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Integrated Instructional Approaches to Foster Critical Thinking in Science Teacher Education: A Systematic Literature Review

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Abstract

This study presents a systematic literature review of recent research on the impact of integrated instructional approaches in strengthening critical thinking skills among prospective science teachers. Through an in-depth analysis of selected publications, the findings indicate that reflective learning strategies such as explicit rubric-based simulations, argument mapping, journaling, project-based learning, and the integration of socio-scientific contexts consistently enhance the cognitive, metacognitive, and affective dimensions of critical thinking. The review further demonstrates that emotional engagement and metacognitive awareness function as essential conditions for the effectiveness of reflective instruction. In addition, embedding local cultural contexts is shown to increase the relevance and meaningfulness of science learning. From a practical perspective, these findings imply that teacher education programs should systematically integrate reflective instructional designs, formative assessment rubrics, and culturally responsive learning tasks into their curricula. Moreover, institutions are encouraged to strengthen lecturer professional development, improve digital learning infrastructure, and adopt flexible curriculum policies to address implementation challenges such as institutional resistance and variability in student engagement. Collectively, these implications support the development of adaptive, inclusive, and context-sensitive science teacher education aligned with the demands of 21st-century learning.

Keywords*:* Critical Thinking; Integrated Learning; Science Teacher Education; Reflection and Metacognition; Cultural Contextualization.

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INTRODUCTION

Modern science education faces multidimensional challenges, including the need to cultivate not only students' conceptual understanding but also higher-order thinking skills such as critical thinking. Critical thinking has become a core competency in the age of information disruption, where learners are required to evaluate scientific information objectively, interpret data, and make evidence-based decisions. In the context of science teacher education, these skills are especially crucial, as teachers are expected not only to master subject matter but also to inspire students to think reflectively and rationally about scientific phenomena.

The growing interest in integrative approaches in science education is reflected in the increasing number of scientific publications, both in quantity and quality, as reported by Zhan et al. (2022) through a bibliometric study. These studies indicate that integrative instructional approaches have gained global attention, supported by diverse methodological designs and implemented across various educational contexts. Qualitative investigations, in particular, have contributed significantly to understanding the complexity of curriculum integration and its potential to foster higher-order cognitive skills (Winarno et al., 2020).

However, literature addressing the simultaneous and integrated development of scientific literacy and critical thinking in science teacher education remains relatively limited. Many existing studies examine these constructs in isolation, despite their conceptual and empirical interdependence. Primasari et al., (2020) demonstrated that critical thinking contributes 11.83% to scientific literacy, underscoring the importance of integrated instructional designs that address both competencies within a unified learning framework.

Empirical evidence suggests that instructional models such as Inquiry-Based Learning (IBL), Project-Based Learning (PBL), and Argument-Driven Inquiry (ADI) are effective in promoting critical thinking. Lamb et al. (2020), for example, showed that the Science Writing Heuristic significantly enhances students' analytical and evaluative skills. Similarly, Chan et al. (2024) highlighted that structured inquiry experiences are particularly effective for preservice science teachers, as they combine conceptual understanding with reflective reasoning processes.

Collaborative learning models, including Cooperative Integrated Reading and Composition (CIRC), have also demonstrated positive effects on critical thinking development through social interaction and scientific discourse. Habiddin et al. (2023) found that cooperative learning not only strengthens scientific literacy but also enhances self-regulation, a key component of critical thinking.

Among integrative models, Project-Based Learning (PBL) is widely recognized for its capacity to connect problem-solving, reflection, and teamwork. Kristiantari et al. (2022) reported that PBL supported by digital technology improves engagement and conceptual understanding in science learning. Nevertheless, the effectiveness of PBL is highly context-dependent, influenced by institutional readiness, instructional design quality, and learner characteristics.

Integrated science education further enables the development of affective and contextual dimensions of learning. Isa et al. (2022) emphasized that culturally and contextually responsive instruction strengthens the meaningfulness of science learning. Within this perspective, critical thinking is not solely a cognitive skill but also a socially situated practice shaped by values, norms, and cultural experiences.

