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Enhancing Critical Thinking Through Coastal Culture-Based Differentiated Science Learning

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Abstract: The purpose of this study was to enhance critical thinking skills through the implementation of coastal culture-based differentiated science learning. The research was conducted from August to November 2024 using a quasi-experimental nonequivalent control group design at at Junior High School 2 Bengkulu, Indonesia. The sample consisted of three eighth-grade classes: Experimental Group 1 (8A), Experimental Group 2 (8B), and the Control Group (8C), selected through purposive sampling. Students' critical thinking skills were assessed using a validated and reliable test instrument (r = 0.89). Data were analyzed with one-way ANOVA, which revealed significant differences among groups ($p < 0.001$). The average N-gain score of critical thinking skills in Experimental Group 1 (0.40, medium category) was higher than that of Experimental Group 2 (0.20, low category) and the Control Group (0.009, low category). Based on the hypothesis testing, it can be concluded that coastal culture-based differentiated science learning has a significant effect on students' critical thinking skills ($p < 0.001$). These findings confirm that culturally contextualized differentiated learning significantly enhances critical thinking. Theoretically, this model contributes to science pedagogy by integrating cultural relevance to support effective, innovative instruction.

Keywords: coastal culture, critical thinking skills, differentiated science learning.

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INTRODUCTION

In the current era of global transformation, critical thinking has become a core demand within educational systems worldwide. This skill equips learners to analyze information, construct logical arguments, and make reasoned decisions (Chusni, 2022). Such capabilities are vital for navigating the scientific, technological, and social challenges of the 21st century. Critical thinking has emerged as an essential competency for students to navigate the complex challenges of the 21st century. It equips learners with the ability to analyze information, construct logical arguments, and make well-reasoned decisions skills that are critical for addressing scientific, technological, and socio-environmental issues in today's rapidly changing world. Numerous studies emphasize that critical thinking is not an innate ability but must be systematically developed through structured and inquiry-based learning experiences. However, evidence shows that the development of critical thinking skills remains suboptimal in many developing countries, including Indonesia (Anggraini et al., 2019). Students often struggle with higher-order thinking tasks, especially in science subjects where rote learning and procedural approaches dominate (Albashtawi et al., 2020; Wekwete & Higgs, 2024). This situation is further exacerbated by teacher-centered pedagogy that limits opportunities for inquiry, reasoning, and reflective thinking (Puspa et al., 2020; Mustakim et al., 2024; Astutik et al., 2025). Therefore, there is an urgent need for innovative science learning approaches that can explicitly foster critical thinking skills in meaningful and contextually relevant ways. Strengthening students' critical thinking also contributes to building broader 21st-century skills, such as collaboration, creativity, communication, and problem-solving, which are essential for lifelong learning and global competitiveness.

Science education plays a pivotal role in cultivating these competencies, as it requires students to observe phenomena, interpret data, and evaluate explanations based on empirical evidence (Handayani et al., 2018; Azari et al., 2024; Astawan et al., 2023). Science learning holds significant potential to cultivate critical thinking because it inherently involves inquiry, evidence-based reasoning, and contextual problem-solving. Science education requires students to observe phenomena, interpret data, and evaluate explanations based on empirical evidence (Astawan et al., 2023). Understanding the Nature of Science (NOS) is essential in science learning because it emphasizes how scientific knowledge is developed, justified, and connected to cultural and social contexts. NOS highlights that scientific knowledge is empirical, tentative, theory-laden, creative, and socially embedded, meaning it is built through observation, evidence-based reasoning, and influenced by scientists' prior knowledge and cultural settings. Integrating NOS into science learning helps students not only acquire scientific facts but also develop the ability to think critically, evaluate arguments, and reflect on the reliability and limitations of scientific claims. This perspective aligns with the goal of this study, which seeks to enhance students' critical thinking by connecting scientific concepts to their local coastal culture as a real-life context for meaningful and reflective learning.

