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PRISMA's Guided Review of Critical Thinking Development in Physics Education Across Educational Levels and Topics

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Abstract: *Critical thinking is an essential competency in 21st-century physics education. However, comprehensive evidence regarding instructional models, assessment approaches, educational levels, physics topics, and recent research trends remains limited. This study aimed to synthesize recent research on the development of critical thinking in physics education through a systematic literature review. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. A search of the Scopus database identified 118 records published between 2017 and 2024. After the identification, screening, and eligibility stages, 64 articles met the initial criteria, while 12 studies satisfied all inclusion criteria and were analyzed using qualitative content analysis. The findings indicate that Project-Based Learning (PBL) was the most frequently implemented instructional model, appearing in 3 of the 12 reviewed studies (25%). Problem solving was the most commonly assessed critical thinking indicator, and authentic assessment methods were increasingly adopted. Research was concentrated at the senior high school and higher education levels and predominantly focused on General Physics. This review provides a multidimensional synthesis of instructional models, assessment practices, educational contexts, physics topics, and research trends. The findings offer evidence-based guidance for physics educators, curriculum developers, and researchers while highlighting future research opportunities involving artificial intelligence (AI), local wisdom, and underexplored educational contexts and physics topics.*

Keywords: *Critical Thinking, Physics Education, Project-Based Learning*

Abstrak: Kemampuan berpikir kritis merupakan kompetensi esensial dalam pembelajaran fisika abad ke-21. Namun, sintesis komprehensif mengenai model pembelajaran, indikator, instrumen penilaian, jenjang pendidikan, topik fisika, dan tren penelitian masih terbatas. Penelitian ini bertujuan menganalisis perkembangan penelitian tentang kemampuan berpikir kritis dalam pembelajaran fisika melalui systematic literature review. Kajian ini menggunakan pedoman Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Penelusuran pada basis data Scopus mengidentifikasi 118 artikel yang diterbitkan selama 2017–2024. Setelah melalui tahap identifikasi, penyaringan, dan penilaian kelayakan, 64 artikel memenuhi kriteria awal, sedangkan 12 artikel memenuhi seluruh kriteria inklusi dan dianalisis menggunakan analisis isi. Hasil menunjukkan bahwa Project-Based Learning (PjBL) merupakan model pembelajaran yang paling dominan, digunakan pada 3 dari 12 penelitian (25%). Problem solving menjadi indikator kemampuan berpikir kritis yang paling banyak digunakan, sedangkan asesmen autentik semakin banyak diterapkan. Penelitian didominasi pada jenjang sekolah menengah atas dan perguruan tinggi serta lebih banyak mengkaji topik General Physics. Kajian ini memberikan kontribusi berupa sintesis multidimensional mengenai model pembelajaran, asesmen, jenjang pendidikan, topik fisika, dan tren penelitian. Temuan ini dapat menjadi acuan bagi guru, peneliti, dan pengembang kurikulum dalam mengembangkan pembelajaran fisika yang berorientasi pada kemampuan berpikir kritis serta menjadi dasar penelitian lanjutan mengenai integrasi Artificial Intelligence (AI), local wisdom, dan topik fisika yang masih kurang dieksplorasi.

Kata Kunci: Berpikir Kritis, Pembelajaran Fisika, Project-Based Learning

INTRODUCTION

The rapid advancement of science, technology, and digital communication has transformed the competencies required for learners in the twenty-first century. Contemporary education no longer emphasizes the acquisition of factual knowledge alone but also requires students to develop higher-order thinking skills that enable them to analyze information critically, solve complex problems, evaluate evidence, and make informed decisions. Consequently, critical thinking has become one of the core competencies promoted in international educational frameworks as an essential skill for preparing learners to address increasingly complex scientific and societal challenges (Bailin, 2002; Ennis, 2011; Pirinen et al., 2023). In physics education, this competency is particularly important because learning physics requires students to interpret natural phenomena, analyze experimental data, evaluate scientific arguments, and construct evidence-based explanations. Therefore, developing students' critical thinking has become one of the primary objectives of contemporary physics instruction (Rihs et al., 2022).

