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Enhancing Critical Thinking Skills in Science Education Through a Local Wisdom-Based E-Module: An Inquiry-Based Learning Approach

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a b s t r a c t

Science education has historically relied on conventional teaching materials that are frequently disconnected from students' local cultural contexts, thereby diminishing learner engagement and undermining the contextual authenticity of the science learning experience. Furthermore, although the Inquiry-Based Learning (IBL) model has been widely recognized as an effective pedagogical framework for cultivating critical thinking skills in science education, its implementation within culturally responsive instructional contexts that meaningfully integrate local wisdom remains considerably underexplored in the existing literature. This study aims to analyze the implementation of a local wisdom-based e-module, developed in the context of the natural dyeing process of Mega Mendung batik, within the IBL framework, and to evaluate its effectiveness in enhancing eighth-grade students' critical thinking skills in science learning. A pre-experimental research design with a one-group pretest-posttest configuration was employed. The research sample comprised 32 eighth-grade students selected through random sampling. Data were collected using a validated critical thinking skills assessment instrument aligned with science learning objectives, and subsequently analyzed using a paired sample t-test and effect size calculation to determine the magnitude and practical significance of the instructional intervention. The findings demonstrate that the implementation of the local wisdom-based e-module significantly enhanced students' critical thinking skills across all assessed indicators, with an effect size classified within the high category. These results collectively affirm that science learning mediated through culturally contextualized, local wisdom-based e-modules within the IBL framework constitutes a promising and empirically supported pedagogical strategy for fostering critical thinking in science education. This study further offers practical guidance for science educators and curriculum developers engaged in designing culturally responsive, inquiry-based instructional materials for middle school science contexts.

1. Introduction

Critical thinking constitutes one of the most essential competencies in 21st-century learning. These skills do not develop in isolation but are inherently interconnected with other cognitive abilities, including metacognition, problem-solving, and information literacy, all of which play a foundational role in the formation and consolidation of critical thinking capacities. Learning activities that effectively cultivate critical thinking skills encompass problem-solving, the evaluation and support of theories or statements, experimental inquiry, argumentation, interpretation, critical analysis, in-depth conceptual understanding, and informed decision-making. These activities collectively demonstrate that critical thinking is not merely reflective in nature but is simultaneously valid and generative in its outcomes (Bahtiar et al., 2022).

The deliberate cultivation of critical thinking skills in educational settings is of considerable importance, as it equips students with the analytical competencies necessary to address complex problems effectively (Sumarni et al., 2018). The enhancement and stimulation of critical thinking in learning contexts has been demonstrated to improve overall student academic performance. These skills play a pivotal role in enabling students to draw evidence-based conclusions and make informed decisions when confronted with challenging situations (Rahmadana Hidayati et al., 2021). Furthermore, instructional approaches that promote critical thinking empower students to leverage their knowledge, engage meaningfully with technology, and design innovative solutions to address real-world challenges encountered in everyday life (Faradilla et al., 2024).

Observational findings conducted at SMPN 1 Gegesik, Cirebon Regency, revealed that students' critical thinking skills were notably underdeveloped, as evidenced by a lack of initiative in posing questions, difficulties in explaining scientific concepts, an inability to identify viable solutions to problems, and challenges in making informed decisions. Interview data obtained from classroom teachers further corroborated these findings, indicating that this condition is primarily attributable to students' limited intrinsic learning motivation. Students require structured stimulation to engage with problems, and tend to prioritize recreational screen-based activities over academic engagement. These conditions are further compounded by the predominant use of lecture-based, teacher-centered instructional methods, which have resulted in diminished student enthusiasm for learning. Students frequently report experiencing monotony in conventional learning environments characterized by passive reception of teacher explanations, leading to disengagement from the learning process.

In contrast, students demonstrate markedly greater enthusiasm and active participation when learning activities involve student-centered engagement, such as direct observation, collaborative group investigations, and discovery-based practical processes. This observation is corroborated by a growing body of recent empirical research, which consistently highlights the persistently low critical thinking skills among Indonesian students. Specifically, students continue to encounter difficulties in explaining concepts, interpreting statements, articulating opinions, associating information across contexts, making decisions, and formulating solutions to scientific problems (Akhdinirwanto et al., 2020; Faradilla et al., 2024). This condition is largely attributed to the failure of prevailing instructional approaches to sufficiently prioritize the systematic development of critical thinking skills (Bustami et al., 2018; Sarah, 2014).

