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ORIGINAL PAPER

Microlearning-Based Case Study: Innovative Strategies For Enhancing Students' Conceptual Understanding and Critical Thinking Skills in Physics Education

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Abstract
Physics learning in the digital era faces the challenges of cognitive overload and a decline in students' attention spans toward abstract and dense material. Innovative strategies are required to bridge the efficiency of material delivery with the depth of problem analysis. This study aims to examine the effectiveness of the Microlearning-Based Case Study strategy in improving students' conceptual understanding and critical thinking skills in physics. The research employed a quasi-experimental method with a non-equivalent control group design. The research sample consisted of 64 eleventh-grade students at SMA Negeri 51 Jakarta, selected through a purposive sampling technique. The research instruments included two-tier multiple-choice tests to measure conceptual understanding and essay tests for critical thinking skills, both of which were expert-validated. Data were analyzed using Normalized Gain (N-gain) and t-tests via jamovi software version 2.3. The results indicated that the developed learning media was categorized as highly feasible (96.25%). The implementation of this strategy significantly improved learning outcomes, with the experimental class achieving an N-gain score of 0.74 (High) for conceptual understanding and 0.71 (High) for critical thinking, significantly outperforming the control group ($p < .001$) with a very large effect size ($d > 1.5$). In conclusion and implications, the Microlearning-Based Case Study strategy is effective in mitigating cognitive load while sharpening scientific reasoning through real-case analysis. The researchers suggest that educators integrate digital micro-content with contextual scenarios to create more adaptive and meaningful physics learning.

Keywords:
Microlearning
Case Study
Critical Thinking Skills
Conceptual Understanding

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INTRODUCTION

Physics education at the secondary level still faces fundamental challenges, specifically the gap between the complexity of abstract concepts and students' cognitive capacity to process information (Bao & Koenig, 2019; Sharma, 2025; Anderman et al., 2012). The cognitive overload phenomenon, as explained in Cognitive Load Theory, indicates that information overload can hinder the encoding process in long-term memory, thereby impacting retention and conceptual understanding (Sweller, 2020; Sigolo & Casarin, 2024). Numerous studies confirm that physics instruction delivered densely and simultaneously tends to result in surface learning rather than deep learning (De Bézenac et al., 2019). This condition is exacerbated by the characteristics of the Gen Z-Alpha generation, who are

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more adaptive to short, visual, and interactive digital content (Duisenbekova, 2023; Neamtu et al., 2020), rendering conventional, linear, and lecture-oriented learning approaches increasingly less relevant.

In this context, the microlearning approach has begun to gain attention as an instructional strategy capable of accommodating students' limited attention spans (Rith et al., 2025; Garshasbi et al., 2021; Monib et al., 2024). Microlearning is defined as the presentation of material in small, focused, brief, and specific units designed to enhance information processing efficiency (Santi et al., 2024; Cronin & Durham, 2024). Microlearning is effective in increasing learning engagement and retention because it aligns with the segmentation principle in multimedia learning (Marlina, 2025; Boumalek et al., 2025). Furthermore, recent studies also indicate that digital-based microlearning can enhance learning flexibility and student autonomy (Munawarah, 2025; Karlina & Muali, 2025). Nevertheless, this approach is not without criticism. Some researchers argue that the fragmentation of material in microlearning potentially reduces students' ability to integrate concepts and analyze complex problems, making it less optimal for developing higher-order thinking skills (Monib et al., 2025; Hamdani et al., 2026; Taylor & Hung, 2022).

To address these limitations, the case study approach emerges as a relevant alternative in physics education. Case studies provide authentic contexts that allow students to connect theoretical concepts with real-world phenomena while simultaneously fostering analytical, evaluative, and reflective thinking processes (Wei et al., 2024; Joshi, 2026; Mahdi et al., 2020). Case-based learning has proven effective in enhancing critical thinking skills, as students are engaged in evidence-based decision-making processes (Dewi & Rahayu, 2023). This aligns with the Critical Thinking framework, which emphasizes the importance of interpretation, analysis, evaluation, and inference skills in resolving scientific problems (Hitchcock, 2017).

The integration of microlearning and case studies into an approach termed the Microlearning-Based Case Study offers an innovative solution to contemporary problems in physics education. This approach combines the cognitive efficiency benefits of microlearning with the analytical depth of case studies. Preliminary research indicates that merging bite-sized content-based learning strategies with real-world problem contexts can enhance both students' conceptual understanding and critical thinking skills (Robles et al., 2023; Kohnke et al., 2025). In its implementation, physics topics are packaged into structured micro-content and subsequently integrated with contextual case scenarios that demand active conceptual exploration.

Consequently, the Microlearning-Based Case Study strategy not only addresses the challenges of limited time and student attention span in the digital era but also has the potential to create a more meaningful and sustainable learning experience. This study is crucial to test the effectiveness of the approach in strengthening the understanding of physics concepts and simultaneously enhancing students' critical thinking skills. Furthermore, this study is expected to provide an empirical contribution to the development of innovative learning models that are adaptive to the dynamic characteristics of 21st-century learners.

