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Effect of an Electronic Module Based on Project-Based Learning Integrated with Local Wisdom on Students' Critical Thinking Skills

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ABSTRACT

In the 21st century, critical thinking skills are regarded as essential competencies that every student must develop, particularly in physics. However, preliminary test results indicate that students' critical thinking skills remain low, with an average score of 61.77%. This study examined the effect of an electronic module (e-module) based on Project-Based Learning (PjBL) integrated with local wisdom on students' critical thinking skills, compared to learning using the Independent Curriculum textbook and PjBL-based worksheets. This study employed a quantitative approach with a quasi-experimental design using a Posttest-Only Control Group Design. The research sample comprised 32 students in the experimental class (F2.4) and 30 students in the control class (F2.3). Data analysis included normality tests, homogeneity tests, and an independent samples t-test. The results showed that the mean critical thinking score of the experimental class (M = 87.97) was significantly higher than that of the control class (M = 72.58), with a mean difference of 15.39 points. Statistical analysis confirmed a significant effect: t(60) = 8.581, p = 0.000 (< 0.05). Effect size analysis using Cohen's d yielded d = 1.7, indicating a very large practical significance. It is therefore concluded that the PjBL-based e-module integrated with local wisdom has a significant and practically meaningful effect on students' critical thinking skills compared to the conventional learning approach

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INTRODUCTION

Education in the modern era requires students to possess critical thinking skills, creativity, teamwork, and effective communication as essential competencies for addressing global challenges (Chusni et al., 2020;Nurhayati et al., 2024). Among these competencies, critical thinking skills are a fundamental aspect, as they encompass the ability to analyze problems, evaluate information, and draw logical, evidence-based conclusions (Aini et al.,

2022; Wulandari & Warmi, 2022)These skills fall under the category of higher-order cognitive abilities, which involve processes of interpretation, analysis, evaluation, and decision-making (Ennis, 2011;Sihotang, 2019;Sofiani et al., 2024). In studying physics, critical thinking is essential because physics is not merely about theory; it also involves a process of thinking that requires a logical understanding of concepts, as well as a scientific process that demands logical, analytical, and reflective thinking to explain natural phenomena (Halpern, 2014).

Essentially, physics education encompasses three main dimensions: as a body of knowledge, as a series of scientific processes, and as a means of fostering a scientific mindset (Mahardika, 2023;Sakliressy et al., 2021). Physics as a process requires students to engage in scientific activities such as observation, experimentation, data analysis, and drawing conclusions (Ekasari, 2020;Sarifah & Nurita, 2023). Based on this, physics instruction should be designed to develop critical thinking skills through activities that encourage scientific exploration and problem-solving. This aligns with the Independent Curriculum, which emphasizes enhancing students' competencies and independence in critical reasoning, problem-solving, and the ability to apply concepts in real-world contexts

Nevertheless, a number of studies indicate that students' critical thinking skills have not yet developed to their full potential. Wulandari & Warmi (2022)reports that the achievement of critical thinking skills indicators is not yet optimal, while Azka et al. (2024)identified weaknesses in the areas of evaluation and conclusion. Other studies indicate that students are not yet able to construct scientific arguments in a logical and contextual manner (Nurjanah et al., 2022;Wulandari et al., 2023). This situation is reinforced by the results of preliminary observations at the research school, which indicate that student participation remains low, with the lowest scores in the indicators of drawing conclusions (55.28%) and strategies and tactics (50.85%). The assessment results show that students' critical thinking skills reached only 61.77%, which, according to the criteria Arikunto (2010)falls into the low category. This indicates that students still face difficulties when tackling questions that require higher-order thinking skills (HOTS) (Octaviani, 2024; Khushaalahussaniyyati, et al., 2023).