Contemporary science education in Indonesia continues to be predominantly teacher-centered, characterized by the pervasive use of lecture methods, limited instructional media variation, monotonous learning routines, and a predominantly conventional pedagogical orientation that affords students insufficient opportunities for cognitive challenge and authentic learning experiences (Sari et al., 2019). As a consequence, students have become accustomed to concrete and verbal modes of thinking, while their capacity for abstract reasoning and critical analysis remains significantly underdeveloped. Students exhibiting low critical thinking skills are particularly disadvantaged in science learning contexts, as foundational scientific concepts become increasingly difficult to comprehend, ultimately resulting in constrained academic capabilities and diminished learning outcomes. The development of critical thinking among students is further influenced by individual cognitive orientations and the manner in which each learner approaches and processes the material under study (Hayati & Setiawan, 2022).

The enhancement of students' critical thinking skills can be effectively facilitated through the strategic use of well-designed teaching materials within the learning process. One such teaching material that has demonstrated considerable potential in fostering critical thinking skills is the electronic module, or e-module. The utilization of e-modules as structured instructional materials — developed in accordance with specific learning needs and designed to support independent, self-directed study without requiring continuous guidance — has been shown to facilitate deeper and more meaningful comprehension of scientific content among students (Sudjana, 2007).

Beyond the selection of instructional materials, the integration of local wisdom content into science learning has similarly been identified as an effective strategy for enhancing students' critical thinking skills (Deti Ratih & Rohaeti, 2024). Kelana et al. (2025) assert that the use of teaching materials integrated with local wisdom actively encourages students to pursue deeper levels of knowledge construction, thereby rendering instructional materials more effective in strengthening both scientific knowledge acquisition and critical thinking development in science education. Optimal learning outcomes are further contingent upon the adoption of instructional models that actively engage students and foster constructivist understanding. In this regard, the Inquiry-Based Learning (IBL) model has emerged as a particularly effective pedagogical framework, with empirical evidence consistently demonstrating its capacity to enhance students' critical thinking skills (Febrianti et al., 2022).

The IBL model is conceptualized as a series of teaching and learning activities that systematically emphasizes higher-order thinking processes and analytical reasoning, guiding students to independently search for and construct answers to posed problems (Sanjaya, 2006). This thinking process is operationalized through structured question-and-answer interactions between teachers and students, wherein scientific content is not delivered didactically but is instead discovered by students themselves through guided inquiry. In the IBL framework, educators assume the role of facilitators and guides rather than primary knowledge transmitters, while students take ownership of the process of searching for and constructing their own understanding of the material (Muhammad, 2014).

Despite its well-documented effectiveness, the practice of developing critical thinking through independent knowledge discovery remains insufficiently implemented in many science learning contexts. This is particularly significant given that inquiry-driven learning processes have been demonstrated to produce deeper and more enduring comprehension of scientific material. This assertion is further supported by Laili Rosita and Nuranisa (2019), who established that students who actively engage with lesson material through inquiry and discovery retain acquired knowledge for a considerably longer duration compared to students who receive information passively through listening or direct transmission from educators.

Previous studies have discussed the use of e-modules, the integration of local wisdom in learning, and the application of Inquiry-Based Learning (IBL) in science education (Febrianti et al., 2022; Parmiti et al., 2021). However, these aspects are generally examined separately. Studies that integrate e-modules, IBL, and local wisdom simultaneously, particularly to enhance students' critical thinking skills, are still limited (Ramdani et al., 2021; Melikhova & Skorobogatova, 2020). In addition, most existing research focuses on general learning contexts and does not sufficiently emphasize culturally relevant learning that connects scientific concepts with students' daily experiences (Melikhova & Skorobogatova, 2020). Therefore, this study aims to develop and implement a local wisdom-based science e-module using the IBL model to enhance students' critical thinking skills.

2. Method

This study employed a quantitative approach using a pre-experimental design with a one-group pretest-posttest design. The population consisted of all eighth-grade students at SMPN 1 Gegesik. The sample included 32 students from class VIII E, selected through random sampling. The development of the e-module began with a needs analysis related to science learning in the local context. This was followed by designing the content based on the Inquiry-Based Learning (IBL) model. The e-module was validated by subject matter experts and media experts, and revised based on their feedback. The e-module integrates the process of making Mega Mendung batik using natural materials into inquiry-based learning activities to enhance students' critical thinking skills.