Despite these promising findings, the implementation of innovative instructional models faces persistent challenges, including infrastructure limitations, institutional resistance, varying levels of teacher and student readiness, and the lack of validated assessment instruments. Öcek et al. (2021) noted that the development of critical thinking requires sustained practice and mentoring, which are often constrained in teacher education institutions. Moreover, methodological limitations in existing studies such as small sample sizes, heterogeneous instruments, and short intervention durations pose challenges for cross-study comparison and limit the generalizability of findings (Kazu & Yalçın, 2022). These methodological constraints highlight the need for systematic synthesis to critically examine patterns, consistencies, and gaps across studies.

In addition to global considerations, contextual challenges within the Indonesian education system warrant specific attention. The implementation of integrated and reflective learning models in Indonesia often encounters constraints related to uneven digital infrastructure, curriculum rigidity, large class sizes, and limited professional development opportunities for teacher educators. While several studies conducted in Indonesia have demonstrated the potential of inquiry-based and project-based learning to enhance critical thinking and scientific literacy (e.g., Suhirman & Khotimah, 2020; Susanti et al., 2020), their effectiveness varies widely depending on institutional support and contextual adaptation. These conditions suggest that global instructional models require contextual modification to align with local educational policies, cultural practices, and resource availability.

Recent studies further indicate variability in instructional effectiveness across learner profiles. PBL, for instance, appears more beneficial for low-achieving students (Suhirman & Khotimah, 2020), whereas flipped classroom approaches do not consistently outperform conventional instruction (Susanti et al., 2020). Such findings reinforce the importance of aligning instructional models with contextual and learner-specific factors.

Given these dynamics, there is an urgent need for a systematic literature review that not only examines the effectiveness of instructional approaches in fostering critical thinking, but also critically analyzes their methodological characteristics, contextual applicability particularly within developing education systems such as Indonesia and implementation challenges. A comprehensive synthesis of recent literature is essential for developing a theoretically robust and practically relevant framework for science teacher education.

Research Questions

1. What are the characteristics of innovative learning models that support the development of critical thinking in science teacher education?
2. What are the key components of effective instructional interventions for fostering critical thinking skills?
3. What challenges are faced in implementing these approaches in teacher education contexts?
4. What strategic recommendations can be offered for developing a critical thinking–based teacher education curriculum?

METHOD

This study employed a Systematic Literature Review (SLR) approach following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure transparency and replicability in the review process. The primary objective of this SLR was to identify, evaluate, and synthesize empirical evidence related to instructional approaches for developing critical thinking skills in science teacher education.

Literature Search Strategy and Article Selection

The literature search was conducted using the Scopus database, selected for its comprehensive coverage of high-quality, peer-reviewed international journals in education and science education research. A structured search strategy was applied using Boolean operators and combinations of the following keywords: *“critical thinking” AND “preservice science teachers” OR “science teacher education” OR “science education” OR “STEM education” AND “instructional intervention”*. The search was limited to article titles, abstracts, and keywords to enhance relevance.

To minimize selection bias, the search and screening process was conducted in several stages. First, all retrieved records were screened based on titles and abstracts to exclude clearly irrelevant studies. Second, full-text screening was conducted to assess eligibility based on predefined inclusion and exclusion criteria. Studies that did not explicitly report instructional interventions or lacked empirical data were excluded at this stage. The screening process followed the PRISMA 2020 flow diagram, and decisions at each stage were documented to enhance transparency and reduce subjective bias in article selection.

The inclusion criteria were as follows: (a) peer-reviewed journal articles; (b) published between 2010 and 2024; (c) written in English or Indonesian; and (d) explicitly focused on the development of critical thinking within science teacher education contexts.

Inclusion and Exclusion Criteria

Inclusion criteria:

1. Studies that explicitly examined instructional interventions or learning models targeting critical thinking skills.
2. Studies involving preservice teachers or students in science teacher education programs.
3. Studies presenting empirical evidence using quantitative, qualitative, or mixed-methods designs.

Exclusion criteria:

1. Descriptive or conceptual studies that did not include any instructional intervention.
2. Studies focusing solely on affective or motivational variables without empirical linkage to critical thinking outcomes.
3. Studies lacking sufficient methodological detail to allow evaluation of research design and outcomes.

