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Innovative science teaching materials based on case-based learning to improve critical thinking skills

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Abstract

The development of critical thinking skills among pre-service elementary teachers remains a persistent challenge, particularly given the limited availability of instructional materials that explicitly integrate higher-order thinking processes into science instruction. While case-based learning (CBL) has been widely recognized as an effective pedagogical approach, its systematic integration into structured teaching materials in elementary teacher education contexts remains underexplored, especially in local Indonesian settings. This study aims to develop and evaluate the feasibility and effectiveness of CBL-oriented science teaching materials designed for pre-service elementary teachers. This research employed a Research and Development (R&D) design based on the Borg and Gall model, involving multiple stages of product validation and field testing. The participants consisted of undergraduate students from a Primary School Teacher Education program. The effectiveness of the developed materials was examined using a quasi-experimental design with pretest–posttest control groups. Data were collected through expert validation instruments, response questionnaires, and a critical thinking skills test, and analyzed using descriptive statistics, independent-sample t-tests, and normalized gain (N-gain) scores. The findings indicate that the developed CBL-based teaching materials are highly feasible, as demonstrated by expert validation scores across language, content, instructional design, and practitioner assessments, all categorized as "excellent." Furthermore, the materials were effective in improving students' critical thinking skills, as evidenced by a statistically significant difference between the experimental and control groups ($p = 0.00 < .05$) and a moderate learning gain. This study contributes to the field by providing empirically validated, context-specific instructional materials that integrate case-based learning into science education for pre-service elementary teachers. The findings highlight the potential of structured CBL materials to enhance critical thinking and support the preparation of future teachers capable of implementing higher-order thinking-oriented instruction in elementary classrooms.

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1. Introduction

Critical thinking is widely acknowledged as an essential competence in 21st-century education, particularly for pre-service teachers. This skill involves the capacity to systematically analyze, evaluate, and synthesize information in a logical, objective, and reflective manner when making decisions (Jaenudin et al., 2020; Saadah et al., 2023; Zhang, 2017). In elementary teacher education programs, critical thinking is a fundamental skill (Dafit et al., 2024; Waite & Davis, 2006; Barif et al., 2026). Capability that supports students in mastering subject matter, encouraging creativity, and solving instructional problems independently and adaptively (Ardiansyah et al., 2025). Therefore, cultivating critical thinking skills is increasingly viewed as a priority, especially in science-related courses.

Critically minded students seek to explore new ideas in order to develop their inherent potential. The development of students' potential must be supported by critical thinking skills (Arndt et al., 2025; Sulaiman, 2018). Critical thinking is the ability to analyze and evaluate information, reasoning, and situations based on appropriate standards, to construct new knowledge Bailin et al., 1999; Sutoyo et al., 2023). Through critical thinking, students are trained to systematically analyze the problems they encounter, enabling them to resolve them effectively.

Critical thinking remains a major challenge for university students (Dwyer et al., 2014; Hall & Starzec, 2024; Sutoyo et al., 2023). On average, Indonesian university students demonstrate low levels of critical thinking skills (Fauzi et al., 2023; Jaenudin et al., 2020; Siwi et al., 2025; Utami et al., 2017). This low level of critical thinking is attributed to several factors, including limited learning conceptions among students (Abrami et al., 2008; Bellaera et al., 2021) and the absence of adequate instructional materials (Bezanilla et al., 2021; Brooke, 2006; Changwong et al., 2018).

Despite its significance, empirical evidence indicates that students' critical thinking skills in Indonesian Elementary Teacher Education Programs (PGSD) remain relatively low (Rahayu & Bandjarjani, 2021; Umam & Fauziah, 2022; Nawangsari et al., 2022). Initial observations of students enrolled in the Basic Science Concepts course at Nusa Cendana University showed that average achievement scores were below the expected standard, with most students scoring below 70. This condition is influenced by several factors, including teaching approaches that lack contextual relevance, limited opportunities for engaging with complex problem-solving tasks, and the absence of learning materials explicitly designed to foster critical thinking skills (Fauzi et al., 2023; Hodijah et al., 2022; Bellaera et al., 2021; Virijai et al., 2022).

This condition is further supported by the results of the preliminary test on students' critical thinking skills. The findings indicate that, across nine critical thinking indicators, each indicator scored below 51%. The average percentage score across the nine indicators was 46%, suggesting that students' critical thinking skills remain low and require further improvement.