Data were collected using a test consisting of five essay questions administered before (pretest) and after (posttest) the learning process. The instrument was developed based on critical thinking indicators, including interpretation, analysis, evaluation, and conclusion. The validity of the instrument was confirmed through expert judgment and is presented in Table 1. The data were analyzed using a paired sample t-test to determine the significance of differences between pretest and posttest scores. In addition, effect size (Cohen's d) was calculated to measure the magnitude of the treatment effect.

Table 1. Indicator of Critical Thinking Skills in the Electronic Module

Critical thinking indicators	Indicators of Critical Thinking Skills in the E-Module
Interpretation	Explaining metal and non-metal elements
Analysis	Distinguishing elements and compounds in batik production using natural materials
Evaluation	Evaluating mixtures in batik production using natural materials
Conclusion	Provide a conclusion about the separation of mixtures in batik activities.

Source: Adapted From Facione (2020), Marzano (2007), Kemendikbud (2022), and Edwar (2012)

3. Result and Discussion

This section presents the results of data analysis on students' critical thinking skills before and after the implementation of the e-module. The results show an increase in the average score from 65.62 in the pretest to 77.25 in the posttest. Before conducting the hypothesis test, prerequisite tests including normality and homogeneity were performed. The results showed that the data were normally distributed ($p > 0.05$), indicating that parametric tests could be applied.

The results of the paired sample t-test showed a significant difference between pretest and posttest scores ($t = -8.598$, $p < 0.05$). The mean difference value of -0.36281 indicates that the average posttest score was higher than the pretest score. The 90% confidence interval ranged from -0.43436 to -0.29127, confirming the improvement in students' critical thinking skills after the treatment. Furthermore, the effect size analysis showed a very large effect, indicating that the implementation of the e-module had a strong impact on improving students' critical thinking skills.

Table 2. Paired sample t-test results

	Paired Differences				
	Mean	**Std. Deviation**	**Std. Error**	**t**	**Sig.(p)**
Pretest - Posttest	-0,36281	0,2387	0,0422	-8.598	< 0.001

The results of the paired sample t-test, as systematically presented in Table 2, revealed a statistically significant difference between pretest and posttest scores ($t = -8.598$, $p < 0.001$), confirming the effectiveness of the local wisdom-based e-module within the IBL framework in enhancing students' critical thinking skills. The mean difference of -0.36281 indicates that posttest scores were substantially higher than pretest scores, reflecting a meaningful improvement in students' critical thinking performance following the instructional intervention. The 90% confidence interval, ranging from -0.43436 to -0.29127, further corroborates the consistency and reliability of this improvement across the sample, providing robust statistical evidence that the implementation of the e-module produced a significant and practically meaningful enhancement in students' critical thinking skills.

To determine the magnitude of the instructional treatment effect, effect size was calculated using Cohen's d statistic. Cohen's d is a widely adopted measure for quantifying the strength of the difference between two groups or experimental conditions, thereby providing an indicator of practical significance beyond mere statistical significance (Cohen, 1988). Based on the calculation, a Cohen's d value of 3.14 was obtained, which falls within the very large effect size category. This finding substantiates that the implementation of the local wisdom-based e-module within the IBL framework exerted a substantial and practically meaningful impact on the enhancement of students' critical thinking skills in science education.

These findings are consistent with those of previous empirical studies demonstrating that the integration of Inquiry-Based Learning (IBL) and digital learning media significantly enhances students' critical thinking skills (Febrianti et al., 2022; Ramdani et al., 2021). Furthermore, the incorporation of local wisdom into instructional materials provides a contextually authentic learning experience that renders abstract scientific concepts more meaningful, accessible, and personally relevant to students (Parmiti et al., 2021). Collectively, these findings affirm that the synergistic combination of the IBL model, e-module-based instruction, and local wisdom content not only deepens students' conceptual understanding of scientific material but also substantially strengthens their capacity to apply critical thinking skills in addressing real-world problems encountered within their immediate cultural and natural environments.