Despite its recognized importance, numerous empirical studies indicate that students' critical thinking skills in physics remain below the expected level. Several studies report that students experience difficulties in interpreting scientific information, analyzing physical phenomena, and constructing logical arguments during problem-solving activities (Hidayati et al., 2022; Fadly et al., 2025). These shortcomings are often associated with teacher-centered instructional practices that continue to emphasize memorization rather than conceptual understanding and scientific reasoning (Asniar et al., 2022; Lubis et al., 2022). Furthermore, the increasing demand for twenty-first-century competencies has encouraged researchers to investigate various innovative instructional approaches including Project-Based Learning (PjBL), Problem-Based Learning (PBL), inquiry learning, STEM integration, virtual laboratories, and digital learning environments to enhance students' critical thinking skills in physics (Khoiri et al., 2023; Membrillo-Hernández & Martínez-Ortiz, 2025). As the number of empirical studies has expanded substantially, synthesizing these findings has become increasingly important for identifying effective instructional practices and guiding future research.

Several systematic reviews have attempted to summarize research on critical thinking in physics education. Ubaidillah et al. (2023) synthesized studies published between 2011 and 2021 and primarily examined five dimensions of critical thinking in physics learning. Their review successfully established a conceptual understanding of critical thinking; however, it provided limited discussion regarding the instructional models used to foster critical thinking, the indicators employed for assessment, the distribution of studies across educational levels, and the specific physics topics investigated. More recently, Tugirin et al. (2025) reviewed studies published between 2015 and 2025 using the PRISMA framework and summarized learning models, assessment instruments, educational levels, and physics topics related to critical thinking. Nevertheless, the review primarily described the characteristics of the included studies without providing a comprehensive synthesis of research trends, identifying remaining research gaps, or critically comparing findings across different instructional contexts. Moreover, neither review specifically focuses on recent developments following the rapid growth of technology-enhanced learning environments and digital pedagogies that have significantly influenced physics education during the last decade.

These limitations indicate the need for a more focused and up-to-date systematic review. Rather than merely cataloguing instructional approaches, the present study integrates multiple

analytical dimensions to provide a more comprehensive understanding of critical thinking development in physics education. Specifically, this review synthesizes evidence regarding (1) instructional models used to promote critical thinking, (2) critical thinking indicators and assessment instruments, (3) educational levels in which these studies have been conducted, (4) physics topics most frequently investigated, and (5) emerging research trends that may inform future instructional practices and research agendas. By integrating these dimensions within a single review, this study provides a broader perspective than previous reviews and identifies areas that remain insufficiently explored.

The review focuses on studies published between 2017 and 2024 for several reasons. First, this period represents the widespread implementation of twenty-first-century learning frameworks that place critical thinking at the center of curriculum development and classroom practice (Pirinen et al., 2023). Second, research published during this period reflects substantial advances in student-centered pedagogies, including project-based learning, inquiry-based learning, STEM integration, blended learning, virtual laboratories, and other technology-supported instructional innovations that have become increasingly prominent in physics education (Rihs et al., 2022; Rahmayani et al., 2024). Third, educational transformations accelerated by the COVID-19 pandemic significantly changed teaching and assessment practices, resulting in a rapid increase in studies investigating critical thinking within digital and hybrid learning environments. Consequently, restricting the review to this period enables the synthesis to capture the most recent developments while minimizing overlap with previous systematic reviews.

Based on these considerations, this study aims to systematically synthesize recent evidence on the use of interactive AI-based learning media in primary education, with particular emphasis on its contribution to students' learning interest, reading literacy, scientific literacy, digital literacy, and cognitive, motor, and behavioral skills. The review also examines the implementation of AI in science learning, its potential to enhance learning outcomes compared with traditional instructional approaches, and the contextual factors that influence its effectiveness, including teacher competence, parental involvement, digital infrastructure, and learning environments. Using a systematic literature review approach, this study synthesizes relevant empirical evidence to identify patterns, contributions, challenges, and emerging trends in the integration of AI into primary education. The findings are expected to provide evidence-based insights for researchers, teachers, and educational policymakers regarding the effective implementation of AI-based interactive learning media and to inform the development of innovative, adaptive, and contextually appropriate learning practices in primary education.

METHOD

This study employed a Systematic Literature Review (SLR) following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines and was adapted from the review framework proposed by Ubaidillah et al. (2023). The review consisted of four sequential stages: (1) identification of relevant studies, (2) screening based on predefined inclusion and exclusion criteria, (3) eligibility assessment through full-text evaluation, and (4) qualitative synthesis of the selected studies. The complete study selection process is presented in Figure 1.