These issues can be addressed through the use of innovative and contextual learning models, such as Project-Based Learning (PjBL). This model requires students to actively participate in solving real-world problems through projects, thereby fostering their analytical, evaluative, and synthetic skills (Farcis et al., 2022; Aktafianto & Yudana, 2023; Fitriani & Hidayat, 2024; Rohman et al., 2024; Usman et al., 2025). PjBL also enables students to develop their knowledge independently through a learning process based on direct, meaningful experiences (Nurhayati & Handayani, 2020; Martati, 2022).In addition, the use of technology-based teaching materials, such as electronic modules, can foster a more dynamic and flexible learning process and enhance multimedia integration (Maiyena & Imamora, 2020;Prieto-Ballester et al., 2021; Serevina, 2024).Research shows that PjBL-based electronic modules can enhance students' engagement and higher-order thinking skills (Mardiyanti, 2025; Mudatsir et al., 2022).

Contextual learning can also be strengthened through the integration of local wisdom. Local wisdom refers to the knowledge and values that have developed within a community and are relevant to the students' living conditions (Akmal, 2021). One cultural value that can be incorporated into physics lessons is the tradition of maelo pukek, a group fishing activity that reflects concepts of fluid dynamics such as the continuity equation and Bernoulli's principle (Yuliyus & Susilawati, 2021). This integration of local context enables students to connect physics concepts with real-world phenomena, thereby enhancing their conceptual understanding and critical thinking skills. A needs analysis by Parhannes and Asrizal (2025) in JIPT similarly identified the importance of developing fluid dynamics digital teaching materials integrated with ethnoscience to promote conceptual understanding and creative

thinking, reinforcing the value of culturally embedded instructional design in physics education.

Although various studies have examined the effectiveness of PjBL, electronic modules, and local wisdom separately, research integrating these three components into a single instructional design remains limited, particularly regarding fluid dynamics material in Phase F. Therefore, this study offers a novel approach by integrating PjBL-based electronic modules with this local wisdom into a single, contextual, and innovative instructional design. This integration is expected to provide a more meaningful learning experience while optimally developing students' critical thinking skills.

The theoretical basis of this study is grounded in constructivist learning theory, which posits that students actively construct knowledge through meaningful interaction with their environment rather than passively receiving information (Maiyena & Imamora, 2020).In the context of physics education, this principle aligns closely with the PjBL model, as students are required to engage in inquiry-based, collaborative projects that demand active cognitive processing. Critical thinking, as defined by Ennis (2011) encompasses five interconnected dimensions: basic clarification, basic support, inference, advanced clarification, and strategies and tactics. These dimensions reflect a progression from identifying and understanding problems to designing systematic solutions, all of which are cultivated through the project-based learning cycle embedded in the e-module. The e-module itself serves as a mediating tool that scaffolds students through increasingly complex cognitive tasks, providing multimedia representations of fluid dynamics phenomena — including animations of water flow through pipes of varying cross-sections — that support conceptual visualization. Furthermore, Kusyanti (2021) demonstrated that interactive digital modules incorporating virtual laboratories are effective in enhancing students' understanding of dynamic fluid concepts, supporting the appropriateness of e-module use in Phase F physics. Taken together, the theoretical and empirical foundations reviewed here justify the integration of PjBL, e-module technology, and local wisdom as a coherent, evidence-based instructional strategy for developing critical thinking skills in secondary physics education.

Based on the above description, this study aims to examine the effect of learning using an electronic module based on Project-Based Learning (PjBL) integrated with local wisdom on students' critical thinking skills, compared to conventional learning. The benefits of this study include providing empirical contributions to the development of creative physics instruction that is relevant to real-life contexts and aligned with the principles of the Independent Curriculum, as well as serving as a reference for educators in enhancing students' critical thinking skills.

METHODS

This study employs a quantitative approach with a quasi-experimental design to examine the effect of implementing an e-module based on Project-Based Learning (PjBL) integrated with local wisdom on students' critical thinking skills. The research design used is a Posttest-Only Control Group Design (Sugiyono, 2017). The study was conducted from October to December 2025 at MAN Kota Pariaman. Random assignment was used to determine which class served as the experimental group and which served as the control group.

