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To cite this article:

Dookurong, I.D., Yarhands, D.A., & Akwerty, E. (2025). A systematic review of the integration of collaborative learning and Polya's problem-solving strategy for enhancing pre-service teachers' critical thinking. *International Journal of Studies in Education and Science (IJSES), 6*(4), 395-428. https://doi.org/10.46328/ijses.5520

International Journal of Studies in Education and Science
2025, Vol. 6, No. 4, 395-428 https://doi.org/10.46328/ijses.5520

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Article Info

Article History

Received:
9 January 2025
Accepted:
15 May 2025

Keywords

Integration of collaborative learning
Polya's problem-solving strategy
Systematic review
Enhancing pre-service teachers' critical thinking

Abstract

Critical thinking is essential in mathematics education, yet traditional methods often fail to develop it effectively. This systematic review examines the integration of collaborative learning and Polya's problem-solving strategy to enhance critical thinking in mathematics instruction. A comprehensive search of ERIC, SAGE, Taylor & Francis, and Google Scholar was conducted for peer-reviewed studies published between 2021 and 2025. Inclusion criteria required studies to focus on mathematics instruction, apply both strategies, measure critical thinking outcomes, and be in English. Eighteen studies met these criteria. A narrative synthesis approach was used due to methodological diversity, and study quality was assessed using the CASP checklist. Findings reveal that the integrated approach improves Pre-service teachers' critical thinking, engagement, and problem-solving skills, though its effectiveness depends on factors such as facilitator competence, instructional design, and learner characteristics. Despite growing use of both strategies, limited empirical research exists on their combined impact on pre-service teachers' critical thinking. Additionally, critical thinking remains an underemphasized focus in teacher training programs. The review was not registered in a systematic review protocol database. Future research should explore varied educational levels and contexts to strengthen the evidence base and guide the development of effective instructional models.

Introduction

In recent years, critical thinking has emerged as a vital 21st-century skill, necessary for problem-solving, innovation, and informed decision-making in both academic and real-world contexts (Saraswati, Putranto, & Caturtunggal, 2021; Hobri, Susanto, Hidayati, Susanto, & Warli, 2021; Zakaria, Noor Nasran, Abdullah, Ahmad Alhassora, Pairan, & Yanuarto, 2024; Fitzsimns, & Ní Fhloinn, 2024). However, traditional mathematics instruction, which often emphasizes procedural fluency and rote memorization, has frequently proven to miss the mark in nurturing students' ability to think critically and apply mathematical reasoning flexibly (Mariana, & Kristanto, 2023; Abdullah, Suharna, & Ruhama, 2024; Arabaçı, & Kanbolat, 2023; Doğanay, & Doğanay, 2022). Many learners struggle to get their heads around abstract mathematical ideas and lack the cognitive tools to apply these concepts in unfamiliar or real-life situations, resulting in disengagement and poor

transfer of learning (Kusaka, & Habimana, 2025; Yulianto, Umami, & Mony, 2024; Gulam, & Arenas, 2024). For many, mathematics becomes a hard nut to crack, rather than a meaningful and transferable skills. This concern has led to increased advocacy for student-centered pedagogies that emphasize collaboration, inquiry, and structured reasoning. Notably, research has shown that collaborative learning fosters active engagement, lends a helping hand through peer-to-peer scaffolding, and deeper comprehension (Habibah, Suratno, & Iqbal, 2023; Emran, Shahrill, & Asamoah, 2023). while Polya's problem-solving framework provides a structured cognitive model that supports metacognition and strategic thinking (Polya, 1957). Studies suggest that integrating these approaches not only enhances students' ability to engage with mathematical tasks meaningfully but also gets to the heart of critical thinking by encouraging them to justify, reflect, and evaluate solutions collaboratively—putting their heads together to find the best path forward (Yusal, Suhandi, Setiawan, & Kaniawati, 2021; Phillips, Clemmer, McCallum, & Zachariah, 2016).

As mathematics education continues to evolve, combining collaborative learning with Polya's method presents a powerful and context-sensitive approach to developing critical thinking skills in diverse instructional settings (Lei, Charatkamolpong, & Kanjanakate, 2025). Collaborative learning, rooted in the constructivist paradigm, promotes active engagement, mutual dialogue, and the co-construction of knowledge. It encourages students to see eye to eye, share diverse perspectives, question assumptions, and build understanding collectively, which aligns well with the development of critical thinking skills (Vygotsky, 1978). When integrated with Polya's four-step problem-solving strategy—understanding the problem, devising a plan, executing the plan, and reflecting on the solution—students are equipped with a structured, reflective approach to tackle tasks head-on (Polya, 1957). This integration supports not only procedural accuracy but also sharpens their thinking through logical reasoning, metacognitive awareness, and collaborative problem-solving, all of which are essential for cultivating critical thinking.