The literature search was conducted using the Scopus database to identify studies published between 2017 and 2024. The search strategy employed combinations of the keywords "critical thinking," "critical thinking skills," "physics," and "physics education." The review included only

English-language journal articles and conference proceedings indexed in Scopus. To ensure methodological consistency and the comparability of findings, only empirical studies employing experimental or quasi-experimental research designs that explicitly investigated the development or assessment of critical thinking skills in physics education were included. Review papers, book chapters, editorials, opinion papers, and studies unrelated to physics education or critical thinking were excluded.

The initial search identified 118 records. During the screening stage, 95 records were excluded because they did not satisfy the predefined inclusion criteria, comprising 56 studies that were not experimental or quasi-experimental research and 39 studies that did not focus on critical thinking. Consequently, 23 full-text articles were assessed for eligibility. Following the full-text review, 11 articles were excluded because they did not provide explicit information on physics learning content or did not fully satisfy the eligibility criteria established for this review. As a result, 12 studies were included in the qualitative synthesis. The selected studies were analyzed using a content analysis approach based on five analytical dimensions: (1) instructional models used to develop critical thinking skills, (2) critical thinking indicators and assessment instruments, (3) educational levels, (4) physics topics investigated, and (5) emerging research trends and implications for future studies in physics education.

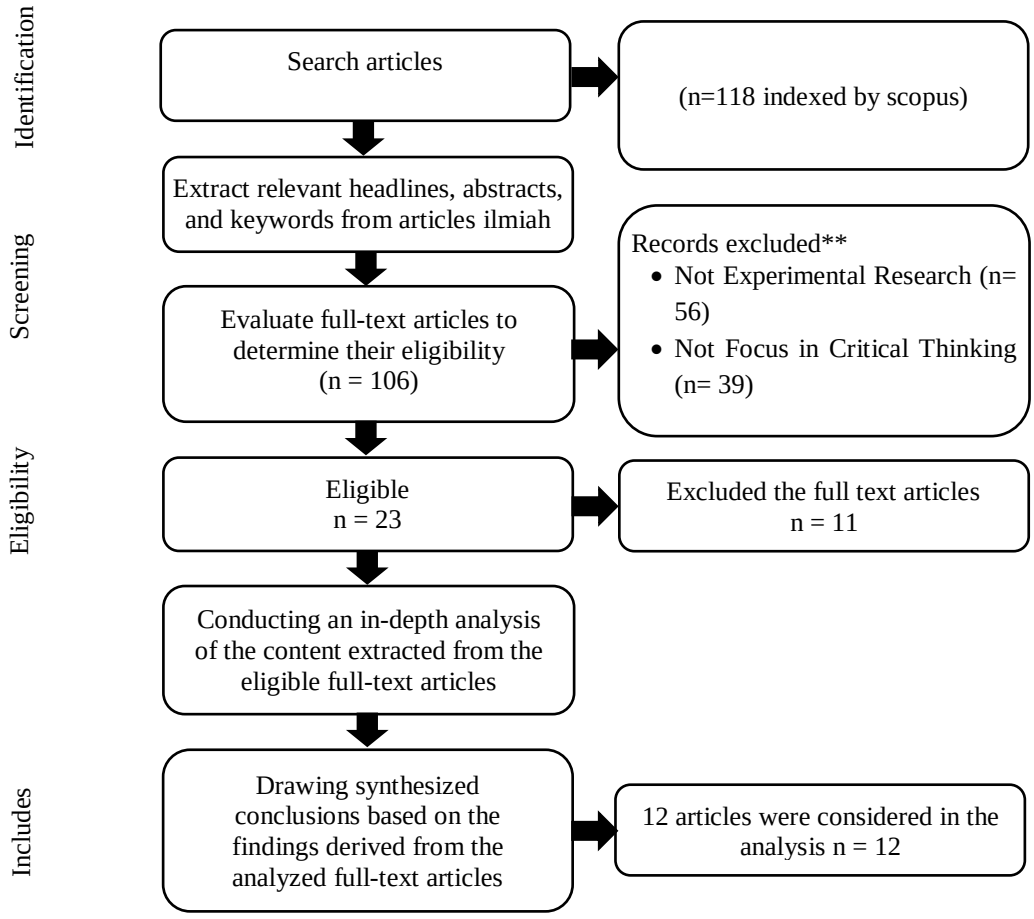

Figure 1. Research procedure

RESULTS AND DISCUSSION

The systematic review identified five primary analytical dimensions that address the research questions formulated in this study: (1) the instructional models used to foster critical thinking, (2) the critical thinking indicators and assessment instruments employed, (3) the educational levels in which the studies were conducted, (4) the physics topics investigated, and (5) the emerging research trends and future directions in critical thinking research within physics education. Each dimension is discussed in the following sections.