The study population consisted of all 11th-grade Phase F Science students at MAN Kota Pariaman, comprising two classes: F2.3 with 30 students and F2.4 with 32 students. Total sampling was used as the sampling technique (Sugiyono, 2012), resulting in a research sample of 62 students in total. The experimental class (F2.4) received instruction using the PjBL-based e-module integrated with local wisdom, while the control class (F2.3) used the

Independent Curriculum textbook with PjBL-based worksheets. Prior to the main analysis, normality testing was conducted using the Shapiro–Wilk test and homogeneity testing using Levene's test, both of which confirmed that the data met the required statistical assumptions ($p > 0.05$).

The research variables consisted of an independent variable (the PjBL-based e-module integrated with local wisdom), a dependent variable (students' critical thinking skills), and control variables including the educator, instructional time, and learning strategies employed (Payadnya & Jayantika Gusti, 2018). The research was conducted in three stages: (1) preparation, which included the development of instructional materials, the validation process, and instrument pilot testing; (2) implementation, involving application of the instructional materials in both the experimental and control classes; and (3) finalization, comprising posttest administration and data analysis (Payadnya & Jayantika Gusti, 2018). The choice of this three-stage procedure ensured systematic control over potential extraneous variables and maintained consistency in the implementation of the learning intervention across both classes.

The primary instrument used in this study was an essay-based posttest designed according to Ennis (2011)five indicators of critical thinking: basic clarification, basic support, inference, advanced clarification, and strategies and tactics. Supporting instruments included observation sheets for monitoring the implementation of learning in both classes. Instrument quality was verified through validity, reliability, discriminant validity, and difficulty-level analysis, yielding a reliability coefficient of $\alpha = 0.944$, indicating high reliability. Data were analyzed using SPSS 25 via the independent samples t-test, with Welch's t-test as an alternative if homogeneity was not met. Effect size was computed using Cohen's d, and the significance criterion was set at $p < 0.05$ (2-tailed).

RESULTS AND DISCUSSION

Results

This section presents the research findings in three main parts: (1) a description of the PjBL-based e-module, (2) a comparison of critical thinking skill indicators between both classes along with descriptive statistics of posttest scores, and (3) inferential statistical analysis comprising normality, homogeneity, and hypothesis tests.

Description of the PjBL-Based E-Module

The e-module developed in this study is a digital instructional material structured around five PjBL phases: (1) the start of an essential question, (2) designing a plan for the project, (3) creating a schedule, (4) monitoring students and the progress of the project, and (5) evaluating the experience. The module integrated local wisdom as a real-world context for learning fluid dynamics, specifically the continuity equation and Bernoulli's principle. The material was presented through interactive content including videos, animations, and project-based activities, making abstract physics concepts more accessible and engaging for students. Expert validation confirmed that the module met the validity criteria in terms of content, presentation, language, and graphical design, with an average validity score classified as very valid. The e-module cover is presented in Figure 1.