In today's classrooms, the integration of Collaborative Learning with Polya's Problem-Solving Strategy provides a flexible and powerful instructional approach that can reach far beyond the boundaries of mathematics. This combined model emphasizes structured reasoning, teamwork, and systematic steps for solving problems — skills that are valuable not only in mathematics but across disciplines like science, technology, and even the humanities. For pre-service teachers, engaging with this model goes beyond strengthening their mathematical thinking; it equips them with versatile, transferable problem-solving skills that can be applied in diverse educational contexts. Because of this broad potential, conducting a systematic review is important to showcase its cross-disciplinary benefits and to guide curriculum designers in building active, student-centered learning across many subject areas. Moreover, an advantage of this integrated strategy is that it can be delivered within the same instructional time as traditional, individual-focused teaching models, while offering potentially greater gains. Often, individual teaching misses the rich dialogue, peer feedback, and cooperative processes that collaborative learning encourages. When these social elements are merged with Polya's logical, step-by-step framework — identifying the problem, planning, carrying out, and evaluating the solution — they create a powerful learning environment that promotes critical thinking. Importantly, this does not extend lesson times or disrupt schedules, which is crucial for busy teacher education programs. Reviewing the research on this integrated model will help reveal how effectively it supports pre-service teachers in developing the critical thinking skills they need to succeed in modern

classrooms.

Numerous studies have examined collaborative learning and Polya's method either independently or in tandem, yet the extent to which this integrated model reliably enhances critical thinking across varied educational contexts remains inconclusive (Abdullah, Suharna, & Ruhama, 2024; Arabaçı, & Kanbolat, 2023; Doğanay, & Doğanay, 2022; Kusaka, & Habimana, 2025; Yulianto, Umami, & Mony, 2024). Differences in instructional design, assessment tools, and learner characteristics often throw a wrench in the works, leading to mixed and inconsistent findings. While both strategies are widely acknowledged for their individual contributions to improving students' learning experiences in mathematics, research exploring their combined impact is still thin on the ground. The lack of clarity surrounding their integration leaves a gaping hole in understanding how this instructional integration might elevate students' reasoning and problem-solving abilities. What's more, studies examining this model in developing settings such as Ghana are few and far between, despite the pressing need for innovative, context-specific pedagogies. As efforts to reform mathematics education continue to gather steam, a systematic review is urgently needed to bring together existing findings, separate the wheat from the chaff in terms of methodological rigor, and provide a roadmap for effective practice and future inquiry.

Objectives

This systematic review seeks to identify, evaluate, and synthesize empirical studies that investigate the integration of collaborative learning with Polya's problem-solving strategy to enhance students' critical thinking skills. Guided by the PICO framework, the review focuses on studies involving Kindergarten to tertiary students (Population) who are engaged in learning mathematics through an instructional approach that combines collaborative learning with Polya's four-step problem-solving method (Intervention). Where applicable, it contrasts these integrated approaches with traditional or non-integrated teaching methods (Comparison), with a primary focus on measuring the development or improvement of students' critical thinking abilities (Outcome).
The PICO framework was first employed to systematically define the scope of the review by clearly identifying the population (pre-service teachers), intervention (collaborative learning with Polya's method), comparison (traditional methods), and outcomes (critical thinking skills). Following the selection of relevant studies based on these criteria, the CASP checklist was then applied to assess the methodological rigor and credibility of each included study, ensuring the reliability of the synthesized findings.

Even though the population for this study was pre service teachers, the decision to include studies involving learners from Kindergarten to tertiary levels is rooted in the need to understand how the integration of collaborative learning with Polya's four-step problem-solving method can support the development of mathematical thinking across the full educational continuum. Early exposure to structured problem-solving strategies builds foundational cognitive and collaborative skills, which are critical for later academic success. At the same time, examining how this integrated approach functions at the tertiary level provides insights into its capacity to support higher-order thinking, critical analysis, and independent reasoning—skills essential for advanced mathematics learning and future teaching roles, particularly for pre-service teachers.