What instructional models have been implemented to develop students' critical thinking skills in physics education?

The reviewed studies employed a wide range of instructional models to develop students' critical thinking skills in physics education. As presented in Table 1, nine instructional approaches were identified across the twelve selected studies. Project-Based Learning (PBL) emerged as the most frequently implemented model, appearing in three studies (Oyewo et al., 2022; Mutakinati et al., 2018; Marcinauskas et al., 2024). Two studies implemented instructional interventions without explicitly identifying the underlying pedagogical model (Tiruneh et al., 2018; Iwuanyanwu, 2023), whereas the remaining studies each adopted a distinct instructional approach. Table 1 summarizes the distribution of instructional models identified in the reviewed studies.

Table 1. Learning Models That Facilitate The Development Of Critical Thinking Skills

No	Author	Model of Teaching	Frequency
1.	Oyewo et al., 2022; Mutakinati et al., 2018; Marcinauskas et al., 2024	Project Based Learning	3
2.	Danday, 2021	Microteaching Lesson Study	1
3.	Danday & Monterola, 2019	Multi-Representation	1
4.	Tiruneh et al., 2017	Test Development	1
5.	RizkiVerawati et al., 2020	Inquiry + Development	1
6.	Danday Sriyansyah & Azhari, 2017	Normalized Change	1
7.	Asriz Kiliç & Şen, 2014	Outdoor School Activity	1
8.	Saregar et al., 2018	SSCS + Scaffolding	1
9.	Tiruneh et al., 2018; Iwuanyanwu, 2023	Unknown	2

Although no single instructional model overwhelmingly dominated the reviewed literature, the distribution presented in Table 1 reveals a clear tendency toward student-centered learning approaches. Most instructional models require students to actively construct knowledge through problem-solving, investigation, experimentation, discussion, and reflection rather than relying on direct knowledge transmission. This finding indicates that recent research in physics education increasingly views critical thinking as a competency that develops through active engagement in scientific practices instead of passive acquisition of conceptual knowledge.

While Table 1 provides an overview of the instructional models identified in the reviewed

studies, understanding how these approaches foster critical thinking requires a deeper conceptual analysis. Therefore, the instructional models were further synthesized according to the critical thinking dimensions they target and the assessment strategies employed, as presented in Table 2.

Table 2. Conceptual synthesis of instructional models, targeted critical thinking skills, and assessment approaches in physics education

No	Classification	Key CT Skills Targeted	Assessment of CT
1.	Project-Based Learning (PBL)	Problem-solving, Analysis, Evaluation, Synthesis	Rubrics (e.g., CRITICAL) project portfolios
2.	Microteaching Lesson Study	Metacognition, Explanation, Self-regulation	Reflection journals, peer feedback, video analysis
3.	Multi-Representation	Interpretation, Logical reasoning, Flexibility	Multi-representation tasks, concept mapping
4.	Test Development	Inference, Evaluation, Clarity	Pre/post-tests with CTspecific items
5.	Inquiry + Development	Questioning, Hypothesistesting, Evidence evaluation	Lab reports, experimental design tasks
6.	Normalized Change	Measuring CT growth	Normalized gain (g) = (post-pre)/(100-pre)
7.	Outdoor School Activity	Observation, Systems thinking, Data interpretation	Field notebooks, phenomenological explanations
8.	SSCS + Scaffolding	Problem-framing, Creativity, Justification	SSCS portfolios, peer evaluation

The conceptual synthesis presented in Table 2 demonstrates that, despite differences in instructional procedures, the reviewed models share several common pedagogical characteristics. Most approaches emphasize authentic problem-solving, scientific inquiry, evidence evaluation, collaborative learning, and reflective thinking. These learning experiences require students not only to understand physics concepts but also to formulate hypotheses, interpret scientific evidence, evaluate alternative explanations, and communicate reasoned conclusions. Consequently, the reviewed studies suggest that the development of critical thinking depends less on the specific label of an instructional model than on the extent to which learning activities engage students in higher-order cognitive processes.