The test instrument used in this study was designed to measure students' critical thinking skills across several indicators, including analysis, evaluation, interpretation, and conclusion. The results of students' responses indicate an improvement in all these indicators after the implementation of the e-module. A detailed comparison of the average pretest and posttest scores for each indicator is presented in Table 3.

Table 3. Comparison of pretest and posttest scores for each indicator

No	Indicator	Pretest	Posttest	Percentage Increase (%)
1	Analysis	2.15	2.53	17.43%
2	Evaluation	2.07	2.34	12.78%
3	Interpretation	2.09	2.50	19.39%
4	Conclusion	1.87	2.28	21.70%

The results indicate that students’ critical thinking skills improved across all indicators after the implementation of the e-module. This improvement suggests that the integration of Inquiry-Based Learning (IBL) and local wisdom in the e-module effectively supports the development of higher-order thinking skills. These findings are consistent with previous studies showing that inquiry-based learning can enhance students’ critical thinking skills by encouraging active exploration and problem-solving (Febrianti et al., 2022; Ramdani et al., 2021). In addition, the integration of local wisdom provides meaningful and contextual learning experiences that help students better understand scientific concepts (Parmiti et al., 2021). Therefore, the combination of IBL, e-modules, and local wisdom not only improves students’ learning outcomes but also strengthens their ability to think critically in solving real-world problems.

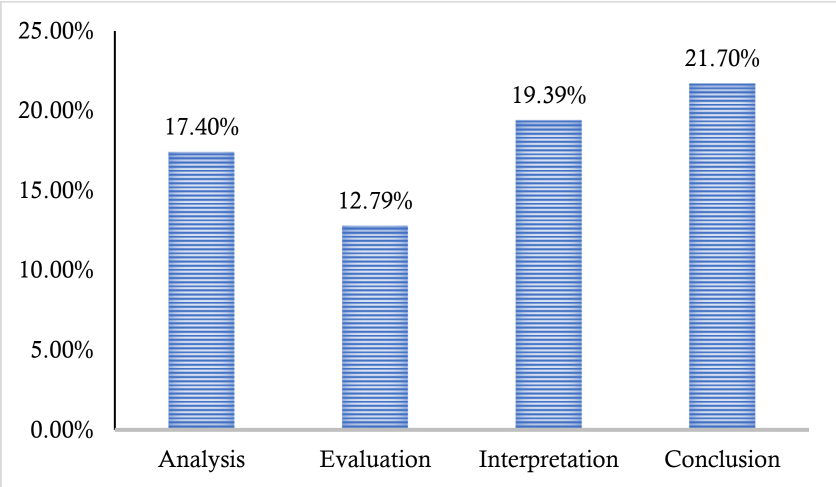

Figure 1. Efect size Cohen's d calculation

The results show that students' critical thinking skills improved across all indicators after the implementation of the e-module. The magnitude of this improvement was further substantiated through the calculation of Cohen's d effect size, as presented in Figure 1, which provides a quantitative measure of the practical significance of the instructional intervention on students' critical thinking skill development. The most notable improvement was observed in students' ability to draw conclusions, indicating that they became more capable of synthesizing information obtained during the learning process. This improvement can be attributed to the use of the Inquiry-Based Learning (IBL) model, which encourages students to actively explore, analyze, and construct knowledge through structured learning activities (Hmelo-Silver et al., 2007; Pedaste et al., 2015). Within the IBL framework, students are systematically guided to observe natural phenomena, formulate inquiry questions, conduct structured investigations, and formulate evidence-based conclusions, thereby progressively enhancing their metacognitive awareness and problem-solving capabilities.

This improvement is closely related to the use of the IBL model, which promotes student-centered learning and increases students’ engagement in classroom activities. Students are actively involved in discussions, investigations, and collaborative learning processes, allowing them to exchange ideas and deepen their understanding of the material. This is in line with constructivist learning theory, which emphasizes that knowledge is actively constructed through interaction and experience.

In addition, the integration of local wisdom, such as Mega Mendung batik, provides meaningful and contextual learning experiences that help students connect scientific concepts with their daily lives. This contextual approach not only enhances students' understanding but also increases their motivation to learn. These findings are consistent with previous studies indicating that inquiry-based learning and local wisdom integration can significantly enhance students' critical thinking skills (Febrianti et al., 2022; Ramdani et al., 2021; Parmiti et al., 2021). The integration of local wisdom provides meaningful and contextual learning experiences that help students better understand scientific concepts (Parmiti et al., 2021; Melikhova & Skorobogatova, 2020; Parmin et al., 2017).