Moreover, in the Ghanaian context where mathematics education reform is ongoing at all levels—from the basic to tertiary sectors—understanding the impact of such a pedagogical model across developmental stages offers a holistic perspective on curriculum alignment and progression. Including a broad educational range ensures that the review captures variations in instructional outcomes and informs evidence-based practices that can be scaled and adapted across different learner populations. This comprehensive scope ultimately strengthens the applicability of findings to national educational policies aimed at nurturing critical thinking and problem-solving competencies from an early age through to teacher preparation.

This review seeks to:

1. Determine the effectiveness of the integrated instructional approach on students' critical thinking.
2. Explore the instructional conditions or contexts that influence its impact.
3. Identify gaps in the current literature to inform future research.

Methods

Eligibility Criteria

An eligibility criteria are essential for ensuring the rigor, reliability, and credibility of systematic reviews (Moher et al., 2009; Higgins et al., 2022; Aromataris & Munn, 2020; Haddaway et al., 2017; Hu et al., 2021). Studies included in this systematic review were selected based on clearly defined inclusion and exclusion criteria aligned with the review's objectives. Eligible studies focused on all students enrolled in mathematics courses, regardless of their age or level of study. The core intervention involved the integration of collaborative learning strategies with Polya's problem-solving approach within critical thinking. To ensure comparative rigor, only studies that contrasted this integrated approach with traditional or non-integrated instructional methods were considered. Outcomes had to include an assessment of students' critical thinking skills, measured through standardized tests, problem-solving assessments, or validated qualitative tools. The review targeted peer-reviewed experimental, quasi-experimental, and observational studies published in English between 2021 and 2025 to reflect current pedagogical practices.

The selection of the 2021 to 2025 publication range for this systematic review is both deliberate and strategic, grounded in the need to capture the most current and contextually relevant educational research. This period marks a transformative phase in global education, largely shaped by the aftermath of the COVID-19 pandemic, which disrupted conventional teaching models and prompted widespread adoption of innovative instructional strategies. From 2021 onwards, scholarly interest in collaborative learning, critical thinking development, and inquiry-based approaches has surged, as educators and researchers sought to adapt to the evolving needs of learners in hybrid and technology-enhanced environments.

Moreover, narrowing the review to this recent five-year span ensures alignment with Ghana's contemporary educational reforms, particularly those initiated under the National Teacher Education Curriculum Framework (NTECF) introduced in 2018. While the policy was launched in 2018, its full implementation began gaining momentum in the early 2020s, making it essential to examine research that reflects these ongoing shifts in teacher

education practice. By focusing on studies published from 2021 to 2025, the review is positioned to assess the relevance and impact of integrated instructional methods—such as combining collaborative learning with Polya's problem-solving strategy—within the specific realities of post-pandemic teaching and Ghana's reformed educational landscape. This timeframe, therefore, not only guarantees recency but also ensures practical relevance to current classroom practices and policy goals.

Studies were excluded if they did not specifically focus on critical thinking, failed to incorporate either collaborative learning or Polya's strategy, or lacked a critical thinking outcome. Non-peer-reviewed publications, articles in languages other than English, and non-empirical works such as opinion pieces and reviews were also excluded to maintain the review's methodological rigor. Although the review included studies spanning from early childhood to tertiary levels, the core focus remained on pre-service teachers. This broader scope was deliberate—it enabled the identification of best practices, gaps, and patterns in critical thinking instruction across educational stages. Since pre-service teachers are future educators, insights from early to advanced levels provide a foundational understanding of how critical thinking is nurtured throughout a learner's academic journey. These cross-level findings can inform how pre-service teachers should be trained to foster such skills in their future classrooms. Thus, the exclusive focus on pre-service teachers in the topic reflects the end goal of shaping instructional competence, using evidence drawn from the full educational continuum.