Among the reviewed instructional approaches, Project-Based Learning (PBL) provides one of the most comprehensive learning environments for developing critical thinking skills. Across the reviewed studies, students were required to identify authentic problems, design investigations, analyze experimental data, evaluate alternative solutions, and communicate evidence-based conclusions. These activities directly support essential dimensions of critical thinking, including analysis, inference, evaluation, explanation, and synthesis. Similar cognitive processes were also observed in Inquiry with Development and SSCS with Scaffolding, which encourage students to formulate hypotheses, conduct investigations, and justify scientific reasoning using empirical

evidence. Likewise, the Multi-Representation approach develops interpretative reasoning by requiring students to connect verbal, graphical, mathematical, and symbolic representations of physics concepts. Although these instructional models differ in classroom implementation, they converge in promoting active knowledge construction through inquiry and scientific reasoning.

The synthesis also reveals that each instructional model emphasizes different dimensions of critical thinking. Project-Based Learning primarily develops problem-solving, analysis, evaluation, and synthesis, whereas Microteaching Lesson Study focuses on metacognitive reflection and self-regulation. Inquiry-based learning places greater emphasis on questioning, hypothesis testing, and evidence evaluation, while Outdoor School Activities strengthen observation, systems thinking, and contextual interpretation. These differences indicate that no single instructional model addresses all dimensions of critical thinking equally. Instead, each pedagogical approach contributes to the development of specific cognitive competencies, suggesting that educators should select instructional models according to the critical thinking outcomes expected within particular physics topics and learning contexts.

Another important finding concerns the diversity of assessment approaches employed to evaluate critical thinking. Rather than relying exclusively on conventional written examinations, the reviewed studies incorporated authentic assessment methods, including project portfolios, laboratory reports, concept maps, reflective journals, peer assessment, field notebooks, and performance rubrics. This diversity reflects the multidimensional nature of critical thinking, which extends beyond factual recall to include scientific reasoning, problem-solving, argumentation, and reflective judgment. Therefore, authentic assessment should be considered an integral component of instructional models intended to develop critical thinking because it enables educators to evaluate both students' reasoning processes and the quality of their scientific understanding.

Overall, the reviewed studies demonstrate a consistent shift toward student-centered and inquiry-oriented pedagogies in physics education. Rather than identifying a single superior instructional model, the evidence suggests that successful development of critical thinking is primarily determined by shared pedagogical characteristics, including authentic problem-solving, inquiry-based investigation, collaborative knowledge construction, reflective reasoning, and the use of authentic assessment. These findings imply that future instructional design should emphasize these underlying pedagogical principles rather than focusing exclusively on adopting a particular instructional model. Furthermore, future research should examine how these instructional characteristics interact with different physics topics and educational levels to optimize the development of students' critical thinking skills.

What critical thinking indicators and assessment instruments are most frequently used in physics education?

The reviewed studies employed a variety of indicators and assessment instruments to evaluate students' critical thinking skills in physics education. Although the operationalization of critical thinking differed across studies, several recurring dimensions were identified, reflecting both shared theoretical foundations and differences in instructional objectives. Table 3 summarizes the critical thinking indicators adopted by the reviewed studies together with their frequency of occurrence.

Table 3. Aspects of indicators and types of critical thinking skill instruments

No	Reference	Indicator of Critical Thinking	Frequency

1.	Danday, 2021; Mutakinati et al., 2018; Marcinauskas et al., 2024; Kiliç & Şen, 2014	Problem Solving	4
2.	Oyewo et al., 2022; Tiruneh dkk., 2018	Analysis, Evaluation	2
3.	Tiruneh et al., 2017; Saregar et al., 2018	Analysis, Interference	2
3.	Verawati et al., 2020; Iwuanyanwu, 2023	Critical Reflection	2
4.	Danday & Monterola, 2019	Multimodal Representation	1
5.	Sriyansyah & Azhari, 2017	Evaluation	1

As shown in Table 3, problem-solving emerged as the most frequently employed indicator, appearing in four studies (Danday, 2021; Mutakinati et al., 2018; Marcinauskas et al., 2024; Kiliç & Şen, 2014). Other commonly adopted dimensions included analysis, evaluation, inference, and critical reflection, whereas multimodal representation appeared in only one study. Although the terminology varied among researchers, the reviewed studies consistently emphasized higher-order cognitive processes that require students to analyze information, evaluate evidence, justify conclusions, and solve complex scientific problems. This pattern suggests a broad consensus that critical thinking in physics education extends beyond factual knowledge toward scientific reasoning and evidence-based decision-making.

