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Development of problem-based learning materials on biodiversity using local potential of mangrove forests to enhance critical thinking skills of phase E students

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Abstract: Students' critical thinking skills in Indonesia remained a concern, as evidenced by suboptimal learning outcomes and low problem-solving abilities. This study aimed to (1) develop the feasibility of learning materials, (2) assess their practicality, and (3) determine their effectiveness in enhancing students' critical thinking skills. This development research produced educational tools, including teaching modules (lesson plans) and student worksheets (LKPD). The study used the 4D technique and took place at SMA Negeri 4 Tarakan with 36 students participating. The results indicated that the learning materials received excellent ratings in content feasibility (81.4%), presentation feasibility (86.5%), language and readability feasibility (89.2%), and graphic feasibility (92.5%). All aspects, including material, language, graphics, and functionality, were classified as highly practical. In the control class, students' critical thinking skills were classified as moderate (50%), good (11%), very good (13%), and very poor (25%), indicating a concentration within the medium to low range. Meanwhile, the critical thinking skills of the treatment group were categorised as moderate (33%), good (25%), and very good (42%), demonstrating that the developed learning materials were effective in facilitating the Problem-Based Learning (PBL) method to enhance the critical thinking skills of Phase E students at SMAN 4 Tarakan.

Keywords: Critical thinking, mangrove; problem-based learning, higher-order thinking skills.

Introduction

During rapid globalisation, critical thinking skills have become one of the key competencies of the 21st century. These skills facilitate academic achievement and cultivate individuals ready to engage meaningfully in society. The PISA 2022 report underscores Indonesia's subpar scores (Wijaya et al., 2024) in mathematics (379), science (398), and reading (371). These data emphasise the urgent need to enhance higher-order thinking skills (HOTS) to address educational challenges that are not yet fully aligned with current demands.

Students' critical thinking skills are often linked to outdated rote-learning methods. Therefore, the need to adopt a paradigm shift toward student-centred learning is more urgent than ever. Numerous studies have explored Problem-Based Learning (PBL) as an alternative to traditional teaching methods, demonstrating its potential to enhance students' critical thinking skills. PBL emphasises real-world problem-solving and in-depth exploration (Nofziarni et al., 2019; Suswati, 2021). However, its implementation in various educational contexts has yielded mixed results (Gonzalez-Argote & Castillo-González, 2024), highlighting the need for further research to ensure its effectiveness in improving students' Higher Order Thinking Skills (HOTS).

The utilisation of the mangrove forest ecosystem as a learning resource is highly relevant in supporting the development of scientific knowledge while also fostering environmental awareness (Fitri et al., 2021). For instance, the Mangrove and Proboscis Monkey Conservation Area (KKMB) in Tarakan serves as a rich natural laboratory for exploration and interdisciplinary integration, encompassing ecology, biology, and geography (Rahajeng et al., 2019). Through this context-based learning approach, students not only gain an understanding of the ecological functions of mangrove forests in maintaining environmental balance (Arfan et al., 2023) but also actively participate in conservation efforts such as biodiversity monitoring and habitat restoration. This approach promotes holistic learning that is directly relevant to current global environmental challenges.

Students' critical thinking skills will be enhanced by integrating the potential of local mangrove ecosystems into Problem-Based Learning (PBL) materials, which is the goal of this study. By leveraging the biodiversity and ecological richness of mangrove forests, this approach aims to create a more immersive and interactive learning experience, encouraging students to actively engage in solving real-world problems. The development of these instructional materials is expected to open opportunities for broader contextual learning models, where students learn not only from theoretical concepts but also from their surrounding environment. This approach seeks to bridge academic knowledge with relevant field practices, enriching students' understanding of environmental conservation while sharpening their critical and problem-solving skills.

This study is theoretically grounded in a constructivist and socio-constructivist perspective on learning, which posits that knowledge is actively constructed through learners' engagement with meaningful problems and social dialogue. In this framework, constructivism serves as the overarching theory elucidating how learners develop understanding, whereas PBL acts as a meso-level instructional model that implements these principles through iterative cycles of problem analysis, self-directed inquiry, collaborative discussion, and reflection (Yew & Goh, 2016). This study's PBL-based learning materials operationalise theoretical concepts into specific classroom practices focused on local mangrove ecosystems. Higher-order thinking is defined as an integrated construct that includes analysis, evaluation, and creative problem-solving, with critical thinking viewed as context-dependent reasoning regarding complex environmental and socio-scientific issues (Anggraeni et al., 2023; Kumar et al., 2024).