Numerous studies have highlighted the effectiveness of case-based learning (CBL) in promoting active cognitive engagement and enhancing students' critical thinking abilities

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(Dharmayanthi, 2023). Engaging students in collaborative discussions and evidence-based reasoning Asih et al., 2022; Hysa et al., 2020). CBL exposes learners to authentic problems that require critical analysis, reflection, and solution development (Widiastuti et al., 2022). In elementary science education, this approach is considered particularly effective in stimulating higher-order thinking and linking scientific concepts to real-life contexts.

Learning can be effective when supported by adequate instructional materials and appropriate learning approaches. Case-Based Learning (CBL) is often implemented merely as a teaching strategy rather than being systematically integrated into instructional materials. A study by Puri (2022) demonstrates that Case-Based Learning enhances students' thinking skills, promotes a deeper understanding of problems, and leads to improved problem-solving outcomes. A Case-Based Learning approach seeks to address students' limited skills for solving real-life and global problems (Fauzi et al., 2023). Furthermore, Addy et al. (2018) reported positive perceptions of student performance and the development of critical thinking through the implementation of Case-Based Learning.

Case-Based learning is expected to enhance students' critical thinking skills in solving problems in the Basic Science Concepts for Elementary Education course. The effectiveness of Case-Based Learning in improving students' critical thinking skills will be applied through the development of innovative instructional materials. During the learning process, students are presented with authentic problems to solve, thereby fostering their critical thinking skills. This approach also represents an educational innovation that supports the university's independent learning policy. Case-Based learning has been shown to increase student engagement in the classroom and lead to higher academic achievement(Nuryanti, 2021). Additionally, Williams (2004) states that Case-Based Learning encourages and strengthens essential skills, including critical thinking, problem-solving, and professional decision-making, as well as oral and written communication.

Nevertheless, research focusing on the development of CBL-oriented science teaching materials specifically designed for elementary teacher education students remains limited, particularly within higher education institutions in Eastern Indonesia. There is a clear research gap concerning studies that systematically design, develop, and evaluate the feasibility and effectiveness of such instructional materials within a local educational context, especially those aligned with the Merdeka Belajar (Freedom to Learn) framework.

In response to these gaps, the present study seeks to develop science teaching materials oriented toward case-based learning and to examine their feasibility and effectiveness in enhancing the critical thinking skills of PGSD students at Nusa Cendana University. The findings are expected to contribute to the development of innovative and contextually relevant instructional strategies and to strengthen the pedagogical competence of pre-service elementary teachers, enabling them to become critical, reflective, and adaptive educators prepared to address future educational challenges.

2. Literature review

In the 21st century, the concept of critical thinking has become increasingly emphasized in education. Learning in higher education is expected to train students to think critically (Lavi & Marti, 2023). Education is no longer limited to the transfer of knowledge (Asih et al., 2022; Nora et al., 2023); it also aims to develop students' intellectual maturity so they can solve problems and think creatively (Abdurrahman et al., 2019). This critical thinking ability cannot be replaced by technology.

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Critical thinking has become an essential benchmark in science education (Davies, 2011; Utami et al., 2017). Critical thinking is widely recognized as one of the primary goals of science education(Reynders et al., 2020). Promoting science as a process of discovery involves many components that focus on critical thinking. There is a strong relationship and relevance between critical thinking and science education (Adeyemi, 2012).

The term "critical" refers to "involving or exercising skilled judgment or observation" (Abrami et al., 2008). In this sense, critical thinking means thinking clearly and intelligently. Students who are accustomed to thinking critically tend to explore information deeply and understand problems thoroughly, enabling them to solve problems effectively. Critical thinking includes analytical skills, evaluative judgment, extrapolation abilities, and related dispositions (such as caution, objectivity, and curiosity), which students develop during their studies (Rahayu & Bandjarjani, 2021). Critical thinking is defined as the process of analyzing and evaluating information and reasoning according to appropriate standards to construct sound and insightful new knowledge, understanding, hypotheses, and beliefs.

Critical thinking encompasses the ability to process and synthesize information, enabling individuals to apply it wisely in decision-making and effective problem-solving. (Changwong et al., 2018) describes critical thinking as reasonable and reflective thinking focused on deciding what to believe or do. The purpose of developing students' critical thinking is to enable them to think reflectively in analyzing and evaluating information (Agustina et al., 2022).