A deeper examination of the reviewed studies reveals that the identified indicators can be grouped into three complementary dimensions of critical thinking. The first dimension comprises analytical reasoning, represented by indicators such as analysis, evaluation, and inference, which focus on students' ability to interpret evidence, identify relationships among concepts, and formulate logical conclusions. The second dimension involves problem-solving and scientific inquiry, emphasizing the application of conceptual knowledge to authentic physics problems through investigation and evidence-based reasoning. The third dimension consists of reflective thinking, including critical reflection and metacognitive regulation, which encourage students to monitor, evaluate, and refine their own reasoning processes during learning. This synthesis demonstrates that the reviewed literature conceptualizes critical thinking as a multidimensional construct rather than as a single cognitive ability.

Despite these differences in emphasis, the reviewed studies exhibit considerable conceptual convergence. Studies employing analysis, evaluation, and inference primarily assess students' scientific reasoning and argumentation, whereas those emphasizing critical reflection focus on metacognitive awareness and self-regulation. Meanwhile, the multimodal representation approach proposed by Danday and Monterola (2019) extends conventional conceptualizations of critical thinking by assessing students' ability to construct and communicate scientific understanding through multiple representational forms, including verbal, graphical, mathematical, and symbolic representations. This finding suggests that recent research has begun to recognize communication and representation as integral components of critical thinking in physics learning.

The findings also indicate that the assessment of critical thinking increasingly relies on authentic and performance-oriented instruments rather than conventional achievement tests alone.

Across the reviewed studies, researchers employed essay tests, performance tasks, project-based assessments, laboratory reports, reflective journals, concept mapping, and structured rubrics to capture students' reasoning processes. Such diversity reflects the complexity of critical thinking, which cannot be adequately measured through factual recall or multiple-choice tests alone. Instead, authentic assessment provides richer evidence of students' abilities to analyze information, construct arguments, evaluate evidence, and justify scientific decisions within meaningful learning contexts.

Overall, the reviewed literature demonstrates a clear shift from viewing critical thinking as a single measurable outcome toward understanding it as a multidimensional competency encompassing analytical reasoning, scientific problem-solving, and reflective judgment. Although problem-solving emerged as the most frequently assessed indicator, the evidence suggests that comprehensive evaluation of critical thinking requires integrating multiple cognitive dimensions and authentic assessment strategies. Future studies should therefore develop more standardized yet multidimensional assessment frameworks capable of capturing the complexity of critical thinking across different physics topics and educational levels.

How are studies on critical thinking in physics education distributed across different educational levels?

The reviewed studies investigated critical thinking in physics education across several educational levels, ranging from junior high school to higher education. As summarized in Table 4, the reviewed literature is predominantly concentrated at the higher education and senior high school levels, with five studies conducted at each level. In contrast, only one study focused on junior high school students, while one study did not explicitly report the participants' educational level.

Table 4. Classification of the reviewed studies based on educational level

No	Level	Frequency
1.	Higher Education	5
2.	Senior High School	5
3.	Junior High School	1
4.	Unknown	1

The distribution shown in Table 4 indicates a clear concentration of research at the senior high school and higher education levels. Studies conducted by Oyewo et al. (2022), Mutakinati et al. (2018), Marcinauskas et al. (2024), Danday (2021), Verawati et al. (2020), Tiruneh et al. (2017), Tiruneh et al. (2018), Saregar et al. (2018), Danday and Monterola (2019), and Iwuanyanwu (2023) were all implemented within these two educational contexts. This pattern demonstrates that recent research has primarily focused on learners who are expected to engage in higher-order reasoning, scientific inquiry, and evidence-based problem solving.

Although conducted at different educational stages, studies at the senior high school and higher education levels exhibit similar instructional characteristics. Most implemented student-centered instructional approaches, such as Project-Based Learning (Oyewo et al., 2022; Mutakinati et al., 2018; Marcinauskas et al., 2024), Inquiry-based Learning (Verawati et al., 2020), SSCS with Scaffolding (Saregar et al., 2018), and Multi-Representation (Danday & Monterola, 2019), to facilitate students' abilities to analyze evidence, evaluate scientific arguments, and solve authentic physics problems. Despite differences in curriculum complexity, these studies consistently positioned critical thinking as an essential learning outcome across both educational levels.

A different pattern emerges at the junior high school level. Only one reviewed study, conducted by Kiliç and Şen (2014), investigated the development of critical thinking among lower secondary students. Furthermore, none of the reviewed studies focused on primary education, while one study did not specify the participants' educational level. This finding reveals a significant imbalance in the current literature, indicating that empirical evidence regarding the development of critical thinking at the early stages of physics education remains limited.