This research conceptualises local environmental problems, such as the degradation

of mangrove ecosystems, as valuable contexts for fostering scientific literacy, argumentation, and informed decision-making, in accordance with recent studies on environmental socio-scientific issues (ESSI) (Kumar et al., 2024). Research on inquiry-based and project-based learning in science education shows that students who engage with authentic environmental issues are more likely to connect disciplinary concepts to real-world implications and develop competencies for sustainability (Baptista et al., 2025; Hernández-Ramos et al., 2021). Integrating PBL with ESSI-oriented environmental learning in mangrove ecosystems is anticipated to establish a multi-layered learning environment where cognitive (critical thinking), affective (environmental concern), and behavioural (conservation-oriented actions) dimensions mutually reinforce each other.

Figure 1. Mangrove Forest

Prior research on mangrove-focused environmental education has predominantly focused on assessing changes in students' knowledge, awareness, and attitudes following conservation programs or school-based initiatives (Kamaludin et al., 2022; Tagulao et al., 2022). Although these studies validate the effectiveness of mangrove contexts in fostering environmental awareness, they rarely explore in detail how these learning environments systematically develop students' higher-order thinking skills, especially in relation to analysing ecological data, evaluating conservation strategies, and proposing alternative solutions. Furthermore, a significant portion of the current literature on PBL and ESSI has emerged outside the Indonesian context, resulting in a geographical and curricular disparity in adapting these models to local ecosystems and national education standards (Anggraeni et al., 2023; Kumar et al., 2024).

This study addresses these gaps through two primary contributions. This theoretical framework integrates constructivism as a grand theory, PBL as a meso-level instructional model, and ESSI-oriented environmental education as the applied dimension, elucidating the systematic utilisation of local mangrove ecosystems to enhance students' critical thinking skills. This study designs, develops, and empirically examines PBL-based learning materials focused on local mangrove biodiversity and ecosystem services. It offers teachers a contextualised model of science learning that aligns with the Indonesian curriculum and addresses ongoing challenges identified by PISA 2022. The research aims to enhance students' higher-order thinking skills and

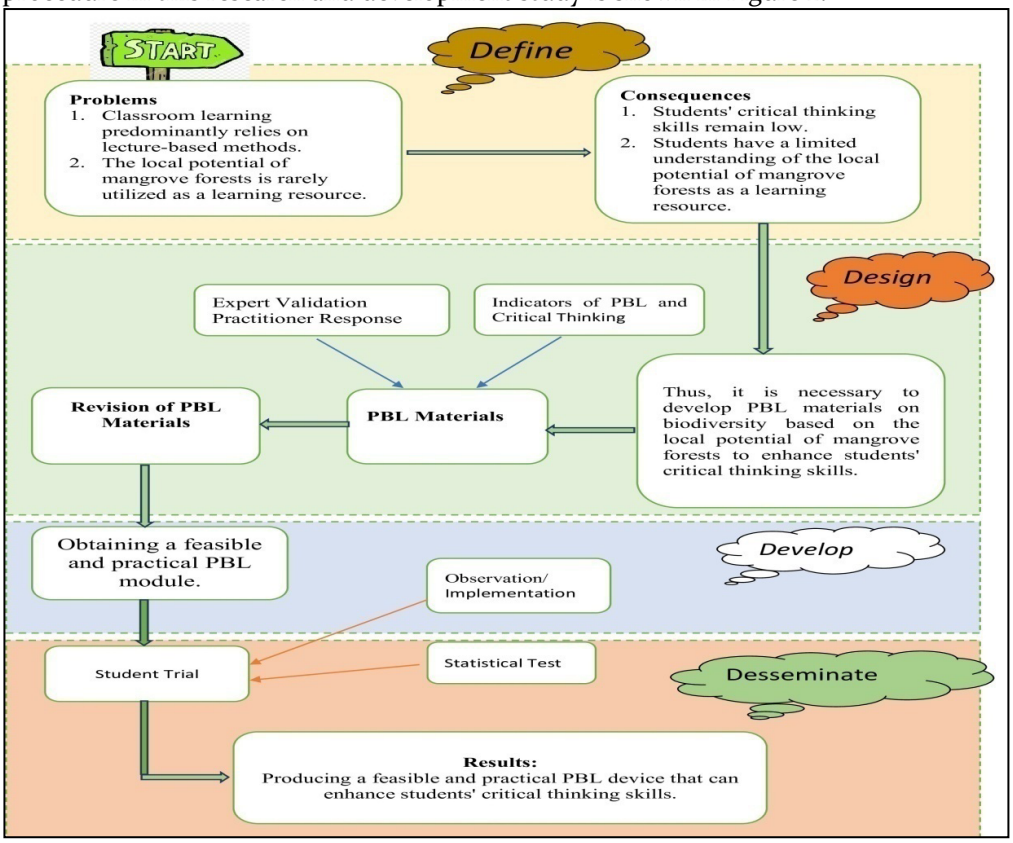
ecological literacy, while providing a replicable and adaptable instructional design for schools situated in coastal and mangrove-rich areas.