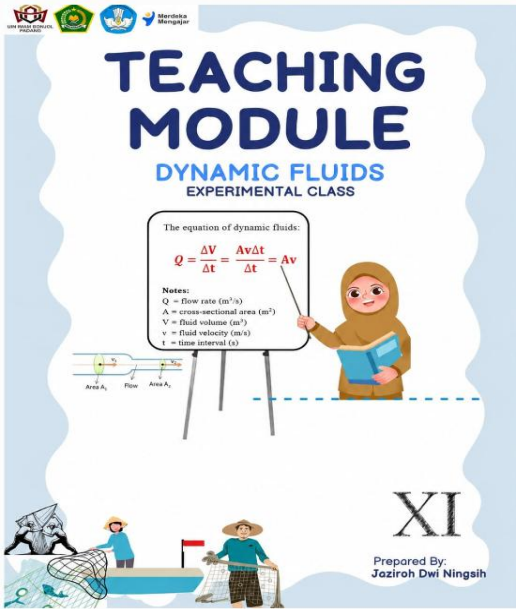

Figure 1. Cover of the PjBL-Based E-Module Integrated with *Maelo Pukek*

Implementation of PjBL in Both Classes

The results of PjBL implementation observations in both classes are presented in Table 1. Based on Table 1, the implementation of learning in both classes received an overall rating of "very good," indicating that PjBL was carried out effectively in both instructional settings. However, a notable difference was observed in the level of student activity: the experimental class achieved a student activity rate of 89.29%, compared to 82.14% in the control class, yielding a mean implementation score of 94.64% and 91.07%, respectively. This 7.15 percentage point gap in student activity suggests that the integration of a culturally contextual PjBL-based e-module was more effective in fostering active student engagement than the conventional PjBL worksheet-based approach. The higher student activity in the experimental class can be attributed to the interactive and multimedia-rich features of the e-module, which provided students with varied and stimulating learning experiences—including animations, videos, and project-based tasks embedded within the familiar cultural context of the local tradition. These elements are known to enhance intrinsic motivation and sustain student engagement throughout the learning process (Mayer, 2009; Mudatsir et al., 2022). In contrast, the control class, despite using the same PjBL phases, relied solely on printed worksheets, which offered limited interactivity and less contextual relevance, resulting in comparatively lower student participation. Both classes achieved full educator implementation scores (100%), confirming that any difference in student outcomes was attributable to the instructional materials rather than variations in teaching quality.

Overall, the observation data in Table 1 affirm that the PjBL-based e-module integrated with local wisdom provides a more conducive learning environment for stimulating active student participation, which is a critical prerequisite for the development of higher-order thinking skills such as critical thinking.

Table 1. Results of the PjBL Observation

Class	Educator (%)	Students (%)	Average (%)
Experiment	100%	89,29%	94,64%
Control	100%	82,14%	91,07%

Descriptive Statistics of Posttest Scores

Following the implementation of the learning intervention, a posttest was administered to both classes to measure students' critical thinking skills using an essay-based instrument structured around Ennis's (2011) five indicators. The posttest scores were then analyzed descriptively to compare the central tendency and score distribution between the experimental and control classes. This descriptive analysis serves as the foundation for understanding the magnitude of difference between the two groups prior to inferential testing. The results of the posttest descriptive analysis, including the mean, maximum, and minimum scores for each class, are presented in Table 2.

Table 2. Description of Posttest Scores

Class	N	Mean	Maximum Score	Minimum Score
Experiment	32	87,97	100	70
Control	30	72,58	85	60

According to Table 2, the experimental class achieved a notably higher mean score (M = 87.97) compared to the control class (M = 72.58), with a mean difference of 15.39 points. The score distribution in the experimental class was concentrated in the 81–100 range, whereas the control class was predominantly in the 61–80 range. The pass rate for the experimental class reached 93.75%, substantially exceeding the control class's rate of 63.3%. These differences in achievement are consistent with the higher active participation observed in the experimental class during PjBL implementation (Table 1). Further analysis of each critical thinking indicator revealed that the experimental class outperformed the control class across all five indicators measured by Ennis (2011) framework, as illustrated in Figure 2.