Information Sources

Systematically selecting and transparently reporting diverse information sources is essential for ensuring the completeness, reliability, and reproducibility of a systematic review (Lefebvre et al., 2024; Higgins et al., 2024; McCool & Glanville, 2025; Haddaway et al., 2015; Atkinson et al., 2015; MacFarlane et al., 2021). To identify relevant studies for inclusion in this systematic review, comprehensive searches were conducted across multiple reputable academic databases. These included ERIC (Education Resources Information Center), Tailor & Francis group, Sage, and Google Scholar. These sources—ERIC, Taylor & Francis group, SAGE, and Google Scholar—were selected because they are widely recognized and reputable academic databases that provide access to high-quality, peer-reviewed literature in education and the social sciences. ERIC, maintained by the U.S. Department of Education, is dedicated specifically to educational research, making it highly relevant for studies on teaching and learning. Taylor & Francis and SAGE are leading academic publishers known for their extensive collections of education and pedagogy journals, including those that focus on mathematics education, instructional strategies, and teacher training. Google Scholar, while broader in scope, enhances the review's comprehensiveness by indexing grey literature, theses, and scholarly works not always available in discipline-specific databases. Together, these sources ensure a diverse, credible, and up-to-date pool of literature necessary for a rigorous and balanced systematic review in mathematics education. The search was carried out in June 2025 to capture the most recent and relevant literature on the integration of collaborative learning and Polya's problem-solving approach in critical thinking. No language restrictions were initially applied during the database search to ensure inclusivity; however, only studies published in English were ultimately included based on the eligibility criteria. In addition to database searches, the reference lists of all eligible studies were systematically reviewed to uncover any additional studies that met the inclusion criteria, thereby enhancing the comprehensiveness and completeness

of the literature search. Table 1 below indicated the database search.

Table 1. Description of Database Search

Database	No. of Article	Percentages
ERIC	76	19.1
Tailor and Francis group	153	38.5
Google Scholar	126	31.7
Sage	42	10.6
Total	397	100

A total of 397 articles were identified through systematic searches across four major databases. The majority of articles (153; 38.5%) were retrieved from the Taylor and Francis Group, making it the largest single source. Google Scholar contributed 126 articles (31.7%), followed by ERIC with 76 articles (19.1%). The smallest contribution came from SAGE Publications, which yielded 42 articles (10.6%). These percentages reflect a diverse and balanced literature search strategy, with an emphasis on peer-reviewed academic sources relevant to education and pedagogy.

Search Strategy

Developing a comprehensive and well-structured search strategy—often combining multiple methods such as database searching, controlled vocabulary, and snowballing—is essential for identifying all relevant literature in a systematic review (Lefebvre et al., 2024; MacFarlane et al., 2022; Mourão et al., 2020; Wohlin et al., 2023; Murdoch University Library, 2025; University of Tasmania Library, 2025). A comprehensive and systematic search strategy was developed in consultation with an information specialist to ensure the retrieval of all relevant literature. The search strategy employed a combination of carefully selected keywords and Boolean operators tailored to the focus of the review is shown in Table 2.

Table 2. Structured Search Terms and Boolean Combinations Used for Database Querying

Search String	**Thematic Focus**	**Keywords and Boolean Operators Used**
1	Collaborative learning + Polya's strategy + Critical thinking	collaborative learning" AND "Polya's problem-solving strategy" AND "calculus instruction" AND "critical thinking"
2	Peer learning + Math problem-solving + Critical thinking	peer learning" AND "mathematics problem solving" AND "critical thinking" AND "calculus education"
3	Group work + Polya method + Math education + Cognitive skills	"group work" AND "Polya method" AND "mathematics education" AND "cognitive skills"
4 (optional)	Collaborative strategies + Problem-solving + Higher-order	collaborative strategies" AND "problem-solving instruction" AND "higher-order

Each search string was systematically adapted across multiple academic databases, including ERIC, Taylor and Francis Group, Sage, and Google Scholar, using appropriate syntax variations specific to each platform. To improve the precision of the search results, phrase searches were enclosed in quotation marks, ensuring that terms such as "collaborative learning" and "Polya's problem-solving strategy" were retrieved as exact matches. Boolean operators such as AND, NOT and OR were employed strategically to combine and refine search terms, enabling more accurate filtering of relevant literature. In addition to the core search strings, broader or exploratory search terms (higher-order thinking, metacognitive process) were included as optional extensions to capture related studies that may not have used identical terminology but addressed the same instructional concepts.

Selection Process

A well-defined and systematically implemented selection process is widely recognized as a cornerstone of high-quality systematic reviews, ensuring transparency, consistency, and reduced bias in study inclusion (Frampton et al., 2017; Page et al., 2021; O'Mara-Eves et al., 2015; Waffenschmidt et al., 2019; Lasserson et al., 2024; Cooper et al., 2025). The screening and selection of studies for this systematic review were conducted by two independent reviewers: the researcher and Mwinlanaa Francis (mathematics teacher) using a structured three-stage process to ensure objectivity and rigor. In the first stage, the reviewers independently examined the titles and abstracts of all retrieved articles, excluding those that clearly did not meet the inclusion criteria. In the second stage, full-text versions of the remaining studies were obtained and thoroughly assessed against the predefined inclusion and exclusion criteria. Any discrepancies in judgment between the two reviewers were resolved through discussion or, when necessary, with the involvement of a third reviewer (Wein Mathew) also a mathematics teacher. The final stage involved the inclusion of only those studies that fully met all eligibility requirements, ensuring the quality and relevance of the selected evidence for the review