Case-based learning is a constructivist instructional approach that promotes active student participation and enables learners to construct new knowledge (Mahdi et al., 2020). Instruction using a case approach is commonly referred to as case-based learning (CBL). CBL represents a form of experiential learning, encompassing both conceptual understanding and embedded information within substantive content, as well as the learning processes that surround it (Asih et al., 2022). In this approach, learning involves case discussions in which instructors present cases for collective analysis, challenging students to defend their arguments and reasoning (Hysa et al., 2020). CBL requires discussion of real-life situations and encourages learners to position themselves within the case context to analyze and draw conclusions. Therefore, case-based learning fosters both problem-solving skills and rigorous thinking and reasoning.

Designing cases that are specifically solved through discussion and situational analysis to build understanding is a key characteristic of case-based learning(Brooke, 2006). Cases are intended to develop students' ability to solve problems by applying knowledge, concepts, and skills relevant to a particular course (Fauzi et al., 2023). Furthermore, cases provide contextualized learning experiences, encouraging students to construct their own understanding as they attempt to resolve the given problems.

3. Method

This study employed a Research and Development (R&D) approach based on the Borg and Gall (1983) model to develop and evaluate case-based learning (CBL)-oriented science teaching materials. The development process followed ten stages, including needs analysis, planning, product development, field testing at multiple levels, revision, and dissemination. This model was selected for its systematic structure, ensuring the development of instructional materials that are valid, practical, and effective in authentic educational contexts.

The participants were undergraduate students enrolled in the Elementary Teacher Education (PGSD) Program at Nusa Cendana University, Indonesia. The sample was distributed across three testing phases: a preliminary trial involving six third-semester students and one lecturer, a small-

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scale trial with 30 third-semester students, and a large-scale trial comprising 66 first-semester students from two classes. Random sampling techniques were applied to ensure representative data collection.

Research instruments included expert validation questionnaires, student and lecturer response questionnaires, and a critical thinking skills test. The validation instruments were completed by language experts, subject-matter experts, instructional design experts, and practitioners using a five-point Likert scale. The critical thinking test consisted of 45 multiple-choice items aligned with nine higher-order thinking indicators derived from established frameworks and covered five main topics in the Basic Science Concepts course.

Content validity was evaluated by ten experts using Aiken's V coefficient, with all items exceeding the acceptable threshold of 0.70 (Aiken, 1985). Reliability analysis using Cronbach's alpha yielded a coefficient of 0.9726, indicating excellent internal consistency. Validation activities were conducted through a Focus Group Discussion (FGD) held on August 30, 2024.

Data were collected through expert validation, pretests and posttests administered to students, and response questionnaires completed by students and lecturers following the implementation of the teaching materials. Data collection was conducted in three phases—preliminary, small-scale, and large-scale field testing—during September 2024 as part of the regular academic schedule.

Data analysis involved both descriptive and inferential statistics. Descriptive analysis was used to assess the feasibility and practicality of the teaching materials based on validation and response data. Inferential analysis examined the effectiveness of the materials in improving students' critical thinking skills through assumption testing (Kolmogorov–Smirnov, Shapiro–Wilk, and Levene's tests), paired-sample t-tests, and independent-sample t-tests. Normalized gain (N-gain) scores were calculated to determine the magnitude of improvement. All analyses were performed using SPSS version 23.

4. Results

The initial stage focused on identifying the need for developing science instructional materials. Data obtained through classroom observations, interviews, and document analysis of the Basic Science Concepts course in the PGSD program at Nusa Cendana University revealed several topics that students found difficult to master, including measurement, matter and its transformations, motion and simple machines, vibrations and waves, energy and heat, and basic electricity. Existing learning resources were found to be insufficient, as they lacked contextualized case examples and did not effectively support independent learning or the development of critical thinking skills. Furthermore, preliminary critical thinking assessments showed that students failed to meet expected standards across nine key indicators, with an average achievement score of only 46%. These findings highlight the urgent need for instructional materials grounded in pedagogical approaches that explicitly promote critical thinking.

Based on the results of the needs analysis, a prototype of science teaching materials was developed using a case-based learning (CBL) framework. The materials were designed in an A5 book format and focused on elementary-level physics topics presented through authentic, real-world cases. Each chapter comprised two case studies, guided group discussion worksheets, conceptual explanations, independent learning tasks, and critical thinking assessments. Content development drew on credible scientific references, including science encyclopedias and introductory physics textbooks. Particular attention was given to readability, visual presentation, and contextual relevance to students' everyday experiences.