Quality Appraisal of Selected Studies

To ensure the methodological rigor and validity of the synthesized findings, a quality appraisal process was applied to all eligible articles. Each study was evaluated using a set of adapted quality indicators commonly employed in educational SLRs, including: (a) clarity of research objectives; (b) appropriateness of research design; (c) adequacy of sample description; (d) transparency of data collection procedures; (e) validity and reliability of critical thinking instruments; and (f) coherence between data analysis and conclusions.

Studies that demonstrated serious methodological weaknesses—such as unclear intervention procedures, insufficient description of assessment tools, or unsupported conclusions—were not excluded automatically but were weighted cautiously during thematic synthesis. This approach allowed for comprehensive coverage of the literature while reducing the risk of overgeneralizing findings from methodologically weak studies.

Data Analysis Technique

Data from the selected studies were analyzed using narrative and thematic synthesis methods. A bottom-up coding approach was applied to identify recurring patterns and themes across studies. Five overarching themes emerged from the analysis:

1. Innovative instructional models employed,
2. Core components of instructional interventions,
3. Critical thinking indicators and measurement tools,
4. Implementation challenges, and
5. Strategic recommendations for science teacher education curricula.

The analytical process involved systematically categorizing findings according to instructional strategies, intervention outcomes, institutional contexts, and reported limitations. To enhance the trustworthiness of the synthesis, cross-study triangulation and citation tracking were employed, allowing consistent findings across multiple studies to be identified and contrasted with context-specific variations.

RESULTS AND DISCUSSION

This systematic review analyzed 10 relevant articles focusing on the development of critical thinking in science teacher education. The selection process followed the PRISMA flow, involving the screening of a large number of publications based on inclusion and exclusion criteria. The PRISMA diagram illustrates the process of identification, screening, eligibility assessment, and final inclusion, which led to the selection of 10 key articles for in-depth evaluation. The screening outcomes and exclusions were documented using the 2020 PRISMA flow diagram. This review also included regular consultations with experts in the field to refine the selection criteria and ensure alignment with the research questions. Figure 1 presents the PRISMA diagram.

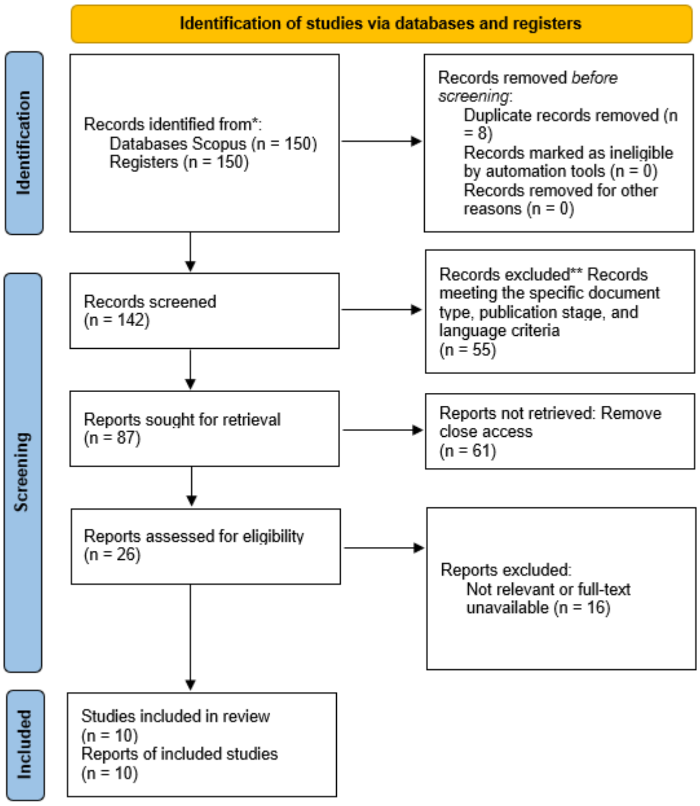

Figure 1. PRISMA 2020 Flow Diagram Illustrating the Screening, Eligibility, and Inclusion Process

1. Key Findings

Table 1 summarizes the critical thinking dimensions used, instructional models applied, and implementation challenges identified in each study:

Table 1. Summary of critical thinking dimensions, instructional models, and implementation challenges from each study.