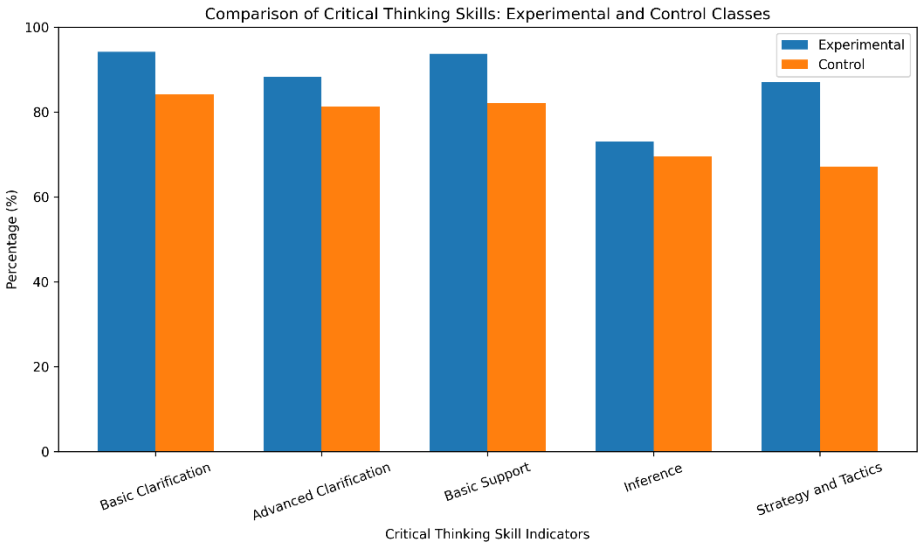

Figure 2. Comparison of Critical Thinking Skills by Indicator

Comparison of Critical Thinking Skill Indicators

Further analysis based on Figure 2 shows that the experimental class outperformed the control class across all five critical thinking indicators. In the basic clarification indicator, experimental class students demonstrated greater ability to accurately identify and understand problems, while in the advanced clarification indicator, they showed stronger capacity to analyze arguments and construct logical explanations. On the basic support

indicator, experimental class students were better able to present relevant evidence in addressing problems. The inference indicator yielded the lowest scores in both classes, suggesting that drawing evidence-based conclusions remains a general challenge that requires additional scaffolding. The most pronounced difference was observed in the strategy and tactics indicator, where experimental class students demonstrated markedly superior ability in planning and systematically executing problem-solving steps, reflecting the direct benefit of the structured PjBL phases embedded in the e-module.

Inferential Statistical Analysis

The normality test using the Shapiro–Wilk test confirmed that both class datasets were normally distributed ($p > 0.05$), and the Levene's test for homogeneity confirmed equal variances between the classes (Sig. = 0.413 > 0.05), satisfying the assumptions required for independent samples t-test. The independent samples t-test yielded $t(60) = 8.581$, $p = 0.000$ (< 0.05), indicating a statistically significant effect of the PjBL-based e-module on students' critical thinking skills. To quantify the practical significance, effect size was calculated using Cohen's d formula: $d = (M_1 - M_2) / SD_{poolea}$. The analysis yielded Cohen's $d = 1.7$, far exceeding the threshold of 0.80 and classified as a very large effect size according to Cohen (1988). This result confirms that the PjBL-based e-module integrated with local wisdom not only produced a statistically significant outcome but also exerted a practically substantial and educationally meaningful impact on students' critical thinking development.

Discussion

The research findings indicate that the implementation of an electronic module based on Project-Based Learning (PjBL) integrated with local wisdom is significantly more effective in developing students' critical thinking skills than conventional learning using the Independent Curriculum textbook. The experimental class achieved a mean score of 87.97, substantially higher than the control class mean of 72.58, with a mean difference of 15.39 points. Statistical analysis confirmed this significant difference ($t(60) = 8.581$, $p = 0.000$), and the effect size (Cohen's $d = 1.7$) indicates a very large practical significance (Cohen, 1988). This improvement can be attributed to the effective synergy among the PjBL learning model, the interactive e-module, and the contextual learning environment created through the integration of local wisdom. The structured project phases in the e-module guide students through higher-order cognitive processes, while the local wisdom context provides a relatable and meaningful anchor for abstract physics concepts in fluid dynamics.

