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Cognitive Conflict and Critical Thinking Skills in Science Education: A Systematic Literature Review

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Abstract

ABSTRACT
Critical thinking is an essential competency in science education because it enables students to analyze information, evaluate evidence, draw inferences, and make reasoned decisions. Cognitive conflict—arising when students' prior conceptions encounter information or phenomena inconsistent with their existing understanding—may provide opportunities to reconsider explanations and examine evidence. This review examines (1) how cognitive conflict strategies have been designed and implemented to support critical thinking in science education, (2) how critical thinking has been operationalized and assessed, and (3) opportunities and challenges associated with integrating Generative Artificial Intelligence (GenAI) and adaptive learning. The study uses a Systematic Literature Review (SLR) with narrative synthesis. Sixteen articles were mapped for the period October 10, 2016–October 10, 2026. The mapped literature includes studies on cognitive conflict in physics education, instructional media development, critical thinking assessment, conceptual change, and GenAI use. The preliminary synthesis indicates that cognitive conflict has been integrated into inquiry learning, discovery learning, interactive multimedia, e-books, augmented reality, and educational websites. However, only a small subset of the mapped studies directly measured critical thinking, while others focused on conceptual understanding, misconception remediation, scientific literacy, creativity, or product development. The GenAI literature provides contextual insights into personalization and the risk of reduced cognitive engagement, but does not establish the effectiveness of integrating GenAI with cognitive conflict in physics education. The review identifies a need to align cognitive conflict activities with measurable critical thinking indicators and to evaluate GenAI as a scaffold.

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INTRODUCTION

Critical thinking is an essential ability to be developed through science education. Science learning aims not only to help students master scientific concepts and principles but also to equip them to evaluate information, assess evidence, identify cause-and-effect relationships, construct explanations, and make reasoned decisions. These abilities are necessary when individuals encounter conflicting information, assess the validity of claims, or make decisions based on available evidence. In science education, the emphasis on reasoning and evidence is important because scientific explanations need to be evaluated rather than accepted solely on authority or familiarity (García-Carmona, 2025).

In science education, critical thinking should be distinguished from conceptual knowledge. Students who can correctly explain a phenomenon may not necessarily be able to evaluate the

quality of the evidence supporting their explanations. Similarly, solving problems by applying familiar procedures does not necessarily demonstrate the ability to identify assumptions, consider alternative explanations, or evaluate an argument. Developing critical thinking therefore requires learning experiences that explicitly engage students in analysis, evaluation, inference, and decision-making.

García-Carmona (2025) emphasizes that scientific thinking and critical thinking are distinct but interrelated intellectual processes. Scientific thinking concerns the development and testing of scientific explanations, whereas critical thinking involves evaluating information, reasoning, and evidence. These processes can support one another, but they should not be treated as identical constructs. Improvements in conceptual understanding or the ability to explain scientific phenomena do not automatically demonstrate improvements in critical thinking.

One approach used to help students reconsider their understanding is cognitive conflict. Cognitive conflict may arise when new information, experimental results, or observed phenomena contradict students' initial conceptions. Such discrepancies may encourage students to question previously accepted explanations and consider alternatives. The conceptual-change literature identifies cognitive conflict as a commonly used instructional strategy, often elicited through anomalous data or contradictory information; however, its effectiveness depends on whether learners recognize and meaningfully engage with the conflict (Limón, 2001).

In physics education, cognitive conflict is particularly relevant because some scientific concepts do not align with everyday intuition. Students may hold intuitive explanations of motion, force, pressure, or electrical phenomena that differ from scientific explanations. If these conceptions are not examined through evidence and reasoning, students may retain them even after receiving formal explanations.

