of pre- and post-tests on the dissemination step.

The two research instruments used in this study consisted of: the IPBA-EcoLisa Logical Thinking Skills Test in a multiple-choice test format and the IPBA-EcoLisa Critical Thinking Skills Test with multiple-choice (numbered 1-10) and essay (numbered 11-15) question formats. The research instrument grids are described in Tables 1 and 2.

Table 1. The ESS-EcoLisa logical thinking skills test

Indicators	Measured Logical Skills	Number of Questions
Identifying cause-and-effect relationships in natural phenomena	Linking events to their causes scientifically (e.g., earthquakes, floods, droughts)	5
Concluding the IPBA phenomenon data	Interpret data, trends, or scientific reports and then draw logical conclusions	5
Comparing and classifying the IPBA phenomenon	Distinguish the characteristics of phenomena (earthquakes, volcanoes, planets, stars) and group them based on scientific criteria	5
Using patterns/rules to predict IPBA phenomena	Applying laws/patterns (rotation, revolution, moon phases, climate) to predict logical outcomes	5
Compiling logical arguments from the IPBA phenomenon	Formulate critical arguments based on scientific evidence (deforestation, fossil energy, greenhouse effects, etc.)	5

Table 2. The ESS-EkoLisa critical thinking skills test

Indicator	Number of Questions
Elementary Classification	1-3
Basic Support	4-6
Inference	7-10
Advanced Clarification	11-13
Strategies and Tactics	14-15

To assess the extent of improvement in students' logical and critical thinking skills, the N-Gain formula is used to calculate the normalized gain (N-Gain) score, following Hake (2002). The interpretation is provided in Table 3.

$$N_{Gain} = \frac{S_{post} - S_{pre}}{S_{max} - S_{pre}} \times 100\% \tag{1}$$

Table 3. Logical and critical thinking interpretation

Score N-Gain (g)	Categoric Interpretation
$0.70 \leq g \leq 1.00$	High
$0.30 \leq g \leq 0.70$	Moderate
$0.00 < g < 0.30$	Low
$g = 0.00$	No increase
$-1.00 \leq g < 0.00$	Decline

Result and Discussion

Result

The results of the students' logical thinking are presented in Figure 1. Figure 1 presents a comparison of students' percentage scores on the pre-test and post-test in five aspects of logical thinking ability. A consistent and substantive improvement was evident across all five evaluated dimensions after the implementation of IPBA

instruction grounded in eco-pedagogical principles and scientific literacy. Comparative analysis indicates that post-test scores surpassed pre-test results on each indicator, reflecting a comprehensive pattern of cognitive enhancement. Collectively, these findings provide compelling evidence that the instructional intervention described the future of students' higher-order logical reasoning skills.