METHODOLOGY

This study employs a quasi-experimental approach utilizing a non-equivalent control group design. However, prior to the experimental phase, a pre-experimental development stage was conducted to produce an instructionally viable Microlearning-Based Case Study module.

The development process involved an expert judgment stage, engaging media experts, physics content experts, and language experts. The media validation focused on visual readability, navigation ease, and micro-content aesthetics; the content validation focused on the accuracy of physics concepts and the relevance of the presented case studies; meanwhile, the language validation ensured communicative effectiveness and the appropriate use of scientific terminology. The experts' assessment results were analyzed using a validity index (such as Aiken's V or a feasibility percentage) to ensure the media met the "Highly Feasible" category prior to being field-tested on the research subjects.

Table 1. Non-Equivalent Control Group Design

Class	Pre-Test	Implementation	Post-Test
Experiment	Problem-solving ability & critical thinking skills test	Physics learning with microlearning-based case study	Problem-solving ability & critical thinking skills test
Control	Problem-solving ability & critical thinking skills test	Conventional physics learning (without microlearning-based case study)	Problem-solving ability & critical thinking skills test

The population of this study comprised all eleventh-grade students at SMA Negeri 51 Jakarta, from which samples were selected using a purposive sampling technique to determine the experimental class (Microlearning-Based Case Study strategy) and the control class (conventional learning). Data collection instruments included a conceptual understanding test in the form of two-tier multiple-choice questions and a critical thinking skills test consisting of structured essays. The instructional procedure in the experimental class followed an innovative syntax comprising three phases: (1) Micro-Engagement via short digital content, (2) collaborative Case Analysis, and (3) Deepening Synthesis for conceptual reinforcement.

All pre-test and post-test data were processed using jamovi statistical software version 2.3. The analysis initiated with prerequisite tests for normality (Shapiro-Wilk) and homogeneity (Levene's test). Subsequently, the effectiveness of the students' improvement was measured through the Normalized Gain (N-gain) calculation. To test the hypothesis regarding differences in effects between the groups, an independent-samples t-test was performed, accompanied by an Effect Size (Cohen's d) calculation. The utilization of jamovi ensured data transparency through accurate p-values and confidence intervals.

RESULTS & DISCUSSION

Results

The data on students' learning outcomes were analyzed using jamovi statistical software version 2.3 to examine the effectiveness of the instructional strategy on conceptual understanding and critical thinking skills. The analysis results, as presented in Table 4, indicate that the experimental class consistently achieved higher post-test scores and N-Gain values compared to the control class across both variables.

Regarding the conceptual understanding variable, the experimental class showed an increase from a pre-test average of 48.2 to a post-test average of 86.5, with an N-Gain of 0.74 (high category). In contrast, the control class only achieved an N-Gain of 0.45 (medium category). A similar trend was observed in critical thinking skills, where the experimental class score increased from 41.5 to 82.8, with an N-Gain of 0.71 (high), while the control class only reached 0.41 (medium). The independent samples t-test results revealed a significance value of $p < .001$, indicating a significant difference between the two groups. Furthermore, the effect size values (Cohen's d) of 1.62 and 1.75 demonstrate a very large effect, far exceeding the threshold for the large category ($d > 0.8$). This confirms that the implemented instructional strategy has a robust impact both practically and statistically. To clarify the difference in learning outcome improvement, the visual comparison of N-Gain between the experimental and control classes is illustrated in Figure 1.

Table 2. Statistics of Learning Outcomes in Concept Understanding and Critical Thinking

Variable	Class	N	Mean Pre-Test	Mean Post-Test	N-Gain	p-value	Effect Size (d)
Conceptual understanding	Experiment	32	8,2	6,5	0,74	< 0.001	0,62
	Control	32	9,0	2,1	0,45		
Critical Thinking	Experiment	32	1,5	2,8	0,71	< 0,001	0,75
	Control	32	2,8	6,4	0,41		

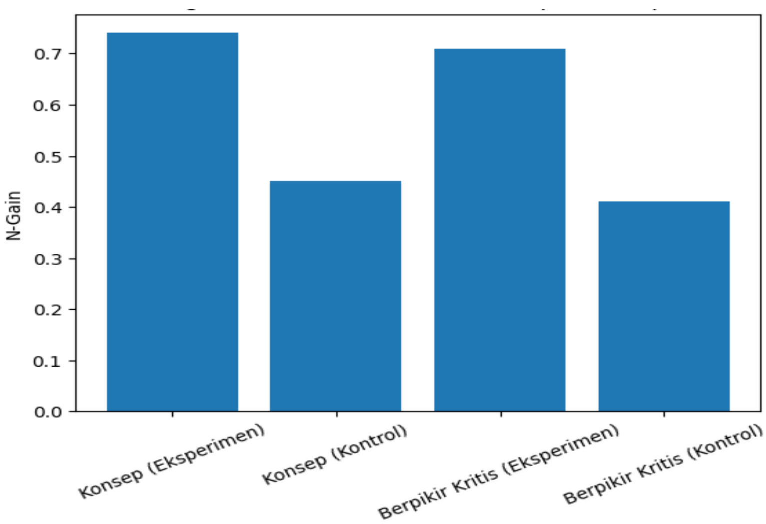

Figure 1. Comparison of N-Gain in Concept Understanding and Critical Thinking between the Experimental and Control Classes