Cognitive conflict has been incorporated into various instructional models. Mufit et al. (2018) described a cognitive conflict-based learning model comprising four stages: activating prior conceptions, presenting cognitive conflict, discovering concepts or equations, and reflection. Similar approaches have been explored in misconception remediation and conceptual understanding. A recent meta-analysis of 218 primary studies involving 18,051 students reported a positive overall effect of conceptual-change strategies on science achievement; the cognitive-conflict subset also showed a positive mean effect, although substantial heterogeneity across studies remained (Paçacı et al., 2024). Subsequent developments have integrated cognitive conflict with digital media, including e-books, smartphone-based interactive multimedia, augmented reality (AR), and physics learning websites.

However, success in facilitating conceptual change does not necessarily mean that cognitive conflict directly improves critical thinking. Limón (2001) noted that meaningful cognitive conflict can be affected by prior knowledge, motivational and epistemological factors, cognitive engagement, reasoning strategies, and social context. Students may evaluate evidence and revise their explanations, but they may also become confused, reject evidence, or accept a new explanation without understanding the underlying reasoning. Cognitive conflict therefore needs to be connected to explicit reasoning activities if its contribution to critical thinking is to be examined. This distinction is also consistent with the broader evidence base: Paçacı et al. (2024) found positive effects on science achievement but reported substantial heterogeneity, so these results should not be interpreted as direct evidence of improved critical thinking.

Verawati et al. (2019) provide relevant empirical evidence by integrating cognitive conflict strategies into inquiry-based learning and assessing pre-service physics teachers' critical thinking through an essay test. Mufit et al. (2023) also reported critical thinking outcomes in a study of smartphone-based interactive multimedia integrated with a cognitive conflict model. These studies indicate that the relationship between cognitive conflict and critical thinking has been examined empirically, although the number and diversity of studies directly measuring critical thinking remain important to establish.

Research on cognitive conflict also shows variation in instructional models, media, subject matter, and assessment instruments. Kera and Ozdemir (2026), through an analysis of 229

implementations of cognitive conflict strategies in physics education, examined variation in strategy use, tools, topics, and misconceptions addressed. Such variation highlights the importance of identifying instructional design characteristics and examining how they relate to measured outcomes.

Digital technologies create further opportunities. Interactive media can help students observe phenomena and compare predictions with results. GenAI may generate learning cases, pose follow-up questions, and provide feedback tailored to student responses. In cognitive conflict-based learning, these capabilities could be used to generate cases related to students' initial conceptions and provide graduated hints.

Nevertheless, GenAI also presents challenges. AI systems may generate inaccurate information or explanations inconsistent with physics concepts. Excessive reliance on AI may reduce students' engagement in independently analyzing problems and constructing explanations. Lee et al. (2025) examined GenAI use and critical thinking engagement among knowledge workers, while Roy and Jony (2026) explored university students' experiences of cognitive offloading when using GenAI. These studies provide contextual perspectives but do not directly investigate GenAI in cognitive conflict-based physics education.

The need to distinguish learning outcomes is particularly important when evaluating instructional interventions. A study may demonstrate conceptual change, improved science achievement, or the validity of a learning resource without directly demonstrating an improvement in critical thinking. Accordingly, this review classifies evidence according to whether critical thinking is measured directly, treated as a design objective, or discussed only in relation to associated outcomes.

A synthesis is therefore needed to integrate research on cognitive conflict, critical thinking, assessment, and instructional media while distinguishing studies that directly measure critical thinking from those measuring related outcomes. This distinction helps ensure that conclusions do not exceed the available evidence.

This review aims to analyze how cognitive conflict strategies have been designed and implemented to support critical thinking in science education, identify how critical thinking has been operationalized and assessed in cognitive conflict-based science learning and examine the outcomes reported, and identify opportunities, challenges, and research gaps concerning the integration of cognitive conflict with generative artificial intelligence (GenAI) and adaptive learning.

To achieve these aims, the review is guided by three interrelated research questions. First, how have cognitive conflict strategies been designed and implemented to support critical thinking skills in science education during the review period? Second, how have critical thinking skills been operationalized and assessed in cognitive conflict-based science learning, and what outcomes have been reported? Third, what opportunities, challenges, and research gaps emerge from the potential integration of cognitive conflict with GenAI and adaptive learning to support students' critical thinking skills?.