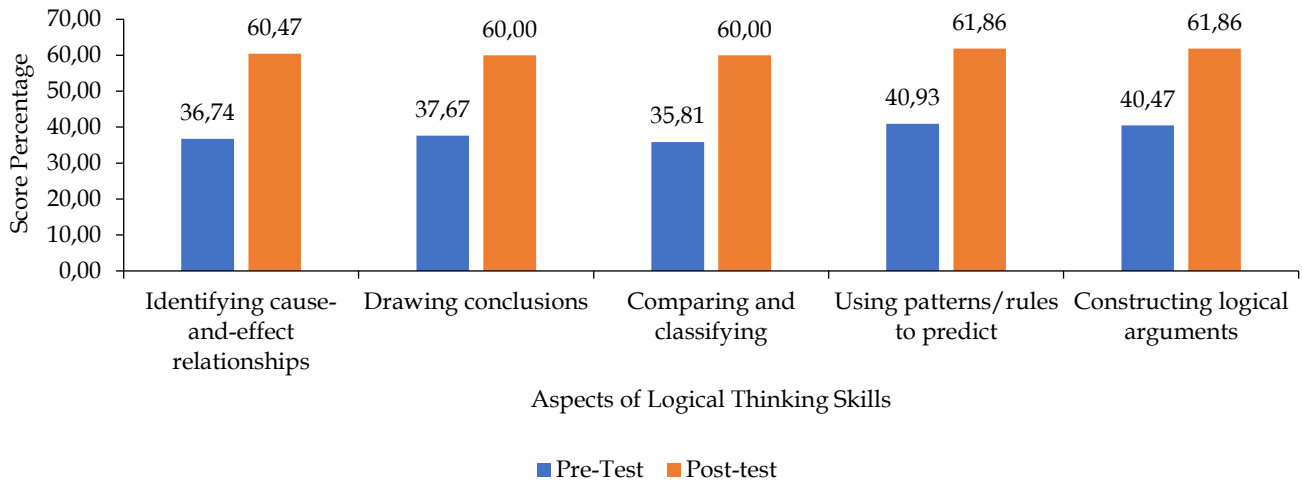


Figure 1. Comparison of the score (%) of the pre-test with the post-test logical thinking

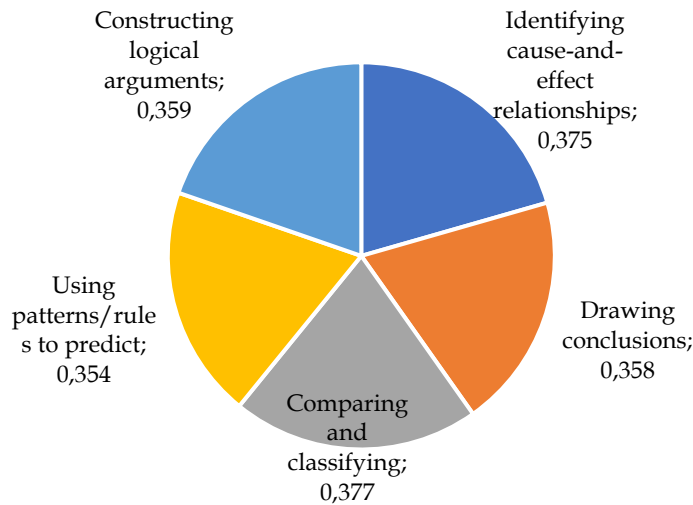


Figure 2. N-Gain value logical thinking based on the indicators

A description of the N-Gain data per logical thinking indicator is shown in Figure 2. Based on the calculation of normalized N-Gain, an average N-Gain score of 0.36 was obtained in the medium category. From Figure 2, the most striking improvement can be seen in the indicators of the use of patterns or rules to

predict and the ability to conclude. Meanwhile, other aspects such as identifying cause-and-effect relationships, comparing and classifying, and building logical arguments also increased, although not as high as the previous two indicators.

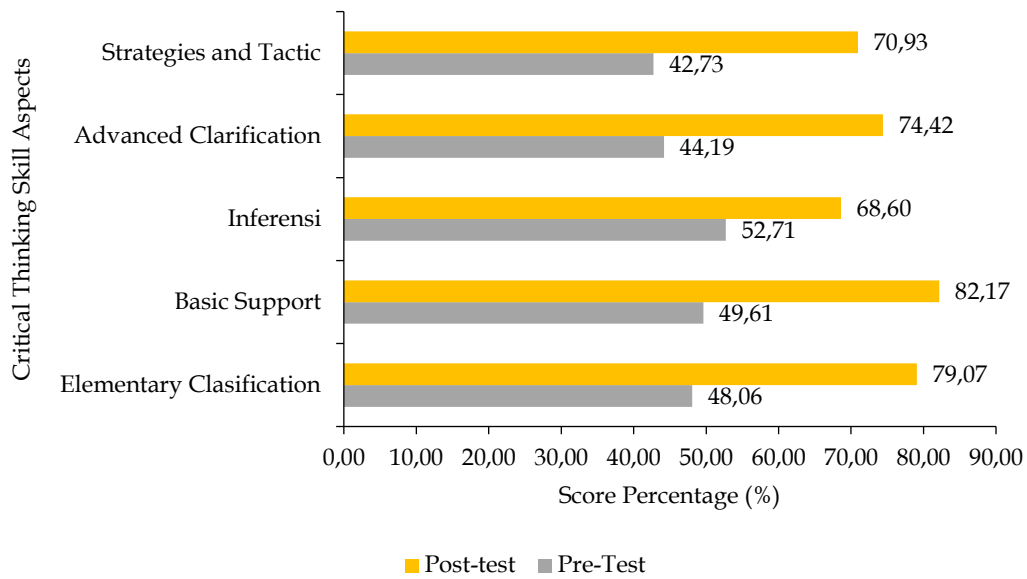


Figure 3. Comparison of pre-test score percentage with post-test critical thinking skills