This finding aligns with previous research results showing that PjBL is capable of enhancing student engagement and critical thinking skills (Matahari et al., 2023). However, this study shows higher achievement levels because it is supported by the integration of e-modules and local wisdom, which enhances the meaningfulness and relevance of learning. A bibliometric analysis by Fauziah Ulmi and Asrizal (2024) confirmed that PjBL integrated with STEM has consistently emerged as a trend for enhancing 21st-century skills in physics learning, further supporting the growing relevance of project-based approaches in physics education. Furthermore, the contextual embedding of local wisdom in the e-module provides students with culturally familiar anchor points, which deepens their engagement with abstract physics content and facilitates more meaningful knowledge construction. The superior performance of the experimental class therefore reflects not only the effectiveness of PjBL as a pedagogical model, but also the added value of culturally responsive instructional design in developing students' higher-order thinking skills (Matahari et al., 2023).

The PjBL model actively engages students in project-based activities that require analytical, evaluative, and problem-solving skills, thereby fostering critical thinking skills through hands-on learning experiences. The five structured phases of PjBL — beginning

with an essential question and culminating in project evaluation — guide students through progressively higher-order cognitive demands that promote deep learning rather than surface-level memorization. Meanwhile, e-modules facilitate the learning process by presenting content in a structured and interactive manner, making abstract concepts easier to grasp (Serevina, 2024; As'ari, 2023). The combination of project-based task design and multimedia-rich digital content within the e-module thus creates a learning environment that simultaneously stimulates cognitive engagement and supports autonomous knowledge construction.

The integration of local wisdom plays a pivotal role in maximizing the meaningfulness of learning through a contextual approach, enabling students to connect fluid dynamics concepts with real-world fishing practices familiar to their community. By anchoring abstract physics principles such as the continuity equation and Bernoulli's principle within this cultural context, students are able to perceive scientific knowledge as directly relevant to their lived experiences. This strengthens their analytical and reasoning skills (Yuliyus & Susilawati, 2021). Moreover, the need analysis study by Parhannes and Asrizal (2025) in JIPT similarly identified the importance of developing fluid dynamics digital teaching materials integrated with ethnoscience for promoting conceptual understanding, reinforcing the value of culturally embedded instructional design in physics education. Collectively, the PjBL model, digital e-module, and local wisdom create a synergistic learning environment that simultaneously supports cognitive engagement, contextual relevance, and student motivation.

The effectiveness of the PjBL-based e-module in this study can also be interpreted through the lens of self-determination theory (Ryan & Deci, 2008), which posits that learning motivation is maximized when students experience autonomy, competence, and relatedness. The e-module's project-based structure grants students a degree of autonomy in designing and executing their projects, while the culturally familiar context of local wisdom provides a sense of relatedness that connects abstract scientific principles to students' lived realities. This motivational dimension is particularly significant in physics learning, where students often perceive the content as abstract and disconnected from their daily experiences (Halpern, 2014). The higher pass rate in the experimental class (93.75% versus 63.3% in the control class) further reflects not only cognitive gains but also the affective and motivational benefits of contextually embedded, technology-enhanced instruction. Consistent with this interpretation, Mudatsir et al. (2022) demonstrated that combining project-based learning with local wisdom and digital platforms substantially enhances both student engagement and learning outcomes, reinforcing the motivational value of culturally responsive instructional designs.

From a broader pedagogical perspective, the findings of this study are consistent with the growing body of literature advocating for culturally responsive science teaching as a mechanism for improving educational equity and outcomes among students from diverse backgrounds. Gay (2010) argues that when instructional materials reflect students' cultural heritage and community practices, students are more likely to develop a positive academic identity and engage deeply with the subject matter. In the context of physics education, this principle is especially pertinent because students from regions with rich local traditions — such as West Sumatra, with its Minangkabau cultural heritage — may disengage from instruction that presents scientific knowledge as culturally neutral or Western-centric. By embedding this local tradition as a scientific learning context, this e-module affirms students' cultural identity while simultaneously cultivating disciplinary competence. Moreover, Hidayati et al. (2024) found that students demonstrate significantly stronger critical thinking skills when physics instruction is connected to phenomena they can observe and relate to in their environment, supporting the pedagogical rationale of local wisdom integration in this

study. The alignment between the results of the present study and this broader literature suggests that culturally responsive, technology-mediated instruction represents a viable and scalable approach for improving critical thinking skills across diverse physics classrooms in Indonesia.