METHOD

This study employed a Systematic Literature Review (SLR) using narrative synthesis. This approach was selected to integrate findings from studies that vary in research design, context, interventions, measurement instruments, and reported outcomes. Narrative synthesis enables comparison without assuming that all studies investigate identical constructs or use the same methods. It is relevant because the mapped literature includes experimental studies, educational product development, needs analyses, conceptual studies, and research on digital technologies.

A meta-analysis was not conducted because the mapped articles differ in objectives, methods, instruments, and outcome measures, and not all directly measure critical thinking. Findings were categorized thematically in accordance with the review's three aims: examining how cognitive conflict strategies have been designed and implemented in science education; identifying how critical thinking has been operationalized, assessed, and reported in cognitive conflict-based learning; and considering opportunities, challenges, and research gaps related to integrating cognitive conflict with GenAI and adaptive learning. The findings are presented through narrative descriptions and comparative tables.

The working corpus comprises 16 articles mapped through previous literature collection and searching. Initial records indicate that 10 articles were obtained from Scopus and three from Google Scholar; three additional articles were subsequently added. The review period was set from October 10, 2016, to October 10, 2026.

Complete records of individual search dates, final search strings, database-specific retrieval totals, and duplicate-checking outcomes were not available in the documentation used to prepare this draft. Therefore, the 16 articles are treated as a mapped working corpus, not as a finalized set of studies that have completed all eligibility procedures. The search strategy must be documented before submission by recording database names, search dates, search strings, retrieval totals, and duplicate handling.

These criteria must be applied in light of each article's contribution. Studies that directly measure critical thinking provide the primary evidence for understanding how this skill has been assessed and what outcomes have been reported. Studies of conceptual understanding, misconceptions, creativity, or scientific literacy can inform the analysis of cognitive conflict implementation but are not treated as direct evidence of critical-thinking improvement. GenAI studies conducted outside science education may inform the discussion of opportunities, challenges, and research gaps when their contextual contribution is explicit, but they remain distinct from direct evidence of effectiveness in physics education.

The intended selection procedure comprises identification of records, checking for duplicates, screening titles and abstracts, assessing potentially relevant full texts against the eligibility criteria, and recording inclusion decisions with reasons. Articles that do not directly measure critical thinking need not be excluded if they contribute to understanding instructional design and implementation or the potential role of digital and adaptive technologies; however, their contribution to the synthesis must be stated explicitly.

Sixteen articles have been mapped and categorized in this draft. The final number of eligible studies cannot yet be reported because complete records of full-text selection decisions are unavailable.

Data were organized using an article analysis matrix covering authors and year, research objectives, design and methods, participants or context, instructional strategy or intervention, assessment instruments and indicators, principal findings, limitations where available, relevance to the review's aims, and evidence category.

Three evidence categories were distinguished: (1) direct evidence, consisting of studies explicitly measuring critical thinking or examining instruments designed to measure it; (2) supporting evidence, consisting of studies of cognitive conflict implementation, conceptual change, misconceptions, instructional media, or related cognitive processes without directly measuring critical thinking as the main outcome; and (3) contextual evidence, consisting of theoretical or technology-related studies that do not directly test cognitive conflict interventions in science education.

The narrative synthesis was organized around the review's three aims. First, studies were grouped according to instructional stages, conflict-elicitation strategies, experiments, and digital media to examine how cognitive conflict strategies have been designed and implemented. Second, the analysis focused on critical-thinking indicators, instruments, evaluation designs, and reported outcomes, while distinguishing conceptual understanding, misconceptions, creativity, and scientific literacy from direct critical-thinking outcomes. Third, the analysis considered

digital technologies, potential personalization through GenAI, risks of cognitive offloading, and research gaps concerning the integration of cognitive conflict with GenAI and adaptive learning.

The synthesis distinguishes findings reported by the original authors from interpretations developed in this review. Quantitative values, sample sizes, instruments, and research designs should be retained only after verification against the original publications. Product validity, practicality, and user perceptions are distinguished from intervention effectiveness, as are conceptual understanding and critical thinking outcomes. Because the full search and selection records remain incomplete, the current synthesis is preliminary.