Yet in practice, science learning in many classrooms remains uniform, textbook-centered, and disconnected from students' sociocultural realities—especially in rural and coastal regions (Tytler, 2019). To overcome this, differentiated instruction (DI) has been proposed as a pedagogical approach that addresses the diverse needs, backgrounds, and readiness levels of students within the same classroom (Tomlinson, 2017). Differentiated science instruction, when implemented effectively, can increase student engagement and conceptual understanding by tailoring content, process, and products according to students' learning profiles. Furthermore, growing evidence highlights the value of integrating local cultural contexts into science learning as a way to enhance relevance and affirm students' identities (Ayano et al., 2025; Rizal et al., 2025).

In Indonesia, with its vast coastal regions and rich cultural heritage, coastal culture represents an underexplored yet powerful context for science education. Coastal culture refers to the local knowledge, values, traditional practices, and ways of life of communities living in coastal areas. It includes daily activities related to the sea and its surroundings, such as fishing, managing marine resources, utilizing local natural materials, and maintaining environmental sustainability in coastal ecosystems. Integrating these cultural elements into science learning provides meaningful and contextual experiences for students, allowing them to connect scientific concepts with their cultural and environmental realities (Rizal et al., 2022; Suyitno et al., 2018). Such cultural integration has been shown to enhance students' engagement, critical thinking, and problem-solving skills when studying science concepts (Hikmawati et al., 2021; Zhao et al., 2024).

Coastal communities possess rich indigenous knowledge related to marine biodiversity, sustainable resource use, local weather indicators, and conservation practices (Rahmawati & Ridwan, 2018). Integrating this ethnoscientific knowledge into differentiated science learning can provide authentic, familiar contexts that promote critical reasoning while also strengthening students' cultural identity and environmental literacy. Prior research shows that contextual learning grounded in local socio-environmental issues significantly improves critical thinking (Purwanto et al., 2022), while ethnoscience-based learning enhances scientific literacy and cultural appreciation (Snively & Williams, 2016). However, most DI implementations in science education remain cognitively oriented and lack cultural sensitivity (Banks, 2019; Tanjung et al., 2025). Consequently, empirical studies that integrate coastal cultural contexts into DI-based science learning models remain rare (Drake et al., 2023; Weaver, 2023; Borg & Kumblathan, 2025).

This research addresses that gap by introducing a coastal culture-based differentiated science learning model aimed at enhancing students' critical thinking skills. Unlike previous studies that examined DI and cultural knowledge separately, this study develops an integrated instructional framework in which elements of coastal culture are actively employed as the basis for tailoring tasks and learning projects to students' diverse needs. The model also encourages collaborative, problem-based learning where students engage with real local environmental challenges through scientific inquiry (Kuswandi et al., 2025; Yani et al., 2025). Through this approach, students are expected not only to enhance their critical thinking but also to strengthen their broader 21st-century competencies, including

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creativity, collaboration, communication, and digital literacy. Which are crucial for their future roles as active global citizens. This approach is expected to create an inclusive, dynamic, and intellectually stimulating learning environment that aligns with the principles of *Merdeka Belajar* and the (Ministry of Education, Culture, Research, and Technology of Indonesia, 2022) curriculum framework. Ultimately, the purpose of this study is to enhance critical thinking skills through the implementation of coastal culture-based differentiated science learning. This thereby contributes to both the development of theory and the provision of practical guidance for designing culturally responsive science curricula.

METHOD

This study employed a quantitative method, namely a quasi-experimental design with a non-equivalent control group. This design was chosen because it allowed the researchers to compare the effects of coastal culture- based differentiated science learning with conventional instruction in authentic classroom settings where random assignment was not feasible. By structuring the intervention around differentiated tasks tailored to students' readiness levels and embedding coastal cultural content, such as local ecological practices and traditional knowledge. The design specifically addressed the research question on how cultural integration enhances critical thinking. The interaction between differentiation and cultural context was operationalized by varying instructional strategies and materials across experimental groups, thereby enabling an examination of both the pedagogical and cultural dimensions of the model in shaping students' learning outcomes.

In addition, the study adhered to ethical research procedures. Formal approval was obtained from the principal and subject teachers before implementation. Students were informed about the purpose, procedures, and potential benefits of the study, and participation was voluntary without coercion. Confidentiality of data was ensured by omitting personal identifiers, and all procedures were conducted in compliance with established ethical standards for educational research.