It is also important to note the role of the e-module's multimedia components in supporting students' conceptual development. Mayer (2009) cognitive theory of multimedia learning suggests that combining visual representations (such as animations and diagrams) with verbal explanations reduces extraneous cognitive load and enhances the depth of understanding, particularly for complex scientific concepts. In the context of fluid dynamics — a topic known for its abstract and mathematically demanding nature — the animated simulations embedded in the e-module allowed students to visualize the behavior of fluids through pipes of varying cross-sections, making the continuity equation and Bernoulli's principle more tangible and comprehensible. Mayer (2009) similarly reported that interactive digital content significantly improved student comprehension and engagement in physics courses, underscoring the pedagogical value of multimedia-enriched e-modules. Furthermore, Kusyanti (2021) demonstrated that interactive digital modules with virtual laboratory elements are particularly effective for dynamic fluid topics, directly paralleling the design rationale and outcomes of the present study. These converging findings collectively affirm that the multimedia design of the PjBL-based e-module constitutes a critical factor in the instructional success observed in the experimental class, above and beyond the structural contribution of the PjBL model alone.

When examined by indicators, the highest achievement in the experimental class was observed in basic clarification and basic support, reflecting students' improved ability to identify problems and provide relevant evidence through project-based inquiry. Advanced clarification also demonstrated notable improvement, with students better able to analyze arguments and construct logical explanations grounded in physics principles. The inference indicator yielded the lowest scores in both classes, suggesting that drawing evidence-based conclusions requires more scaffolded practice and extended reflection time beyond what was possible within the study timeline. The strategy and tactics indicator showed the largest performance gap between classes, with experimental class students demonstrating superior ability in systematically planning and executing problem-solving steps, likely due to the structured project phases embedded in the e-module. These findings indicate that the integration of PjBL-based e-modules with local wisdom not only increases student engagement but also strengthens critical thinking skills more comprehensively than PjBL without local contextual integration.

CONCLUSION

This study reveals that the implementation of a PjBL-based e-module integrated with local wisdom significantly and meaningfully improves students' critical thinking skills compared to conventional learning, with a very large effect size of Cohen's $d = 1.7$ and a statistically significant difference ($t(60) = 8.581$, $p = 0.000$). The improvement was evident across all five critical thinking indicators measured by Ennis's framework, with the most notable gains observed in basic clarification, advanced clarification, and strategies and tactics. The effective synergy of PjBL, digital media, and contextual local wisdom enabled students to connect fluid dynamics concepts with real-world phenomena from their own cultural environment, thereby fostering deeper analytical and reasoning skills. The integration of local wisdom as a learning context not only made abstract physics concepts more meaningful but also enhanced student engagement and intrinsic motivation throughout the learning process. The inference indicator yielded the lowest scores in both classes, suggesting that

scaffolded support for drawing evidence-based conclusions should be strengthened in future instructional designs. The primary contribution of this research lies in demonstrating that the integration of pedagogical innovation, digital technology, and local cultural values into a single coherent instructional design produces a more effective and contextually relevant learning experience. Future studies are recommended to explore the long-term retention of critical thinking skills and to investigate the applicability of this integrated instructional model in diverse geographic and cultural contexts. These findings offer a strong empirical basis for physics educators to adopt locally contextualized, technology-enhanced, project-based approaches as an evidence-based alternative strategy for developing students' higher-order thinking skills in 21st-century education.

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