Table 1. Inclusion and exclusion criteria

Criterion	Inclusion	Exclusion
Publication period	Articles dated October 10, 2016–October 10, 2026	Articles outside the review period
Research field	Science or physics education, or relevant contextual studies contributing to the research questions	Articles with no identifiable contribution to the research questions
Cognitive conflict	Studies discussing, implementing, developing, or analyzing cognitive conflict	Studies unrelated to cognitive conflict and irrelevant to RQ3
Critical thinking	Studies measuring, developing, discussing, or providing a conceptual foundation for critical thinking	Studies with no relevant information about the review constructs
Study type	Empirical studies, development studies, needs analyses, conceptual studies, or relevant contextual studies	Publications with insufficient information for synthesis
Information availability	Objectives, methods or approach, and main findings can be extracted	Insufficient information to assess relevance

RESULTS AND DISCUSSION

Results:

The 16 mapped articles vary in objectives, methods, and outcomes. They include studies of cognitive conflict in physics education, instructional media development, critical thinking assessment, conceptual analyses, and GenAI use. Several focus on conceptual understanding or misconception remediation; others directly examine critical thinking or develop tools intended to support it.

Table 2. Evidence categories in the mapped working corpus

Evidence category	Articles	Number
Direct evidence of critical thinking in cognitive conflict-based learning	Verawati et al. (2019); Mufit et al. (2023), smartphone-based interactive multimedia	2
Instructional or assessment development explicitly oriented toward critical thinking	Mufit et al. (2026), physics learning website; Admas et al. (2025)	2
Cognitive conflict implementation, conceptual change, or related outcomes	Dhanil and Mufit (2025); Kera and Ozdemir (2026); Akmam et al. (2023); Mufit et al. (2018); Akmam et al. (2022); Gunawan et al. (2021); Mufit et al. (2022), e-book; Mufit et al. (2023), misconception remediation	8
Conceptual foundation of critical thinking in science education	García-Carmona (2025)	1
Contextual GenAI and critical thinking studies outside cognitive conflict-based science education	Liu et al. (2025); Roy and Jony (2026); Lee et al. (2025)	3
Total working corpus		16

This classification shows that directly measured critical thinking outcomes are less common than studies addressing conceptual change, product development, or technology use. The categories describe each article's contribution, not equivalent evidence strength, and do not represent a finalized full-text selection count.

Mufit et al. (2018) described a cognitive conflict-based learning model with four stages: activating prior conceptions, presenting conflict, discovering concepts or equations, and reflection. A similar sequence was discussed by Mufit et al. (2023) in relation to misconception remediation. These stages position conflict as part of a learning process intended to support changes in understanding.

Kera and Ozdemir (2026) reported variation across implementations in strategy selection, instructional tools, topics, and the misconceptions addressed. Cognitive conflict therefore does not represent a single uniform procedure.

Digital media form another implementation pattern. Mufit et al. (2022) developed an e-book integrating real-experiment video analysis for kinematics. Mufit et al. (2023) integrated cognitive conflict with smartphone-based interactive multimedia. Dhanil and Mufit (2025) examined augmented reality in dynamic-fluid learning, while Mufit et al. (2026) developed a physics learning website integrating cognitive conflict, AR, and STEM.

These examples show that cognitive conflict has been implemented in face-to-face and technology-supported settings. Nevertheless, the use of a particular medium or model does not itself establish an improvement in critical thinking; that claim requires outcome measures aligned with the construct.

Verawati et al. (2019) used an essay test adapted from the Ennis–Weir Critical Thinking Essay Test. The indicators were analysis, inference, evaluation, and decision-making, measured before and after instruction. Admas et al. (2025) developed an electronic assessment framework based on cognitive-conflict phenomena. Its indicators included basic clarification, bases for a decision, inference, advanced clarification, and supposition and integration. The study reported expert validation and collected physics teachers' perceptions and senior high school students' perspectives.