The uneven distribution of studies across educational levels has important implications for future research. Since the existing evidence is largely derived from senior high school and university settings, current knowledge about effective instructional models may not be directly applicable to younger learners. Future studies should therefore investigate how instructional approaches that have demonstrated effectiveness at higher educational levels can be adapted for junior and primary school students. Expanding research across the educational continuum would provide a more comprehensive understanding of how critical thinking develops progressively throughout physics education and would support the design of developmentally appropriate instructional interventions.

Overall, this review demonstrates that research on critical thinking in physics education between 2017 and 2024 has been heavily concentrated at the senior high school and higher education levels. While these studies provide substantial evidence regarding instructional practices for older learners, they simultaneously reveal a notable research gap at lower educational levels. Addressing this imbalance should become a priority for future research to establish a more comprehensive evidence base for the development of critical thinking across all stages of physics education.

Which physics topics have been most frequently investigated in studies concerning the development of critical thinking skills?

The reviewed studies investigated critical thinking across a variety of physics topics, ranging from broad introductory concepts to specific disciplinary content. As presented in Table 5, General Physics was the most frequently investigated subject area, appearing in five of the twelve reviewed studies. The remaining studies each focused on a single topic, including Basic Physics, Science Project, General Science, Electricity and Magnetism, Temperature and Heat, and Microteaching, while one study did not explicitly specify the physics content addressed.

Table 5. Classification Based On Physics Subject Matter

No	Subject Matter	Frequency
1.	General Physics	5
2.	Basic Physics	1
3.	Science Project	1
4.	General Science	1
5.	Electricity And Magnetism	1
6.	Temperature And Heat	1
7.	Micro Teaching	1
8.	Unknown	1

The distribution presented in Table 5 demonstrates that research on critical thinking in physics education has predominantly focused on General Physics. Studies conducted by Mutakinati et al. (2018), Oyewo et al. (2022), Marcinauskas et al. (2024), Tiruneh et al. (2017), and Tiruneh et al. (2018) investigated broad physics concepts rather than highly specialized content. This tendency suggests that researchers generally prefer foundational physics topics because they provide opportunities for integrating multiple scientific concepts while requiring students to analyze evidence, evaluate explanations, and solve authentic problems through scientific reasoning.

In contrast, specialized physics topics were considerably less represented. Only one reviewed study addressed Electricity and Magnetism, while Temperature and Heat, Basic Physics, Science Project, General Science, and Microteaching each appeared in a single study. Although these topics differ substantially in conceptual characteristics and instructional objectives, the reviewed studies consistently positioned them as contexts for developing higher-order thinking rather than as isolated content knowledge. This finding indicates that critical thinking can be fostered across diverse areas of physics, provided that learning activities encourage scientific inquiry, evidence-based reasoning, and active problem solving.

Another notable observation is the relatively limited diversity of physics content represented in the reviewed literature. Important areas of physics, such as Mechanics, Waves, Optics, Modern Physics, Atomic Physics, and Quantum Physics, were absent from the reviewed studies. This imbalance suggests that current research has primarily emphasized foundational concepts while giving comparatively little attention to more advanced or conceptually abstract domains. Consequently, existing evidence remains insufficient to determine whether the effectiveness of instructional models for developing critical thinking varies across different areas of physics.

The reviewed studies also indicate that the choice of physics topic is closely associated with the instructional model employed. General Physics was frequently combined with student-centered approaches such as Project-Based Learning (Oyewo et al., 2022; Mutakinati et al., 2018; Marcinauskas et al., 2024), whereas specialized topics tended to be integrated with inquiry-based learning, experimental activities, or contextual learning environments. This pattern suggests that researchers selected physics topics not merely as subject content but also as instructional contexts for engaging students in analysis, evaluation, and scientific argumentation.

Overall, the reviewed literature demonstrates that research on critical thinking in physics education has concentrated primarily on General Physics, while specialized physics topics remain underrepresented. This finding highlights an important opportunity for future studies to investigate a wider range of physics content, particularly conceptually demanding topics, in order to determine whether different domains require distinct instructional approaches for fostering students' critical thinking skills.

What research trends and future research directions can be identified from studies on critical thinking in physics education published between 2017 and 2024?