No	Author	CT Indicator	Instructional Model	Challenges
1	Sahar et al. (2023)	Paul-Elder: analysis, evaluation, decision-making	PBL, metacognition, interactive technology	Limited digital infrastructure
2	Sari et al. (2023)	CT rubric: clarity, accuracy, precision, relevance	Collaborative project, reflective rubric	Variability in student participation
3	Chu et al. (2024)	Transversal skills: problem solving, reflection	PBL, simulation, reflective rubric	Lack of standardized evaluation
4	Kalgotra et al. (2023)	Analytical thinking via CBL	Community-Based Learning (CBL)	Limited field coordination
5	Elshaiekh et al. (2024)	Analysis, reflection, innovation (ESKBE)	Integrative regression model	Resistance to change
6	Chuayouan & Promnil (2024)	CT in cultural entrepreneurship	Business design workshop & simulation	Lack of psychological integration
7	Nascimento & Morais (2020)	4C: analysis, evaluation, reflection	Flipped classroom, peer review, PBL	Readiness of students & lecturers
8	Maesschalck (2024)	Metacognition, argumentation, reflection	Authentic instruction, roleplay, journaling	Resistance from lecturers & students
9	Ivancu et al. (2023)	Facione: inference, evaluation, reflection	Debate, press conference, academic writing	Decline in CT disposition
10	Crudele & Raffaghelli (2023)	Argument Mapping and reflective discussion	AM hybrid, LMS discussion, HCTSR evaluation	Self-perception bias, varied assessment

2. Thematic Analysis

From the synthesis of Table 1, five major themes emerged:

a. Theoretical Frameworks for Critical Thinking (CT)
Studies such as those by Sahar et al. and Ivancu et al. applied the Paul-Elder and Facione frameworks to explicitly define and measure CT. This reflects a strong conceptual foundation for critical thinking indicators within teacher education.

b. Innovative Models for Reflective Learning
Models such as Project-Based Learning (PBL), Argument-Driven Inquiry (ADI), and Case-Based Learning (CBL) have been widely shown to improve critical thinking through projects, simulations, and reflective activities (Sari et al., Chu et al., Kalgotra et al.).

c. Technology Integration and Assessment Rubrics
The use of flipped classrooms, argument mapping, and LMS-based evaluative rubrics demonstrated a positive synergy between technology-enhanced approaches and reflective assessment (Maesschalck; Crudele & Raffaghelli).

d. Contextual and Cultural Contributions
Approaches involving cultural entrepreneurship and community-based learning revealed that critical thinking can be fostered within local and social contexts (Chuayounan & Promnil; Elshaiekh et al.).

e. Relevant Implementation Challenges
Common challenges included institutional resistance, variability in student participation, limited facilitator capacity, and the absence of standardized evaluation instruments.

3. Interpretation of Findings

The results of this systematic literature review (SLR) reinforce earlier evidence that integrated and reflective learning approaches play a significant role in enhancing critical thinking skills among preservice science teachers. Studies such as those by Sari et al. and Chu et al. emphasized that the use of explicit rubrics in instructional simulations and Problem-Based Learning (PBL) models not only facilitates the evaluation of critical thinking skills but also encourages active student participation. These explicit rubrics function as scaffolding tools, providing targeted feedback and stimulating self-reflection processes, which in turn strengthen students' metacognitive awareness.

These findings align with the study by Atoyebi & Atoyebi (2022), which found that inclusive instructional approaches can reduce academic anxiety and increase student confidence, particularly in mathematics instruction. This is highly relevant in science education, where students' emotional engagement is a key factor in promoting participation and deeper thinking. Kumlu & Yürük (2023) further supported this argument by showing that explicit strategy instruction improves students' metacognitive awareness, enabling them to select appropriate and effective problem-solving strategies.