Discussion

The results of this study provide strong empirical evidence that the Microlearning-Based Case Study strategy is effective in enhancing students' conceptual understanding and critical thinking skills in physics education (Abidin, 2025; Nurussaniah et al., 2025; Arimbawa et al., 2025). The success of this intervention is not viewed as an isolated phenomenon, but rather as the result of a synergy between a systematic media development process, rigorous instrument validation, and the application of modern pedagogical principles that are adaptive to students' cognitive characteristics in the digital era.

Fundamentally, the effectiveness of this strategy is rooted in an instructional design that applies microlearning principles through the presentation of bite-sized content. In physics education, which is frequently perceived as heavy and abstract, segmenting the material into small, specific units of information allows students to perform cognitive encoding gradually (Munfaridah et al., 2021; Opfermann et al., 2017). This prevents the cognitive overload phenomenon, as breaking down the material ensures that students' working memory capacity is not exceeded. Consequently, students' focused attention is maintained on a single physical concept in depth before moving to the next unit. This aligns with the Cognitive Theory of Multimedia Learning, which posits that such segmentation significantly enhances information retention and facilitates a more efficient transfer of knowledge into long-term memory (Mayer, 2024). As a result, students in the experimental class do not merely engage in rote learning; instead, they are able to construct conceptual schemata that are more stable and resilient, providing a crucial foundation for advancing to more complex analytical stages.

The strength of the cognitive structure formed through these micro-units is then optimized through the integration of the case study approach, which proved to be a determining factor in enhancing students' critical thinking skills. As indicated by the research data, the experimental class achieved a critical thinking post-test score of 82.8 with a very large effect size ($d = 1.75$). This achievement was made possible because the contextual cases presented served as "cognitive laboratories" that compelled students to transcend low-level cognitive phases. In this phase, students were required to deconstruct problems, evaluate the validity of physical data, and draw evidence-based conclusions. The validation by content experts (as outlined in Table 2 and Table 3) played a vital role in ensuring that each case scenario possessed precise conceptual depth and relevance to real-world phenomena. This directly stimulated authentic scientific reasoning, consistent with the proposition that case-based learning is effective in constructing Higher-Order Thinking Skills (HOTS) through real-world problem-solving (Martawijaya et al., 2023; Kwangmuang et al., 2021; Julia et al., 2025).

Beyond the media intervention aspect, the accuracy of these research findings is also methodologically supported by the use of two-tier multiple-choice test instruments. The significant difference between the experimental and control classes ($p < .001$) in Table 4 reflects the quality of the instruments in clearly capturing students' conceptual structures. Unlike conventional tests that are susceptible to guessing, this instrument demands consistency between the accuracy of the final answer and its underlying scientific reasoning (Gierl et al., 2017; Butler, 2018). With distractor designs validated to represent common physics misconceptions, researchers could specifically identify thinking errors in students. This reasoning-based assessment approach provides an objective indication that the superiority of the experimental class genuinely stems from deep understanding, rather than mere identification of correct answers.

Overall, these findings confirm that the combination of microlearning’s duration efficiency and the analytical depth of case studies is not only theoretically relevant but also empirically robust. The synergy between validated media and reliable instruments successfully addresses the challenges of 21st-century physics education by creating a learning experience that is more adaptive, meaningful, and capable of strengthening students' cognitive competencies amidst rapid information dynamics.

CONCLUSION

The implementation of the Microlearning-Based Case Study strategy in physics education has proven to significantly enhance students' conceptual understanding and critical thinking skills, supported by the quality of instructional media validated as highly feasible (96.25%) and highly valid test instruments. The superiority of the experimental class, marked by high N-gain achievements in conceptual understanding (0.74) and critical thinking (0.71), demonstrates that the synergy between bite-sized content and contextual case analysis successfully mitigates cognitive overload while stimulating deep scientific reasoning. This effectiveness is rooted in the strategy's ability to reinforce long-term memory retention through focused material segmentation, thereby enabling students to deconstruct problems and draw evidence-based conclusions adaptively. Consequently, this strategy serves as an innovative and highly relevant solution to address student attention challenges in the digital era and is recommended for broad implementation to strengthen 21st-century science competencies.

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