These frameworks use different indicators, underscoring the need to align construct definitions, indicators, and instrument characteristics when comparing studies. García-Carmona (2025) provides a conceptual basis for distinguishing scientific thinking from critical thinking. Mufit et al. (2026) explicitly positioned critical thinking as a design objective for a physics learning website, but development and validation should not be confused with demonstrated effectiveness in improving students' skills.

Table 3. Comparison of studies reporting direct critical-thinking outcomes

Aspect	Verawati et al. (2019)	Mufit et al. (2023), smartphone multimedia
Context	Pre-service physics teachers	Senior high school students
Participants	18	56
Design	One-group pretest–posttest	Experimental and control groups
Intervention	Cognitive conflict in inquiry-based learning	Smartphone-based interactive multimedia integrated with cognitive conflict
Measurement	Essay test	Critical thinking observation score
Reported result	Mean −1 to 9.89; N-gain 0.44	Experimental: 45.2 to 88.1; N-gain 0.78. Control: 44.05 to 60.7; N-gain 0.30
Interpretive limitation	No control group	Instrument and implementation details require consideration

Two mapped studies provided direct empirical information about critical thinking outcomes in cognitive conflict-based learning. Verawati et al. (2019) studied 18 pre-service physics teachers using a one-group pretest–posttest design. Cognitive conflict strategies were

integrated with inquiry-based learning on fluid mechanics. The reported mean score increased from −1 at pretest to 9.89 at posttest, with an N-gain of 0.44, categorized as moderate. Because there was no control group, the study cannot isolate the contribution of cognitive conflict from inquiry-based learning or other factors.

Mufit et al. (2023) studied 56 senior high school students, with 28 students each in the experimental and control groups. The experimental group's critical thinking observation score increased from 45.2 to 88.1 (N-gain = 0.78), while the control group's score increased from 44.05 to 60.7 (N-gain = 0.30). The authors reported a statistically significant between-group difference. Interpretation should nevertheless consider the measurement instrument, implementation details, and participant characteristics.

The values should not be compared as equivalent effect-size estimates because the studies differ in context, instruments, participants, and design. Taken together, they provide promising but limited evidence rather than proof that all cognitive conflict approaches improve critical thinking.

Discussion:

Several studies focused on outcomes related to, but distinct from, critical thinking. Mufit et al. (2018) examined conceptual understanding. Mufit et al. (2022) developed an e-book with real-experiment video analysis for kinematics and reported effects on conceptual understanding. Mufit et al. (2023) examined cognitive conflict-based learning for misconception remediation.

Dhanil and Mufit (2025) focused on scientific literacy in dynamic fluids using AR and cognitive conflict. Akmam et al. (2023) examined creative thinking processes and metacognition in a generative learning model based on cognitive conflict, while Akmam et al. (2022) conducted a needs analysis for a model oriented toward creative thinking in computational physics. Gunawan et al. (2021) investigated discovery-learning materials with a cognitive conflict approach, focusing on conceptual mastery.

Kera and Ozdemir (2026) mapped variations in implementation rather than directly measuring critical thinking. These studies show that cognitive conflict is used for diverse objectives, but conceptual understanding, misconception remediation, creativity, metacognition, scientific literacy, and critical thinking are distinct constructs. Results on one outcome cannot automatically be interpreted as evidence of improvement in another.

Three mapped studies provide contextual perspectives on GenAI and critical thinking but do not directly test GenAI integrated with cognitive conflict in physics education. Liu et al. (2025) examined GenAI and critical thinking in physical education; Roy and Jony (2026) explored university students' experiences of cognitive offloading; and Lee et al. (2025) examined critical thinking engagement among knowledge workers using GenAI.

These studies help frame potential relationships among AI use, cognitive effort, trust in AI systems, and user engagement. However, their contexts differ from cognitive conflict-based physics education and cannot establish the effectiveness of GenAI for students in this setting.