The target population consisted of all 330 eighth-grade students from Junior High School 2 Bengkulu, Indonesia, divided into 11 classes, during the 2024–2025 academic year. Data collection was conducted from August to November 2024. The sample was selected purposively, based on the homogeneity of student abilities, as assessed by report card grades in the even semester of 2023/2024 and the suitability of the schedule to allow for the full implementation of the intervention. The selection resulted in three classes: 8A, 8B, and 8C, each consisting of 30 students and meeting these criteria.

To support the differentiation process, individual student profiles were further assessed through a preliminary diagnostic test, learning style observations, and teacher input regarding students' readiness levels and interests. These profiles were then used to tailor instructional strategies, including variations in task complexity, grouping arrangements, and learning materials. For instance, students with higher readiness levels were provided with more complex problem-solving tasks, while those with lower readiness levels received additional scaffolding and contextual examples. Integrating this profile-based differentiation with coastal cultural content ensured that the intervention was both responsive to student diversity and contextually meaningful.

The experimental and control groups were randomly assigned using a lottery method, in which two classes were randomly selected as the experimental group and one class was randomly selected as the control group. The inclusion of two experimental groups allowed for a clearer comparative analysis: one class received coastal culture-based differentiated science learning, while the other experienced problem-based learning. This design enabled the researchers to examine not only the effect of cultural integration within differentiated instruction but also how it compared with another well-established student-centered approach, thereby strengthening the validity of the findings. The first experimental group received treatment in the form of a coastal culture-based differentiated science learning model. Instruction was conducted over a period of four months (August–November 2024), with one 90-minute session per week for a total of 12 sessions. Differentiation was implemented by varying content, process, and product according to students' readiness levels, interests, and learning profiles. For example, students with higher readiness engaged in more complex problem-solving tasks involving coastal ecological case studies, while those with lower readiness received additional scaffolding, guided worksheets, and contextual examples. Coastal cultural elements were explicitly integrated into the lessons, including traditional fishing practices, local weather and tidal cycle observations, the use of coastal vegetation in daily life, and community-based resource conservation practices. These

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components were presented as case contexts, experiments, and discussion materials to enhance relevance and cultural connectedness.

The second experimental group was taught using problem-based learning strategies, following the same schedule and duration (12 weekly sessions, 90 minutes each), in which students worked collaboratively to solve science-related problems without explicit integration of cultural content. Meanwhile, the control group followed conventional teacher-centered methods, as typically taught by science teachers in regular science learning. Which consisted of lectures and textbook-based assignments, also conducted over 12 sessions of equal duration.

To increase internal validity and minimize allocation bias, the assignment of classes to treatment conditions was determined through a lottery technique. This comprehensive and structured implementation provides transparency and replicability for readers unfamiliar with the Indonesian educational context, while also ensuring a strong basis for assessing the effectiveness of differentiated science learning integrated with the local coastal cultural context.

The data collection process in this study was carried out through the administration of a critical thinking skills test to the students. The instrument used 10 open-ended questions, which were developed based on the critical thinking framework proposed by Facione (1990) and reinforced by the theory developed by Ennis (1991). The indicators included the ability to evaluate arguments, analyze information, draw conclusions, and use logic and reasoning. Each item was designed to require students to demonstrate higher-order thinking skills on the topic of alternative energy. The following is an example of a question on the Evaluating Arguments indicator: “A student argued that utilizing briquettes produced from organic waste represents the most effective solution to address energy challenges in coastal regions, as these briquettes can transform otherwise valueless waste into an efficient and environmentally friendly energy source. How can organic waste-based briquettes convert chemical energy into thermal energy during combustion, and which physical principles underlie this energy conversion process? Do you agree with the student’s statement? Provide your justification based on scientific reasoning.”

Before being used in the study, the instrument was first validated through expert judgment. The validation results showed that the ten questions fell into the valid category in terms of both content and language. After that, the instrument was piloted with a group of students who had similar characteristics to the research participants but were not included in the main sample. The pilot test aimed to assess the feasibility of the questions, evaluate the clarity of instructions, and collect preliminary data to analyze the instrument’s validity and reliability. The questionnaire was validated on 30 students from the same school, in different grades outside the pilot sample. All were in eighth grade.