Unlike the previous sections, which examined instructional models, critical thinking indicators, educational levels, and physics topics separately, this section synthesizes the findings across the reviewed studies to identify broader research trends and future research directions in the field of critical thinking in physics education. The first major trend identified in this review is the growing adoption of student-centered instructional approaches for developing critical thinking skills. Across the reviewed studies, Project-Based Learning (Oyewo et al., 2022; Mutakinati et al., 2018; Marcinauskas et al., 2024) emerged as the most frequently implemented instructional model,

while inquiry-based learning (Verawati et al., 2020), SSCS with scaffolding (Saregar et al., 2018), multi-representation learning (Danday & Monterola, 2019), and Microteaching Lesson Study (Danday, 2021) were also employed to promote higher-order thinking. Although these instructional models differ in their pedagogical procedures, they share common characteristics, including authentic problem solving, collaborative learning, scientific inquiry, evidence-based reasoning, and reflective learning. This convergence suggests that contemporary physics education increasingly emphasizes learning environments that actively engage students in constructing scientific knowledge rather than passively receiving information.

A second trend concerns the conceptualization and assessment of critical thinking. The reviewed studies consistently measured critical thinking through multidimensional constructs, including problem solving, analysis, evaluation, inference, and critical reflection. Furthermore, the assessment approaches extended beyond conventional written examinations by incorporating project portfolios, laboratory reports, reflective journals, concept maps, peer assessment, and performance-based rubrics. This development indicates a gradual shift toward authentic assessment practices capable of capturing the complexity of students' reasoning processes and scientific argumentation.

The review also reveals an imbalance in the educational contexts represented in current research. Most studies were conducted at senior high schools and higher education institutions, whereas only one study investigated junior high school students, and none involved primary education. Similarly, the reviewed literature concentrated predominantly on General Physics, while more specialized physics topics including Electricity and Magnetism, Temperature and Heat, and other disciplinary areas received relatively little research attention. These findings indicate that the existing evidence base is primarily derived from older learners studying foundational physics concepts, thereby limiting the generalizability of current instructional recommendations across educational levels and physics domains.

Several research gaps can therefore be identified. First, future studies should investigate the development of critical thinking at primary and junior secondary levels to better understand how these skills evolve throughout formal education. Second, research should explore a wider range of physics topics, particularly conceptually demanding areas such as mechanics, waves, optics, modern physics, and quantum physics, to determine whether instructional effectiveness differs across disciplinary contexts. Third, although several instructional models have demonstrated positive outcomes, comparative studies evaluating the relative effectiveness of different pedagogical approaches remain limited. Finally, most reviewed studies relied on conventional classroom interventions, suggesting opportunities to investigate how emerging educational technologies including artificial intelligence, virtual laboratories, augmented reality, and learning analytics can be integrated with evidence-based instructional models to further enhance students' critical thinking skills.

Overall, the reviewed literature demonstrates that research on critical thinking in physics education between 2017 and 2024 has progressively shifted toward student-centered pedagogy, authentic assessment, and higher-order cognitive development. At the same time, important gaps remain regarding educational coverage, physics content, comparative instructional effectiveness, and technology integration. Addressing these issues will contribute to a more comprehensive understanding of how critical thinking can be effectively developed across different educational contexts and support the design of innovative physics learning environments that meet the demands of twenty-first-century education.

CONCLUSION

The findings demonstrate that student-centered pedagogies, particularly Project-Based Learning (PBL) and inquiry-oriented approaches, are the most frequently implemented strategies for fostering critical thinking. Furthermore, critical thinking is increasingly assessed through multidimensional indicators supported by authentic assessment practices rather than conventional knowledge-based testing. However, the review also reveals significant research imbalances, with studies predominantly conducted at senior high school and higher education levels and largely focused on general physics topics, leaving younger learners and specialized physics content substantially underrepresented. Theoretically, this review contributes to the growing body of knowledge by demonstrating that the effectiveness of critical thinking instruction depends not on a single instructional model but on shared pedagogical principles, including authentic problem solving, scientific inquiry, collaborative learning, and reflective reasoning. Practically, the findings provide guidance for physics teachers in selecting instructional strategies and assessment methods that better support students' higher-order thinking. From a policy perspective, curriculum developers and educational authorities should strengthen the integration of critical thinking across educational levels while promoting authentic assessment as a core component of physics instruction. Future research should expand investigations to primary and junior secondary education, explore underrepresented physics topics, compare the effectiveness of different instructional models, and examine how emerging technologies, including artificial intelligence, virtual laboratories, and augmented reality, as well as context-based approaches incorporating local wisdom, can support the development of critical thinking in physics education.

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