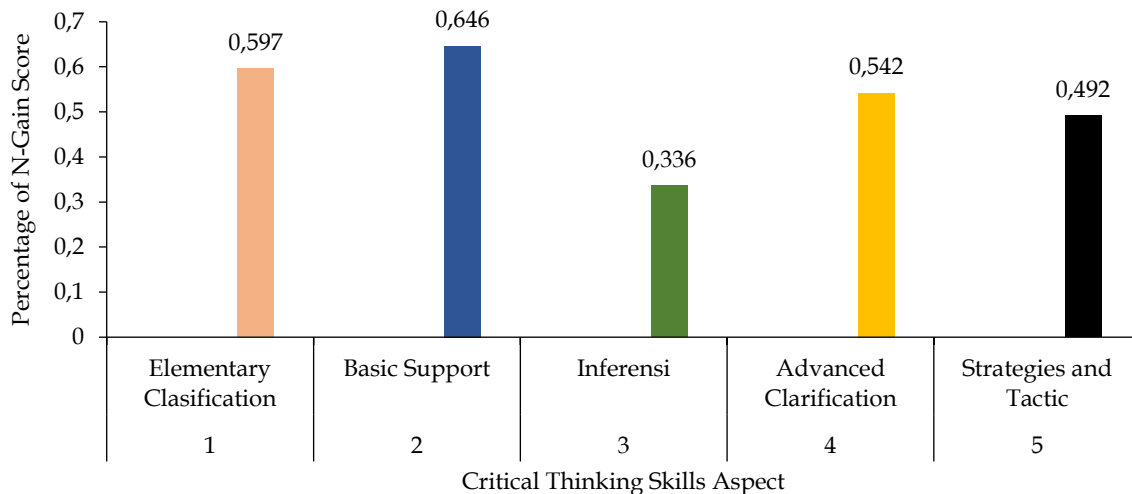


Figure 4. Value of critical thinking skills N-Gain based on indicators

Figure 3 shows the percentage scores across five aspects of critical thinking skills before and after implementing the EcoLisa module in the IPBA course class. In Figure 4, the results of the N-Gain calculation for critical thinking skills, broken down by their aspects, are presented.

Based on the Critical Thinking Skills calculation of normalized N-Gain, an average N-Gain score of 0.52 was obtained in the medium category. As indicated by the data, the five aspects of critical thinking skills have increased in the medium-to-high category. The Basic Support aspect received the highest increase (0.65), followed by Elementary Clarification (0.59) and Advanced Clarification (0.55). The Strategies and Tactics aspect also showed good improvement (0.50). It indicates an increase in students' ability to determine

problem-solving strategies and argue effectively. The inference aspect showed the lowest increase (0.34), although it remained in the medium category.

Discussion

The findings indicate that the IPBA-EkoLisa module has contribution to enhance students' logical and critical thinking skills in the context of IPBA learning. The moderate N-Gain improvement in logical thinking ($g = 0.36$) reinforces that students are progressing from basic recognition of natural phenomena to deeper reasoning performance. The most significant improvement occurred in the ability to apply patterns/rules to predict events, indicating increased scientific reasoning that aligns with environmental literacy goals (Celso et al., 2025; Perea et al., 2025; Putri, 2021). However, aspects

such as identifying causal relationships and constructing logical arguments still require further development. These components are critical in environmental decision-making since ecological problems are often multilayered and require causal mapping and sound reasoning. Therefore, enhancement may be implemented through the inclusion of argument-driven inquiry and ecosystem cause-mapping tasks to strengthen students' insight in connecting IPBA content with actual environmental issues (Dirgantara et al., 2024; Yanti & Irmawati, 2024).