The pilot data were then analyzed using SPSS to calculate item validity (through the correlation between item scores and total scores) and internal reliability (using Cronbach’s Alpha). The results showed that all ten questions were classified as valid in terms of content and language, with a reliability coefficient of $r=0.84$, indicating a high level of reliability. After being declared feasible, the test instrument was used in the main study as both a pretest and a posttest. The pretest was administered before the treatment to measure students’ initial critical thinking skills, while the posttest was administered after the treatment to assess their improvement. Students’ responses to both tests were scored using a rubric developed based on the critical thinking indicators, with a specific scoring scale for each item. The total scores from the pretest and posttest were then processed to calculate the improvement score using the N-gain formula as follows:

$$\text{N-Gain} = \frac{\text{Post test score} - \text{pretest score}}{\text{Maximal score} - \text{skor pre test}}$$

N-Gain Interpretation Category (Hake, 2002):

Table 1. N-Gain Interpretation Categories

N-Gain Value	Category
≥ 0.70	High
$0.30 \leq g < 0.70$	Medium
< 0.30	Low

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All collected data were then calculated for their N-gain values and categorized into several levels of improvement based on specific classifications. Further analysis was conducted in detail for each indicator of critical thinking skills to gain a deeper understanding of the improvement in students' abilities following the implementation of a differentiated science learning model integrated with the local cultural context. The research stage began with a pretest administered to all students from both the experimental and control groups, before the start of the learning process. Next, each group followed the predetermined learning process, which was conducted over three meeting sessions. After the learning series was completed, a posttest was administered to measure final critical thinking skills. All data obtained were then analyzed using descriptive and inferential statistical approaches. As part of the parametric data analysis procedure, a normality test using the Kolmogorov–Smirnov test and a homogeneity test using Levene's test were first performed to ensure that the data met the assumptions of normal distribution and homogeneous variance. If both assumptions were met, the analysis continued with a one-way analysis of variance (ANOVA) test to test whether there were significant differences between the treatment groups. ANOVA is used to determine the effect of treatment on the measured dependent variable. Suppose the ANOVA test results indicate a significant difference ($p < 0.05$). Consequently, the analysis is followed by a post hoc procedure employing multiple comparisons to pinpoint which specific group combinations demonstrate substantial differences. Conducting this test is essential to evaluate the comparative impact of each treatment and to confirm that the observed differences are statistically meaningful rather than incidental. All analyses were performed using statistical software with a 5% significance level.

The implementation of coastal culture-based differentiated science learning consists of eight steps. In the initial phase, teachers provide diagnostic tools to assess students' learning readiness and identify individual student profiles. The second phase focuses on establishing learning objectives that emphasize students' critical thinking skills. Next, in the third stage, the teacher provides explanations of basic concepts relevant to the science material and related to coastal environmental conditions. In the fourth stage, group formation and project planning are conducted, during which students design scientific projects relevant to real-world issues in coastal areas. The fifth phase focuses on executing the project collaboratively within each group, followed by the sixth phase, which involves ongoing supervision and mentoring by the teacher to provide continuous support and constructive feedback. In the seventh phase, students showcase their project outcomes through presentations that emphasize reasoning and structured argumentation. The final stage, the eighth stage, requires reflection, where students and teachers evaluate the learning process and design improvements for subsequent activities to increase the effectiveness of the applied learning model.

RESULT AND DISCUSSION

The following presents the research results obtained from data analysis to answer the formulated research objectives and questions. Before testing for differences between groups, a prerequisite analysis test was first conducted to ensure the data conformed to the statistical assumptions used.The results of the normality and homogeneity analysis (Table 2) show that all data groups (Experiment 1, Experiment 2, and Control) have a normal distribution (significance value > 0.05) and homogeneous variance (significance value > 0.05), thus fulfilling the prerequisites for parametric analysis using one-way ANOVA.