Method

The mangrove forest in Tarakan, located at coordinates 3°14'23"–3°26'37" North Latitude and 117°30'50"–117°40'12" East Longitude, encompasses Tarakan Island and Sadu Island. This forest plays a crucial role in preventing coastal erosion and serves as a habitat for endemic species, including the proboscis monkey (*Nasalis larvatus*) (Chairiyah, 2020). However, one of the primary challenges is the declining population of *Sonneratia alba*, a key food source for proboscis monkeys (Gazali et al., 2019). The reduction in this plant species not only disrupts the ecological function of the mangrove ecosystem but also threatens the sustainability of the proboscis monkey population that relies on it. (see Figure 1)

The research employs the 4-D development model, which comprises four stages: Define, Design, Development, and Disseminate, established in 1974 by S. Thiagarajan. The study was conducted from August to September 2024 at SMA Negeri 4 Tarakan, located at Kusuma Bangsa Street, RT 31, Pamusian Village, Central Tarakan District, Tarakan City, North Kalimantan Province. The target participants were Phase E (Grade X) students at SMA Negeri 4 Tarakan, consisting of 36 students, both male and female, aged 15–16 years. Meanwhile, the control class also comprised 36 Phase E (Grade X) students from the same school, with a similar gender distribution and age range. The procedure in this research and development study is shown in Figure 2.

Figure 2. Research procedure for 4D development



To evaluate the feasibility, practicality, and effectiveness of implementing PBL-based learning materials, various data collection techniques and instruments were used, tailored to the specific indicators being measured.

The feasibility of the PBL instrument was assessed using a product evaluation sheet completed by experts. This evaluation aimed to determine the quality and

appropriateness of the learning materials in accordance with established standards (Asriningtyas et al., 2018).

$$P = \frac{\Sigma X}{\Sigma Xi} X\ 100\% \quad \text{..... (1)}$$

P: Feasibility percentage; ∑X: Total score obtained; ∑Xi: Total score of all items

Practicality: The practicality of implementing the PBL learning tool was measured using two main instruments: (i) A perception questionnaire for practitioners (biology teachers) at SMA Negeri 4 Tarakan, which was used to gather feedback from teachers regarding the ease of use and effectiveness of the PBL tool in teaching; (ii) An observation sheet assessing the implementation of the PBL tool, which was used to evaluate the extent to which the application of the tool aligned with the planned learning objectives (Susanto & Retnawati, 2016).

$$P = \frac{\Sigma X}{\Sigma Xi} X\ 100\% \quad \text{..... (2)}$$

Effectiveness: Through the use of pretests and posttests, we determined whether the use of problem-based learning (PBL) tools, tailored to the local potential of mangrove forests, improved students' critical thinking skills. To compare the level of critical thinking skills, problem-based learning was implemented, and the test was administered to both the control group and the experimental group (Susanto & Retnawati, 2016).

$$NP = \frac{R}{SM} X\ 100\% \text{.....(3)}$$

NP: Percentage score; R: Total score obtained; SM: Maximum total score for all items.

Statistics: To determine whether there is a significant difference in the effect of the PBL tools on critical thinking skills, the data will be analysed using an independent samples t-test with SPSS version 26.

Findings and Discussion

Initial Product Development Results

The feasibility of the Biology Learning Device was obtained from expert validation results. The average total feasibility score from expert validation is presented in Table 1. The feasibility of the Biology Learning Device, as assessed by two validators, indicated that all four aspects, content feasibility, presentation feasibility, language and readability feasibility, and graphical feasibility, fell into the "highly feasible" category.