In adaptive learning, GenAI could potentially generate cases tailored to students' learning needs, ask follow-up questions, and provide graduated hints. For example, in kinematics, a system might ask students to predict an object's motion. If a response reflects reasoning inconsistent with physics concepts, the system could prompt students to examine relationships among position, velocity, and time. Further hints could be adjusted to the student's explanation. In this design, AI would support reasoning rather than immediately provide the final answer.

This proposal requires direct empirical testing. Research should assess the scientific accuracy of AI-generated cases, the quality of cognitive conflict scenarios, the relevance of feedback, and changes in critical thinking. The potential integration of GenAI should therefore be presented as a research direction, not as an established effectiveness claim.

The synthesis identifies five gaps. First, many mapped studies focus on conceptual understanding and misconception remediation, while direct evidence about critical thinking is limited in the working corpus. Second, not all studies connect cognitive conflict stages to measurable critical thinking indicators, making it difficult to explain the processes linking instruction to outcomes. Third, variations in indicators and instruments require stronger conceptual justification for meaningful comparison. Fourth, digital media and assessment frameworks need appropriate effectiveness testing; validity and practicality do not substitute for outcome evaluation. Fifth, sufficient direct evidence was not identified for the effectiveness of integrating GenAI with cognitive conflict in physics education.

Future research could develop and evaluate a GenAI-based adaptive learning platform that integrates cognitive conflict with critical thinking activities. Each instructional stage should be linked to measurable indicators; AI-generated cases should be checked for scientific accuracy; and feedback should encourage independent evaluation of evidence and reasoning. Evaluation should extend beyond validity and practicality to pre–post measures of critical thinking, comparison groups where feasible, and analyses of students' reasoning during platform interactions.

The contribution of future research should therefore be not only the production of new educational technology but also an evidence-based explanation of how that technology supports the reasoning processes targeted by instruction.

CONCLUSION

This review examined the implementation of cognitive conflict to support critical thinking, the operationalization and assessment of these skills, and opportunities for integrating GenAI and adaptive learning. Across the 16 mapped articles, cognitive conflict was used in different science learning models, particularly in physics education, and integrated with AR, interactive multimedia, e-books, and educational websites. Many studies focused on conceptual understanding and misconception remediation.

Direct evidence of critical thinking improvement was identified in only a subset of the mapped literature. Verawati et al. (2019) reported improvement among pre-service physics teachers following inquiry-based learning with cognitive conflict, while Mufit et al. (2023) reported gains in a smartphone-based interactive multimedia intervention. These findings are relevant but must be interpreted in light of research designs, assessment instruments, and intervention characteristics.

The review underscores the need to distinguish conceptual change from critical thinking. Improved conceptual understanding or reduced misconceptions does not automatically demonstrate greater ability to evaluate evidence, construct arguments, or make reasoned decisions. Instructional activities, reasoning processes, and assessment indicators should be explicitly aligned.

The GenAI literature offers contextual perspectives on personalized learning and the risk of reduced cognitive engagement. However, the mapped corpus does not provide sufficient direct evidence that integrating GenAI with cognitive conflict has been shown to improve critical thinking in physics education. Future research should test adaptive systems that use GenAI to present scientifically accurate conflict scenarios, deliver graduated feedback, and support independent reasoning.

These conclusions are provisional because full-text eligibility decisions and data extraction have not been finalized. The synthesis should be updated after the selection process and bibliographic verification are complete.

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AUTHOR CONTRIBUTION STATEMENT

RP was responsible for conceptualization, research design, methodology, data collection, data analysis, interpretation of results, writing the original draft, and reviewing and editing the manuscript. FCW provided supervision, validation, scientific consultation, and critical review of the manuscript. All authors have read and approved the final version of the manuscript.

AI DISCLOSURE STATEMENT

AI-based tools, including ChatGPT, were used to assist with language editing, manuscript organization, and drafting support. The author is responsible for reviewing and editing the manuscript and for verifying the accuracy, originality, citations, and references. This statement should be revised to reflect the actual tools used and the author's review before submission.

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