Table 2. Normality and Homogeneity Test Result

Class	Normality Test	Homogeneity Test
Experiment 1	Sig. 0.218 > 0.05	Sig. 0.086 > 0.05
Experiment 2	Sig. 0.481 > 0.05	Sig. 0.124 > 0.05
Control	Sig. 0.212 > 0.05	Sig. 0.066 > 0.05

The ANOVA analysis presented in Table 3 reveals a statistically significant difference in critical thinking skills among the three treatment groups ($F = 19.332$, $p = 0.000$, $p < 0.05$). This indicates that the applied learning models had a distinct impact on enhancing students' critical thinking skills. To complement the p-values, the effect size was calculated, yielding a partial eta squared (η^2p) of 0.27, which represents a large effect according to conventional benchmarks. Pairwise comparisons further showed substantial differences, with Cohen's d ranging from 0.82 to 1.05 when comparing Experimental Group 1 with the other groups, indicating strong practical significance. Supporting this, the pre-test and post-test results demonstrated that Experimental Group 1 exhibited more consistent and evenly distributed improvements in average item scores than both Experimental Group 2 and the Control Group, underscoring the meaningful educational impact of coastal culture-based differentiated science learning

Table 3. One-Way ANOVA Test Result

		Sum of Squares	df	Mean Square	F	Sig.
Critical Thinking	Between Groups	1244.133	2	622.067	19.332	.000
	Within Groups	3282.114	102	32.178		
	Total	4526.248	104			

The existence of an influence, as proven by the ANOVA results, was then further explored through post hoc analysis. The results of the post hoc analysis, presented in Table 4, using a multiple comparisons test, revealed significant differences between several treatment groups.

Table 4. Post-Hoc Test Result

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Experiment 1	Experiment 2	5.371*	1.356	.000	2.07	8.67
	Control	8.314*	1.356	.000	5.01	11.61
Experiment 2	Experiment 1	-5.371*	1.356	.000	-8.67	-2.07
	Control	2.943	1.356	.097	-.36	6.24
Control	Experiment 1	-8.314*	1.356	.000	-11.61	-5.01
	Experiment 2	-2.943	1.356	.097	-6.24	.36

*. The mean difference is significant at the 0.05 level.

These results highlight the importance of learning design tailored to the needs and context of learners to achieve optimal learning outcomes. Furthermore, the success of Experimental Group 1 opens up opportunities for the development and implementation of similar strategies in broader educational contexts, while still considering their sustainability and adaptability. The N-gain scores of critical thinking skills are presented in Figure 1.

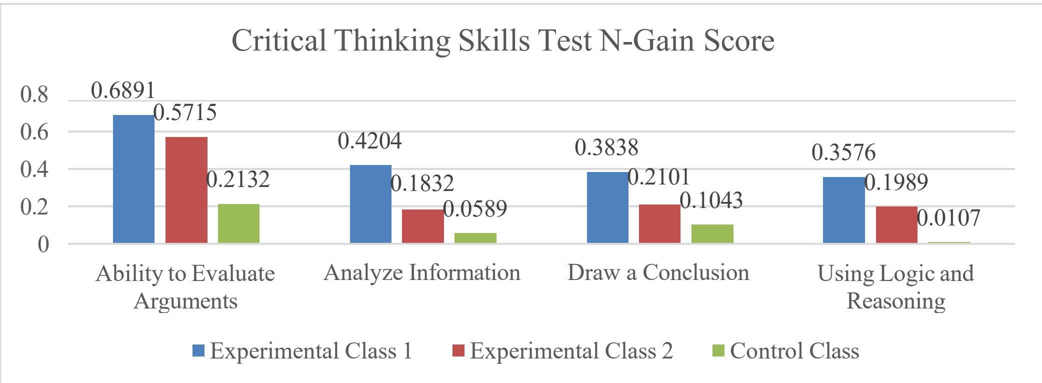

Figure 1. Critical Thinking Skills Test N-Gain Score

The results of the N-Gain score analysis of critical thinking skills, displayed in Figure 1, show that Experimental Group 1 consistently achieved the highest improvement scores on all critical thinking skill indicators compared to Experimental Group 2 and the Control Group. The highest N-Gain score in Experimental Group 1 was seen in the Ability to Evaluate Arguments indicator at 0.6891, followed by Analyze Information (0.4204), Draw a Conclusion (0.3838), and Using Logic and Reasoning (0.3576).

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Meanwhile, Experimental Group 2 showed lower scores but still exceeded those of the Control Group in most indicators, with the highest score in the "Ability to Evaluate Arguments" indicator (0.5715). Conversely, the Control Group showed very low N-Gain scores, particularly in the Using Logic and Reasoning indicator (0.0107), indicating a nearly insignificant improvement.