Table 1. Feasibility and Practicality of Biology Learning Devices

Description	Score Validator 1	Score Validator 2	Average Score	Feasibility (%)	Category
Content Feasibility	63	51	57	81.4%	Highly Feasible
Presentation Feasibility	90	83	86.5	86.5%	Highly Feasible
Language and Readability Feasibility	65	70	62.5	89.2%	Highly Feasible
Graphical Feasibility	54	57	55.5	92.5%	Highly Feasible

Description	Score	Average	Practicality (%)	Category
Material Aspect	4	1	100%	Highly Practical
Language Aspect	4	1	100%	Highly Practical
Graphical Aspect	3	1	100%	Highly Practical
Practicality Aspect	4	1	100%	Highly Practical

The practicality of learning biology on biological variance material based on the local potential of mangrove forests was assessed through a practicality questionnaire

completed by teachers (Table 1). Practitioners assessed all measured aspects, including material, language, and graphical aspects. Overall, the practicality received an average score of 4, categorised as highly practical.

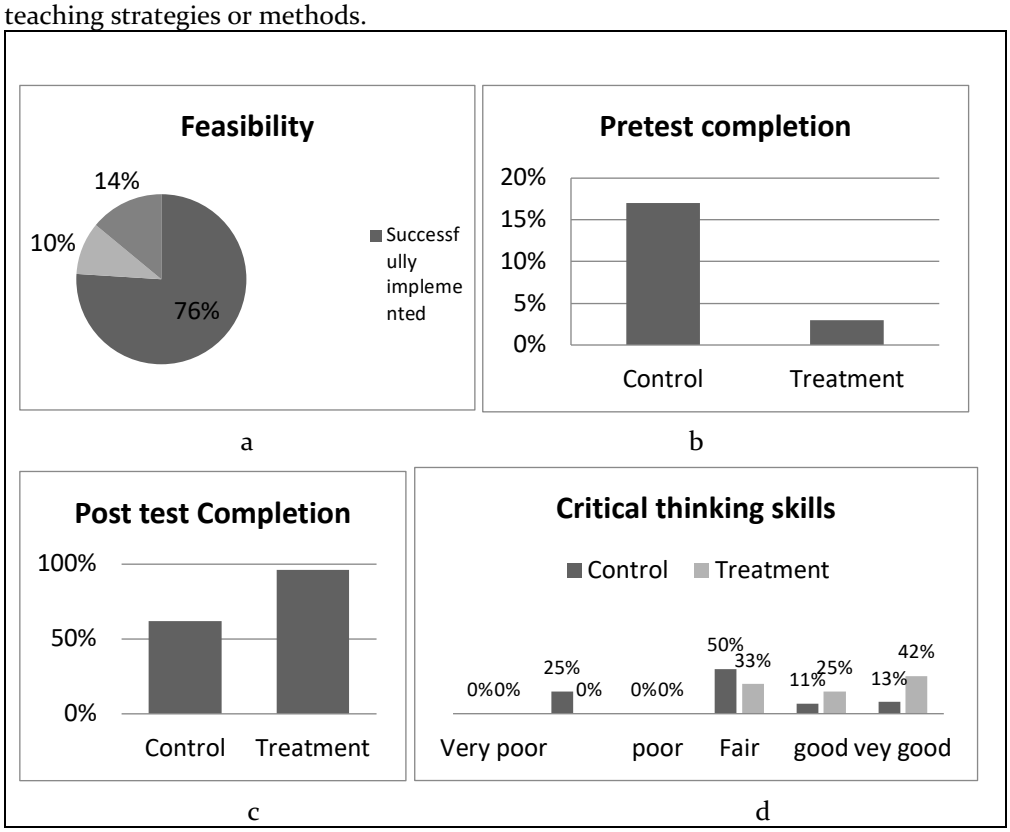
The initial product development results indicate that the biology learning device based on the local potential of mangrove forests has met excellent feasibility and practicality criteria. Based on expert validation, the device was categorised as "highly feasible" in terms of content, presentation, language, and graphical aspects. Furthermore, the practicality assessment by teachers revealed that the device is highly practical for classroom implementation, covering material, language, and graphical aspects. This approach not only enhances the relevance of the material to students' environments but also contributes to the recognition and understanding of biodiversity (Mantek et al., 2019), making it an applicable and meaningful innovation in biology education (Sani & Ambarwati, 2024).