The improvement in the conclusion indicator suggests that students became more capable of synthesizing information and drawing logical conclusions. This is in line with Zubaidah (2010), who states that concluding is a critical thinking skill developed through the integration of analysis, evaluation, and interpretation processes. In inquiry-based learning, students are encouraged to observe, ask questions, conduct investigations, and formulate conclusions, which supports the development of logical and structured thinking (Dwyer et al., 2014). On the other hand, the evaluation indicator showed relatively lower improvement. This may be due to the complexity of evaluative skills, which require deeper understanding and reflective thinking. As noted by Ennis (1985), evaluation is one of the most challenging aspects of critical thinking because it involves metacognitive processes. Therefore, future learning design should incorporate more structured evaluative activities, such as data-based discussions, peer reviews, and case analysis, to better support the development of students' evaluation skills.

Compared to previous studies, this research provides a more contextual learning approach by integrating local wisdom into inquiry-based learning. While earlier studies have applied inquiry-based learning in general contexts, this study emphasizes culturally relevant learning, which makes the learning process more meaningful and relatable for students. This difference highlights the importance of integrating local context into science learning to enhance students' engagement and critical thinking skills. Furthermore, the integration of local context contributes to the development of students' conceptual understanding and positive learning attitudes. These findings are consistent with Melikhova and Skorobogatova (2020), who state that culturally relevant learning can improve conceptual understanding and foster positive attitudes toward learning.

However, this study has several limitations. The sample was limited to one school, which may affect the generalizability of the findings. In addition, this study did not examine external factors such as students' motivation or learning environment. Therefore, future research is recommended to involve more diverse samples and explore additional factors influencing students' critical thinking skills.

Evaluation skills are considered the most challenging aspect of critical thinking because they involve metacognitive processes, or thinking about one's own thinking (Ennis, 1985). In the context of Inquiry-Based Learning (IBL), evaluation activities often take the form of reflective discussions or analysis of experimental results. However, if these activities are not explicitly designed to develop evaluative skills, students may focus more on procedural tasks rather than deeper critical analysis. Therefore, the relatively lower improvement in evaluation skills suggests the need for more structured evaluative activities, such as data-based discussions, peer reviews, and case study analyses.

Compared to previous studies, this research offers a more contextualized learning approach. For example, Zubaidah (2010) applied Problem-Based Learning (PBL) and found improvements in critical thinking, particularly in analysis and interpretation, but did not integrate local wisdom.

Similarly, Nurwidodo et al. (2023) implemented Inquiry-Based Learning (IBL) in biology education and reported improvements in students' critical thinking skills; however, the learning materials remained largely academic and less connected to students' real-life contexts.

In contrast, this study integrates the IBL model with local cultural content, specifically the natural dyeing process of Mega Mendung batik. This approach creates a more meaningful learning experience by connecting scientific concepts with students' daily lives and cultural background. As a result, students become more motivated and actively engaged in the learning process, which contributes to the development of their critical thinking skills.

Furthermore, the integration of local context enhances students' conceptual understanding and learning motivation. These findings are consistent with Melikhova and Skorobogatova (2020), who state that culturally relevant learning can improve conceptual understanding and foster positive attitudes toward learning. However, this study has several limitations. The sample was limited to one school, which may affect the generalizability of the findings. In addition, this study did not examine external factors such as students' motivation or learning environment. Therefore, future research is recommended to involve more diverse samples and explore additional factors influencing students' critical thinking skills.

4. Conclusion

This study concludes that the use of Inquiry-Based Learning (IBL) science e-modules integrated with local wisdom has a positive impact on improving students' critical thinking skills. The integration of inquiry-based learning with culturally relevant content creates meaningful learning experiences that actively engage students in constructing knowledge. The findings imply that combining IBL with local wisdom can enhance students' higher-order thinking skills while making learning more relevant and motivating. This approach can be considered an effective strategy for developing critical thinking skills in science education. Therefore, it is recommended that educators integrate local cultural contexts into inquiry-based learning to create more engaging and meaningful learning environments. Future research is also suggested to involve a wider sample and explore additional factors that may influence students' critical thinking skills.

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