Furthermore, studies by Chen (2022) and Huang & Kuang (2024) emphasized the importance of integrating teaching strategies that foster self-directed learning and self-efficacy. Approaches such as argument mapping and journaling have been shown to be effective in promoting reflective student engagement. By articulating their thoughts and structurally connecting concepts, students not only develop critical thinking but also consciously regulate their cognitive processes.

The collaborative aspect of learning also prominently supports critical thinking skills. Onu et al. (2020) reported that collaborative learning strategies increase students' interest and academic achievement, a finding echoed by Etaneki & Faith (2021), who emphasized the role of peer interaction in enhancing learning outcomes. These findings suggest that critical thinking is not merely an individual endeavor but is also cultivated through social discourse and collective reflection.

Interventions involving blended learning, inquiry-based learning, and metacognitive strategies were also consistently reported to enhance both scientific literacy and critical thinking. Hadiprayitno et al. (2021) and Liu et al. (2022) demonstrated that station rotation models and virtual laboratories within science education contexts significantly supported students in designing experiments and interpreting scientific data critically. These results indicate that dynamic, reflective, and problem-centered learning environments play a key role in fostering higher-order thinking skills.

Moreover, a meta-analysis by Xie et al. (2023) found that metacognitive strategies such as strategic reading have a strong effect on scientific literacy achievement—an important indicator of critical thinking success in science contexts. Meanwhile, Owens & Sadler (2023) and Kola et al. (2020) highlighted the importance of incorporating socio-scientific issues as contexts that enhance the real-world relevance of instruction. These contexts enable students to develop analytical and evaluative skills authentically, as they are faced with real-life problems requiring simultaneous moral and scientific judgment.

Thus, the integration of explicit instructional strategies, reflective activities like journaling, collaborative work, and the use of socio-scientific contexts has consistently proven effective in improving critical thinking among preservice science teachers. These findings also indicate the need for curriculum and teacher training programs to systematically and sustainably incorporate such approaches to support the development of future educators' professional capacities.

4. The Need for Differentiation Strategies and Self-Regulated Learning (SRL)

Effective science education in teacher preparation does not depend solely on the instructional model used but also on the ability to accommodate the diverse learning needs of students. Therefore, the integration of differentiation strategies and self-regulated learning (SRL) has become essential. Both approaches have consistently been shown to support high-level cognitive achievement, including critical thinking, as highlighted in numerous recent studies.

Differentiation as a Response to Learner Diversity

Differentiated instruction involves adapting teaching strategies based on students' readiness, interests, and learning styles. Smets and Struyven (2020) argued that teachers' competence in implementing differentiated instruction is strongly influenced by structured professional training. Through capacity-building programs, preservice teachers can be trained to recognize individual differences and design adaptive learning experiences. This approach not only improves learning outcomes but also reduces academic anxiety and boosts student confidence (Atoyebi & Atoyebi, 2022).

In science teacher education, differentiation is highly relevant, given the diverse academic backgrounds and learning preferences of preservice teachers. Therefore, implementing adaptive instruction based on diagnostic data is a strategic solution to ensure that all students are supported in developing critical thinking skills.

The Importance of Self-Regulated Learning

Self-regulated learning (SRL) emphasizes learners' ability to plan, monitor, and evaluate their own learning processes. Huang and Kuang (2024) showed that SRL interventions significantly enhance self-efficacy and the use of deeper cognitive strategies, especially in scientific problem-solving. In science education, SRL is essential for internalizing scientific processes such as hypothesizing, experimenting, and interpreting data.

A study by Nascimento & Morais (2020) illustrated how flipped classrooms can provide a conducive environment for promoting SRL. In this approach, students access materials independently before class, allowing class time to be devoted to collaborative and reflective activities. This structure gives students the autonomy to regulate their learning pace and delve into topics according to their personal needs.

Collaboration and Metacognition as Reinforcements for SRL and CT

Collaborative elements in SRL strategies also play a vital role in strengthening critical thinking. Etaneki & Faith (2021) and Onu et al. (2020) emphasized that group interactions increase motivation and participation while encouraging analytical and argumentative thinking. Through peer-review discussions or project-based teamwork, students practice evaluating ideas, providing feedback, and constructing data-driven arguments.