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The instructional materials underwent expert validation involving three language experts, three subject-matter experts, two instructional design specialists, and two teaching practitioners. The validation results indicated a high level of suitability for classroom implementation. The average validation scores were 82.7% from language experts, 84.2% from content experts, 84.0% from instructional design experts, and 86.4% from practitioners; all scores were classified as "outstanding." Validators provided constructive feedback, recommending improvements such as refining motivational language, enriching content—particularly on wave-related topics—aligning materials with local contexts, ensuring consistency in image labeling, and incorporating higher-order action verbs in learning objectives.

A limited pilot study was conducted with six students and one lecturer of the Basic Science Concepts course. Observations indicated that the materials offered comprehensive coverage, relevant and accurate case presentations, and visually engaging layouts. Nonetheless, several issues were identified, including incomplete example problems and ambiguous illustrations. The lecturer also noted that the logical organization of content supported student comprehension. Based on this feedback, revisions were made to replace unclear visuals, enhance case representations, refine assessment items, and improve overall visual design.

The small-scale field trial involved 30 third-semester students from Class C. Following three instructional sessions using the developed materials, students completed a critical thinking skills test. Results of normality and homogeneity tests confirmed that the pretest and posttest data met the required statistical assumptions. A paired-samples t-test revealed a p-value of 0.000, indicating a statistically significant improvement in students' critical thinking skills after the intervention.

The operational field-testing phase involved two first-semester classes: an experimental group that used CBL-oriented teaching materials and a control group that received conventional instruction. Statistical analyses confirmed that posttest scores were normally distributed and homogeneous across groups. An independent-samples t-test yielded a p-value of 0.000, indicating a significant difference in critical thinking performance between the two groups. Students in the experimental group achieved a higher mean posttest score, indicating the superior effectiveness of the developed instructional materials. These findings reinforce the conclusion that instructional materials developed using a case-based learning (CBL) approach are effective in improving students' critical thinking skills, consistent with previous studies.

5. Discussion

The preliminary stage describes the learning context of the Basic Science Concepts course in the Elementary Teacher Education (PGSD) Program at Nusa Cendana University, which is implemented under the Merdeka Belajar–Kampus Merdeka (MBKM) curriculum. As part of the national higher education framework, this course is compulsory for pre-service elementary teachers (Laili et al., 2025; Supriyoko et al., 2022).

Classroom observations and interviews indicated that many students perceive the course as challenging, particularly due to the abstract nature and computational demands of physics-related topics. This finding is consistent with Pino et al.'s (2023) assertion that science learning requires experimentation and observation, processes that involve complex cognitive demands and may pose difficulties for undergraduate learners. Specifically, students experienced difficulties in topics such as measurement, matter and its transformations, motion and simple machines, energy and heat, and basic electricity.

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Instructional resources for the course were largely limited to online materials and presentation slides, with no systematically developed teaching materials prepared by lecturers. Previous studies emphasize that well-designed instructional materials are essential for supporting independent learning and aligning content with learners' needs (Parmin et al., 2025). Moreover, student engagement plays a critical role in learning success, as negative perceptions of course difficulty may reduce motivation and critical thinking engagement (Ayşegül Kozak-Çakır, 2020).

The preliminary investigation also revealed a lack of instructional materials explicitly designed to foster critical thinking. Case-based learning (CBL) has been widely recognized as an effective approach for enhancing critical thinking skills (Reed & Brunson, 2018). However, CBL-oriented teaching materials had not yet been developed for the Basic Science Concepts course at Nusa Cendana University. Although lectures and group discussions were commonly employed, they did not involve structured case analysis or brainstorming activities, which are core components of CBL and have been shown to positively influence cognitive skills (Doğan & Batdı, 2021).

Initial assessments further confirmed this issue, showing that students' critical thinking performance was below expectations, with all nine indicators scoring under 51% and an overall average of 46%. These results fall short of the multidimensional framework of critical thinking in higher education proposed by Davies (2011). Given the central role of critical thinking in science education (Bailin et al., 1999), both lecturers and students expressed the need for comprehensive, accessible, and contextually relevant instructional materials. Consequently, the development of CBL-based science teaching materials was deemed necessary.

The development stage focused on designing and producing CBL-oriented science teaching materials for the Basic Science Concepts course, following the Borg and Gall development model. This process aimed to ensure alignment with curriculum objectives and instructional quality standards (Addy et al., 2018)

During the planning phase, research instruments were prepared, including expert validation forms (covering content, language, and visual design), student and lecturer response questionnaires, and a critical thinking test. Instrument validity was examined using Aiken's V, with all questionnaire items meeting the minimum validity threshold of 0.70. The critical thinking test, comprising 45 items across 9 indicators, was also validated and demonstrated excellent reliability (Cronbach's alpha = 0.9726).