In terms of critical thinking, a moderate N-Gain ($g = 0.52$) suggests great improvement in Basic Support, Elementary Clarification, and Advanced Clarification skills. These results are consistent with the argument of Barroso (2022) and Napitupulu et al. (2023) that a logical basis is indispensable for enhancing higher-order critical thinking. The IPBA-EkoLisa module, which links IPBA material to global environmental challenges, enables students to contextualize scientific concepts in sustainable decisions (Baptista et al., 2025; Napitupulu et al., 2025; Nuril et al., 2021; Yanti & Irmawati, 2024). Nevertheless, inference skills—drawing conclusions based on evidence—showed the lowest gain. Studies also emphasize that inference development requires repeated exposure to data evaluation, uncertainty reasoning, and hypothesis testing (Masnick & Morris, 2022; Nogueira & Pugnana, 2022; Yao et al., 2021). To strengthen this aspect, future iterations of IPBA-EkoLisa can include: Climate-data interpretation labs, using authentic NASA or BMKG datasets (Dirgantara et al., 2024; Napitupulu, et al., 2025; Siregar & Sagena, 2023); Virtual reality Earth system simulations to visualize hidden causal relationships (Al Shawabkeh & Arar, 2024; Carmona-Galindo et al., 2025; Mathew et al., 2025; Ruan, 2022; Wu et al., 2013).

Strategically, the IPBA-EkoLisa module can be expanded with a Green Problem-Based Learning that requires students to propose ecological action strategies informed by IPBA concepts (Nuril et al., 2021; Yang et al., 2021; Yanti & Irmawati, 2024). This not only stimulates inferential reasoning but also cultivates sustainability-oriented competence, which is a core mission of eco-pedagogy (Antunes & Gadotti, 2005; Johan et al., 2021; Misiaszek, 2023). In addition, embedding community-based environmental projects (Leach & Scoones, 2025; Rickenbacker et al., 2019), or citizen-science programs would reinforce learning transfer from the classroom to real ecosystems—bridging scientific literacy and responsible eco-behaviour (Edsand & Broich, 2020). Therefore, this study provides empirical evidence that integrating eco-pedagogy with science literacy forms a transformative framework. This is very different from a simple instructional approach. Refining the module through the

development of course achievement indicators, the IPBA-EcoLisa module can evolve into a comprehensive design that shapes students into environmentally intelligent thinkers and decision-makers for sustainable futures (Miani et al., 2025).

Conclusion

This study concludes that the implementation of the Earth and Space Science module integrated with eco-pedagogy and science literacy (IPBA-EcoLisa) demonstrated a positive impact on gaining students' higher-order thinking skills. Logical thinking skills increased with a moderate N-Gain (0.36), especially in indicators related to using patterns/rules to predict IPBA phenomena and drawing conclusions. A moderate N-Gain (0.52) was observed to result in enhanced critical thinking skills, with the most substantial enhancements noted in Basic Support and Elementary Clarification. This finding suggests an enhanced capacity for reasoning and evaluating scientific information. These findings reaffirm that the IPBA-EcoLisa model is effective in fostering logical and critical thinking while simultaneously building students' environmental awareness and responsibility as part of sustainable science education. The development of logical and critical thinking, particularly inference and causal reasoning, still needs to be strengthened in future IPBA-EcoLisa implementations. Therefore, learning activities such as argument-driven inquiry, data interpretation using real environmental datasets, and community-based ecological projects are recommended to deepen scientific reasoning and decision-making skills. Further research is also suggested to involve a larger or more diverse sample, integrate digital learning technologies such as virtual reality-based Earth system simulations, and examine long-term impacts on students' environmental literacy and eco-behavior. The ESS-EcoLisa module is a continuously evolving, innovative learning model that fosters both cognitive achievement and the development of a sustainable character.

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Author Contributions

Conceptualization, N.D.N. and M.; methodology, M. and M.J.; validation, I.W.D., R.I., and M.J.; formal analysis, funding acquisition, R.I.; investigation, I.W.D.; resources, writing—original draft preparation, writing—review and editing, N.D.N.; data curation, M. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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