Moreover, Kumlu and Yürük (2023) demonstrated that explicit metacognitive instruction enhances students' awareness of their thinking processes—closely aligned with the development of critical thinking, where students must identify assumptions, detect bias, and evaluate information systematically.

Implications for Teacher Education

In the context of science teacher education, integrating differentiation and SRL has several practical implications:

a. Teacher education curricula should provide space for students to develop personal and reflective learning strategies, such as learning journals, independent projects, and reflection-based formative assessments.
b. Preservice teacher training should include skills for designing differentiated and SRL-based instruction, along with mastery of technologies that support flexible learning.
c. Critical thinking assessment should align with formative approaches that allow students to self-assess and revise their learning outcomes.

In other words, effective critical thinking instruction is not simply a product of specific teaching models, but the result of learning environments that promote autonomy, reflection, and adaptability. Thus, differentiation and SRL are not supplementary strategies but prerequisites for designing 21st-century learning relevant to teacher education needs.

Contextualization, Visualization, and Cultural Entrepreneurship

Integrating contextual and local aspects into instruction has proven to play a strategic role in developing students' critical thinking abilities. Studies by Chuayounan & Promnil (2024) and Elshaiekh et al. (2024) highlight that learning activities incorporating local contexts, experiential visualization, and cultural narratives actively build students' cognitive connections to their social realities. This aligns with the findings of Owens & Sadler (2023), who emphasized that engagement with socio-scientific issues enhances the quality of students' critical analysis by requiring reflective thinking, perspective-taking, and the evaluation of evidence in real-world contexts.

Context-based approaches also strengthen scientific literacy through problem-solving that is relevant to daily life. As illustrated by Sari et al. (2023), integrating local wisdom into science instruction allows students to see real applications of scientific concepts. This supports constructivist theories of science learning, which argue that meaning is formed through active engagement with the environment and meaningful experiences.

Additionally, visualization and symbolic representation play an important role in developing visual and cognitive literacy. Hadiastriani and Djarot (2024) noted that integrating digital visualization into the science curriculum enhances students' capacity to understand and interpret scientific phenomena more critically. This includes the use of simulations, concept maps, and diagrammatic representations that support abstract and argumentative thinking.

Moreover, cultural entrepreneurship approaches—as outlined by Chuayounan & Promnil (2024)—facilitate the development of 21st-century skills through reflective practices and the analysis of cultural values in decision-making. Activities such as culturally grounded business simulations and region-based product design encourage students to think critically while considering values, ethics, and social impacts.

In the context of teacher education, this approach carries broad implications. First, teachers must be trained to design learning that balances local and global contexts. Second, evaluation models must be developed that assess not only cognitive outcomes but also students' reflective, argumentative, and contextually internalized values.

Reflections on Implementation Challenges

Although many innovative learning models have demonstrated effectiveness in enhancing critical thinking skills, their implementation often faces structural and contextual challenges. Elshaiekh et al. (2024) noted institutional resistance to adopting interdisciplinary and reflective approaches, largely due to rigid curricula and pressure to achieve cognitive learning outcomes exclusively.

Kumari (2024) highlighted digital infrastructure challenges that hinder the integration of interactive technologies as tools for stimulating critical thinking. This is a major constraint given the reliance of models such as flipped classrooms and blended learning on technological access.

Meanwhile, Sari et al. (2023) observed that student participation in reflective project-based learning is not always consistent. This variability may be due to a lack of critical thinking dispositions fostered from the outset or high academic workloads that divert attention from reflective activities.

In response, facilitator (preservice teacher) training must emphasize three key aspects:

1. Designing adaptive and contextualized curricula,
2. Facilitating reflection- and metacognition-based learning, and
3. Implementing ongoing formative assessment.

Alnufaie (2022) and Smets & Struyven (2020) underscored the importance of building teacher capacity in differentiated and reflective strategies to support inclusive and effective learning implementation.

Adaptive curriculum design must also consider integrating technology as a pedagogical tool. Liu et al. (2022) demonstrated that combining virtual laboratories with students' critical assessment of teacher demonstrations significantly sharpens evaluative and interpretive skills.