The developed teaching materials addressed key physics topics—measurement, changes in matter, motion, energy, and electricity—and followed a structured instructional format consisting of an introduction, core content, and conclusion (Ferazona et al., 2023; Guslinda et al., 2025). The core content included learning objectives, sub-course learning outcomes, contextual case studies, group discussions, summaries, individual assignments, and critical thinking assessments. This structure aligns with the principles of CBL, which emphasize problem-solving through authentic cases and collaborative learning (Williams, 2004).

Expert validation was conducted through a Focus Group Discussion (FGD) involving ten validators on August 30, 2024. Validation results indicated high levels of feasibility across all expert groups—language (82.7%), content (85.2%), instructional design (84.0%), and practitioners (86.4%)—all categorized as "outstanding". Based on these results, the materials were considered valid and suitable for implementation(Cheng et al., 2025).

A limited pilot study found that both students and lecturers found the materials engaging, particularly through the use of real-life cases, visual elements, and structured discussions. Feedback from this phase led to refinements in illustrations, case clarity, and visual layout.

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Subsequently, a small-scale field trial involving 30 third-semester students employed a one-group pretest–posttest design. Statistical analysis revealed a significant improvement in critical thinking skills ($p < 0.05$), supporting the effectiveness of the developed materials, consistent with previous findings (Puri, 2022). Practicality was further confirmed through response questionnaires, in which students and lecturers rated the materials as highly practical and user-friendly.

The testing stage evaluated the effectiveness of the CBL-based teaching materials using a pretest–posttest control-group design with 66 first-semester PGSD students. Assumption testing confirmed normality and homogeneity, allowing an independent-samples t-test. Initial balance testing indicated no significant difference between the control and experimental groups prior to the intervention ($p > 0.05$), suggesting comparable baseline critical thinking skills. Posttest results, however, demonstrated a significant difference in favor of the experimental group ($p < 0.05$), indicating the positive impact of the CBL-based materials. These findings are consistent with previous studies highlighting the effectiveness of CBL in fostering critical thinking(Reed & Brunson, 2018).

Further analysis using normalized gain (N-gain) scores yielded a value of 0.645, indicating moderate improvement. This result confirms that the developed CBL-oriented instructional materials effectively enhanced students' critical thinking skills, supporting earlier research findings (Hall & Starzec, 2024) .

6. Conclusion and implications

Based on the findings of this study and the accompanying discussion on the development of case-based learning (CBL)-oriented science teaching materials, several conclusions can be drawn. First, the developed CBL-based science instructional materials were found to be suitable for implementation in the Basic Science Concepts course for PGSD students. This conclusion is supported by expert validation results, with feasibility scores obtained from language experts (82.7%), subject-matter experts (85.2%), instructional design experts (84.0%), and teaching practitioners (86.4%), all of which were classified within the "outstanding" category. Second, the CBL-based instructional materials demonstrated effectiveness in enhancing students' critical thinking skills. The independent-samples t-test showed a p-value of 0.000 (< 0.05), indicating a statistically significant difference in critical thinking performance between the experimental and control groups. Indicates that students in the experimental group experienced greater improvement in critical thinking skills compared to those in the control group.

7. Limitation

Despite the promising findings, this study has several limitations that should be acknowledged. First, the study was conducted within a single institution, involving pre-service elementary teachers from one university in Indonesia. This limits the generalizability of the findings to broader educational contexts with different institutional characteristics, student backgrounds, or curriculum structures.

Second, the quasi-experimental design employed intact classroom groups rather than random assignment of participants. Although initial equivalence between groups was examined, the absence of full randomization may introduce potential bias related to pre-existing differences in students' prior knowledge, motivation, or learning experiences.

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Finally, although the study demonstrates the effectiveness of CBL-based teaching materials, it does not isolate which specific components of the materials (e.g., case design, discussion format, or scaffolding structure) contributed most significantly to the observed improvements. Future research is therefore needed to examine these components in greater detail.

Given these limitations, future studies are recommended to involve larger, more diverse samples, employ fully randomized experimental designs, extend the duration of implementation, and incorporate more comprehensive assessment methods, such as performance-based tasks and qualitative analysis, to provide a deeper understanding of how case-based learning supports the development of critical thinking.

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