Specifically, Experimental Group 1 showed a significant mean difference compared to Experimental Group 2 (Mean Difference = 5.371, $p = .000$) and the Control Group (Mean Difference = 8.314, $p = .000$) (Table 3). This finding indicates that the intervention implemented in Experimental Group 1 was substantially more effective than those in the other groups. In contrast, Experimental Group 2 did not show a significant difference from the Control Group (Mean Difference = 2.943, $p = .097$), as the p-value exceeded 0.05. This suggests that the intervention in Experimental Group 2 did not produce a statistically different effect compared to the group that did not receive any treatment. The 95% confidence intervals reinforce this interpretation, where the confidence intervals for significant comparisons do not include zero, while the non-significant comparison (Experimental Group 2 vs Control) includes zero (-0.36 to 6.24), indicating uncertainty about the treatment effect.

These findings indicate that the treatment applied to Experimental Group 1 had the most significant impact on improving critical thinking skills. The higher effectiveness may be attributed to the characteristics of the intervention, which were more comprehensive, contextual, and involved stronger active learning strategies (Fonger et al., 2019). This result aligns with the findings of Antink-Meyer et al (2023) that science learning embedded in local contexts promotes deeper cognitive engagement and knowledge retention. Furthermore, Hunaepi et al (2024) demonstrated that culturally responsive and contextualized science learning could increase students' cognitive outcomes more effectively than conventional approaches.

In contrast, the intervention in Experimental Group 2 did not show statistically significant benefits over the control group, which may indicate that the instructional approach requires further refinement to achieve a substantial impact. This finding is consistent with Tanjung et al. (2025), who emphasized that partial contextualization without explicit cultural integration tends to have limited influence on students' critical thinking development.

Overall, these findings suggest that the contextual differentiation-based learning model applied to Experimental Group 1 effectively improved students' critical thinking skills. This result is in line with the principles of Constructivism and the Culturally Responsive Teaching (CRT) approach, which emphasize connecting learning content to students' cultural backgrounds and real-life experiences (Abdullah, 2019; Tanjung et al., 2025). This strengthens the argument that science learning, which is not only theoretical but also contextual and dialogical, produces more substantial cognitive impacts (Phillipson & Wegerif, 2019; Antink-Meyer et al., 2023; Hunaepi et al., 2024).

Furthermore,the average N-gain score of critical thinking skills in Experimental Group 1 (0.40, medium category) was higher than that of Experimental Group 2 (0.20, low category) and the Control Group (0.009, low category). This finding suggests that the instructional model implemented in Experimental Group 1 was more effective in enhancing students' critical thinking skills. According to Hake (2002), an N-gain score in the medium category demonstrates a moderate level of learning improvement, whereas low N-gain scores reflect minimal progress. The substantial difference in N-gain values between groups implies that the learning strategies applied in Experimental Group 1 provided more opportunities for students to engage in higher-order cognitive processes such as analyzing, evaluating, and reasoning. This aligns with Ennis (1991), who emphasized that critical thinking development requires instructional approaches that actively involve students in questioning, problem-solving, and evidence-based decision-making. Furthermore, studies by Su et al (2025) and Xu et al (2023) also found that instructional interventions explicitly designed to promote critical thinking yield greater gains compared to conventional teaching methods. Thus, the higher N-gain in Experimental Group 1 highlights the effectiveness of the applied learning model in fostering critical thinking skills. This highlights the need for the implementation more interactive, differentiated, and context-based instructional models in science education for the 21st century (Cheng et al., 2017).

This research also shows that local cultural integration is not merely an affective strategy but has a direct impact on complex cognitive outcomes. By allowing space for cultural identity in the scientific thinking process, students can develop deeper problem-solving and critical thinking skills. This finding aligns with a study conducted by Üstün & Yapıcı (2019) and Sapan & Mede (2022), This states that

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differentiated learning can maximize students' potential through enriched content and processes tailored to their needs and backgrounds.