Product Trial Results

Practicality (Observation of Learning Implementation Feasibility

The observation data reflect the level of adherence to the implementation of the applied teaching strategies or methods.

Figure 3. Visualisation of Product Trial Results



Based on Figure 3a, it can be observed that all activities in the learning device have been implemented. The majority of activities were carried out successfully, with a success rate of 76%, indicating that the learning outcomes of the implemented activities were as planned. This percentage reflects the effectiveness of the learning process in supporting the expected objectives. However, 10% of the activities were less optimal, and 14% were not implemented at all, suggesting some challenges during field execution.

The pretest was conducted to measure students' initial abilities before they received treatment, in both the control and treatment classes. Based on Figure 3b, the pretest mastery level in the control class reached 17%, whereas in the treatment class, it was

only 3%. These results indicate that the mastery level in both classes was still low, particularly in the treatment class.

After the learning process was completed, a posttest was conducted to measure students' learning outcomes in both the control and treatment classes. Based on Figure 3c, the posttest results showed that the mastery level in the control class reached 62%, while in the treatment class, it was 96%. This difference indicates that the treatment provided was more effective in improving students' learning outcomes compared to the control class.

The critical thinking skills results (Figure 3d) showed a significant difference between the control and treatment classes. In the control class, the majority of students (50%) were in the "Fairly Good" category, with only 13% reaching the "Very Good" category, while 25% fell into the "Very Poor" category. In contrast, the treatment class showed a significant improvement, with 42% of students in the "Very Good" category and none in the "Very Poor" or "Poor" categories. These results indicate that the applied treatment effectively enhanced students' critical thinking skills, as reflected in the dominance of the "Good" and "Very Good" categories in the treatment class.

The trial results of the learning product demonstrated the effectiveness of the instructional tools in encouraging active student engagement and supporting a well-structured learning process. The observation of implementation indicated that most learning activities proceeded as planned, although some were less optimal or not executed due to field constraints. The success of the instructional tools was reflected in the increased student participation in interactions with peers and teachers, highlighting the alignment of the learning strategies with the intended educational objectives (Karmita et al., 2023).

The striking difference between the pretest and posttest results confirms the effectiveness of the treatment. The significantly higher posttest scores in the treatment group compared to the control group indicate that this approach not only improves learning outcomes but also enhances critical thinking skills. The treatment group demonstrated a predominance of "Good" and "Very Good" ratings, highlighting the positive impact of the applied method. Overall, these findings reinforce the importance of developing contextualised learning tools (Kartikasari, 2023) and implementing student-centred interactive strategies to achieve optimal learning outcomes (Asrifah et al., 2020).

Independent Sample t-Test

To analyse the effectiveness of the treatment, an independent sample t-test was conducted to compare the pretest and posttest results between the control and treatment groups. This test aims to identify any significant differences that may have resulted from the applied treatment.

Table 2. Levene's Test for Equality of Variances

Test	Description	*Pretest*	*Postest*
Levene's Test for Equality of Variances	F	1,166	0,924
	Sig	0,284	0,340
t-Test for Equality of Means	t-statistic	1,567	-4,683
	df	70	70
	Sig (2-tailed)	0,122	0,000

Based on the results of Levene's test, it was determined that the control and treatment groups had equal variance, indicating that data distribution in both groups was sufficiently diverse. The pretest mean scores of both groups did not differ significantly ($p > 0.05$), suggesting comparable initial conditions. However, the post-test results revealed a significant difference between the mean scores of the control and treatment groups ($p < 0.05$), confirming the effectiveness of the treatment.

The students' learning outcomes significantly improved following the application of the treatment in this study, as indicated by the t-test results. The post-test results, in particular, indicate that the method effectively enhanced students' understanding compared to the control group (Miller, 2012). Furthermore, validity testing confirmed that the measurement instrument used had a strong correlation with the total score, ensuring its reliability in assessing the targeted variables (Sa et al., 2019).

Conclusion

This study demonstrates that the biology learning module based on the local potential of mangrove forests has excellent feasibility across all aspects, with the highest scores in graphical presentation (92.5%) and language feasibility (89.2%). The practicality of this module is also very high, with all assessment aspects scoring 100%. In terms of effectiveness, the post-test results indicate that the experimental class outperformed the control class, both in terms of mastery level (96% vs. 62%) and critical thinking skills, where the experimental class showed a significant improvement.

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