Thus, implementation challenges are not limited to infrastructure but also involve human resource readiness, curriculum policy flexibility, and systemic support from educational institutions. A learning model centered on critical thinking requires an ecosystem that fully supports active participation, deep reflection, and openness to evaluating ideas critically.

While the reviewed studies consistently report positive effects of integrated and reflective instructional models on preservice teachers' critical thinking, several negative findings and implementation failures were also identified and warrant explicit attention. Some studies reported limited or inconsistent gains in critical thinking, particularly when instructional models such as Project-Based Learning (PBL) and flipped classrooms were implemented without sufficient scaffolding or alignment with students' prior knowledge and learning readiness. For instance, flipped classroom designs did not consistently outperform conventional instruction in contexts where students lacked self-regulation skills or access to reliable digital resources. Similarly, reflective and inquiry-based approaches showed diminished effectiveness when assessment instruments were poorly aligned with instructional objectives or when reflective activities were treated as supplementary rather than integral components of the learning process. These findings indicate that the effectiveness of innovative instructional models is highly contingent upon contextual conditions, instructional coherence, and learner preparedness, and that the adoption of such models does not automatically guarantee improved critical thinking outcomes.

Beyond identifying challenges, the literature also provides important insights into strategies for addressing these limitations, although these are often underemphasized. Studies suggest that implementation barriers—such as institutional resistance, variability in student engagement, and limited facilitator expertise—can be mitigated through structured professional development, the use of formative and rubric-based assessment, and gradual model adaptation rather than full-scale implementation. Explicit training in metacognitive scaffolding, for example, has been shown to enhance student participation and reduce cognitive overload in reflective learning environments. Additionally, aligning instructional models with local contexts, resource availability, and curricular flexibility is critical for sustaining effectiveness, particularly in developing educational systems. These findings underscore that successful implementation of critical thinking–oriented instruction requires not only innovative models but also supportive institutional ecosystems, adaptive instructional design, and continuous evaluation mechanisms that allow educators to identify and respond to emerging challenges.

CONCLUSION

This systematic literature review critically examined ten empirical studies addressing integrated instructional approaches for fostering critical thinking in science teacher education. The synthesis of findings demonstrates that reflective and integrative learning models such as Project-Based Learning, Argument-Driven Inquiry, reflective simulations, journaling, and argument mapping consistently contribute to the enhancement of cognitive, metacognitive, and affective dimensions of critical thinking among preservice science teachers. The effectiveness of these approaches, however, is not solely determined by instructional design; rather, it is strongly influenced by learners' emotional engagement and their capacity for metacognitive regulation, both of which play a central role in shaping critical thinking dispositions. Furthermore, the integration of local cultural elements and socio-scientific issues into instructional practices strengthens the relevance and meaningfulness of science learning, enabling students to engage in critical reflection and ethical reasoning within authentic and socially grounded contexts. Despite these positive outcomes, the review also reveals persistent structural and contextual barriers, including limitations in digital infrastructure, institutional rigidity, variability in student participation, and the absence of standardized assessment frameworks for critical thinking. These challenges underscore the necessity of learning environments that are adaptive and responsive to diverse learner needs. In this regard, differentiated instruction and self-regulated learning emerge as essential components for promoting student autonomy, sustained engagement, and higher-order cognitive development in science teacher education.

RECOMMENDATIONS

To ensure the long-term sustainability and scalability of critical thinking development in science teacher education, it is essential to institutionalize a culture of reflective practice and continuous professional development. This involves not only integrating critical thinking into the curriculum, but also embedding it into the daily instructional routines and professional ethos of teacher educators. Universities and teacher training institutions should establish learning communities and mentoring systems where preservice teachers can engage in peer observation, collaborative inquiry, and evidence-based reflection on their teaching practices. Moreover, ongoing research and evaluation must be conducted to monitor the effectiveness of instructional interventions and inform iterative improvements. By fostering a research-driven, reflective, and collaborative teaching culture, science teacher education can more effectively equip future educators with the skills and dispositions needed for 21st-century classrooms.

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