However, several limitations should be acknowledged. First, the study was conducted in a specific coastal context, which may limit the generalizability of the findings to schools in non-coastal or urban settings with different cultural resources. Second, the relatively small sample size (three classes of 30 students each) restricts the extent to which the results can be extrapolated to larger populations. Finally, although the critical thinking instrument demonstrated high reliability, it primarily relied on written open-ended responses, which may not fully capture other dimensions of critical thinking such as oral reasoning or collaborative problem-solving. These limitations suggest caution in broad application, while also pointing to the need for further studies with larger and more diverse samples, multiple cultural contexts, and complementary assessment tools.

The implications of these findings are significant, particularly in the context of education in regions rich in local wisdom. A culturally based, contextual approach is not only relevant for improving the quality of learning but also serves as a strategy for building students' character and environmental literacy (Caingcoy, 2023). In the future, the development of a local culture-based curriculum needs to be systematically strengthened to create a science learning model that is inclusive, adaptive, and has a long-term impact on the quality of students' thinking.

Furthermore, these findings suggest that learning opportunities that facilitate critical argumentation, information exploration, and data-driven decision-making can enhance all aspects of critical thinking. This underscores the importance of teacher professional development, as successful implementation of such approaches depends heavily on teachers' ability to design differentiated tasks, integrate culturally relevant content, and effectively facilitate classroom dialogue. Ongoing training and support are therefore essential to equip teachers with the pedagogical skills and cultural awareness needed to foster critical thinking in diverse learning environments.

To scale the model more broadly, it is recommended that teacher training programs emphasize strategies for differentiated instruction and culturally responsive pedagogy, enabling teachers to adapt content and processes to diverse student needs. Curriculum developers should also consider embedding local cultural knowledge and practices into science syllabi to ensure contextual relevance across regions. Additionally, pilot programs and collaborative workshops between educators, cultural experts, and policymakers could serve as platforms for refining and disseminating the model, thereby supporting its sustainable integration into mainstream education.

Future research could address these boundaries by involving larger and more diverse samples across multiple regions, incorporating a wider range of cultural contexts, and employing mixed-method assessments to gain a more comprehensive understanding of students' critical thinking development. Such studies would provide stronger evidence for scaling and adapting differentiated science learning models in broader educational settings.

CONCLUSION

The results of this study indicate that the coastal culture-based differentiated science learning model is effective in significantly improving students' critical thinking skills. This is evidenced by statistical analysis, which revealed significant differences between the experimental and control groups, as shown in both ANOVA results and N-Gain scores for each critical thinking indicator. The group of students participating in the coastal culture-based differentiated science learning demonstrated the highest improvement, particularly in their ability to evaluate arguments, analyze information, draw conclusions, and use logic and reasoning.

However, several limitations and delimitations should be noted. The study was conducted in a single junior high school in Bengkulu with a relatively small sample size, which may limit the generalizability of the findings. The focus on coastal cultural content also sets a clear delimitation, as the model was designed for contexts where such cultural knowledge is directly relevant; its applicability to non-coastal or urban settings may differ. In addition, the measurement of critical thinking relied mainly on written open-ended test items, which may not fully capture other dimensions of critical thinking such as oral reasoning or collaborative inquiry. Recognizing these boundaries provides

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important context for interpreting the results and underscores the need for future studies involving larger and more diverse samples, different cultural settings, and multiple assessment methods.

Learning that integrates the coastal cultural context enables students to connect science concepts with real-life experiences and local values, creating more relevant and meaningful learning experiences and encouraging higher cognitive engagement. These findings confirm that the culturally based differentiated approach not only improves learning outcomes but also strengthens the higher-order thinking dimensions required for 21st-century education. Future research could extend this work by exploring its application in non-coastal or urban contexts, examining the long-term effects through longitudinal studies, and incorporating qualitative insights to capture students' experiences, perceptions, and cultural engagement more deeply.

The implication of this research is the importance of developing and implementing contextual learning models that accommodate local cultural diversity in science education systems. Furthermore, this research opens up a new exploration space for the development of culturally responsive and differentiation-based curricula to support the equitable distribution of educational quality and the improvement of students' scientific literacy across Indonesia. Future studies are recommended to replicate and extend this approach at different educational levels (e.g., primary, secondary, and higher education) and in various cultural settings to examine its broader applicability and long-term impacts. In addition, subsequent research could explore integrating this culturally based differentiated approach with digital learning environments or interdisciplinary STEM projects to further enhance students' engagement and 21st-century skills.

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