Data Collection Process

Systematic and well-documented data collection processes—such as piloting extraction forms, double-checking entries, and using standardized tools—are essential for ensuring the accuracy, consistency, and reliability of evidence synthesis (Li et al., 2024; Büchter, Weise, & Pieper, 2020; Mathes, Klasen, & Pieper, 2017; Taylor, Mahtani, & Aronson, 2021; Hartling et al., 2021). Data extraction was conducted using a standardized and pilot-tested data extraction form to ensure consistency, accuracy, and completeness across all included studies. The form was initially applied to a subset of studies to refine its structure and verify its effectiveness. Key information extracted included study details (author(s), year of publication, and country), sample characteristics (educational level), and intervention specifics (descriptions of collaborative learning methods and the implementation of Polya's problem-solving strategy). Additionally, outcome measures were documented, including the types of critical thinking assessments used, the instruments employed, and the reported results. Study design and methodological features such as data collection methods and statistical analyses were also recorded. Finally, key findings related to critical thinking outcomes were summarized. To enhance the reliability of the process, two independent reviewers (the researcher and Mwinlanaa Francis) performed the data extraction for each study. Any disagreements were resolved through discussion to reach a consensus.

Data Items

The data items stress on carefully defined and pre-specified data—covering study design, participants, interventions, outcomes, and results—are fundamental to accurate, reliable, and reproducible data extraction in systematic reviews (Li et al., 2024; Büchter et al., 2020; Büchter et al., 2021; Mathes et al., 2017; Taylor et al., 2021; Hartling et al., 2021). The following data elements were systematically extracted from each eligible study to ensure a comprehensive and structured synthesis of evidence. First, the author(s) and year of publication were recorded to provide complete citation information and track the temporal distribution of research. The study design was noted, categorizing each study as experimental or non-experimental to facilitate comparisons based on methodological rigor. Information on the sample size and education levels were extracted. This information was extracted to understand the scope and relevance of each study's findings in relation to the targeted educational population. Detailed descriptions of the intervention were captured, particularly focusing on the nature of the collaborative learning strategies employed and the manner in which Polya's problem-solving steps were integrated into the instruction. For each study, the measurement of critical thinking was also documented, including the specific tools or instruments used, such as standardized assessments, scoring rubrics, or qualitative evaluation methods. This was done to assess the consistency, validity, and comparability of how critical thinking skills were measured across the studies. Finally, the outcomes were recorded (See Appendix 1), detailing the reported effects on students' critical thinking skills, with supporting evidence such as qualitative indicators of improved reasoning and problem-solving abilities.

Risk of Bias Assessment

Assessing the risk of bias is essential to ensuring the credibility, validity, and reliability of evidence synthesized in systematic reviews (Higgins et al., 2011; Sterne et al., 2016; Sterne et al., 2019; Page et al., 2018; Page et al., 2023; Whiting et al., 2016). The quality and risk of bias of the included studies were evaluated using the Critical Appraisal Skills Programme (CASP) checklist tailored for educational research. This appraisal tool was chosen for its suitability in assessing both qualitative and quantitative studies in educational settings. The CASP checklist guided a structured evaluation of each study based on several key criteria. These included the clarity of the research question and objectives, ensuring that the study had a well-defined focus aligned with the systematic review topic.

The appropriateness of the research design was examined to determine whether the chosen methodology effectively addressed the research objectives. Sampling methods were assessed to evaluate the representativeness and adequacy of the study population. The checklist also reviewed the data collection and analysis procedures, focusing on whether these methods were robust, clearly described, and suitable for the research design. Finally, the reporting of findings was critically appraised, with attention to whether the results were presented clearly, logically, and supported by the data. This systematic appraisal helped ensure that only studies with acceptable methodological quality were included in the synthesis. Each study was rated as "low," "high," or "unclear" risk of bias in these areas. Studies were considered low risk if they demonstrated rigorous methodology and transparent reporting.

Synthesis Methods

The systematic reviews must carefully choose appropriate synthesis methods—such as meta-analysis, narrative synthesis, or tabulation—based on data availability and heterogeneity, while also pre-specifying decision rules and employing structured frameworks to ensure transparency and methodological integrity (McKenzie & Brennan, 2019; McKenzie et al., 2021; AHRQ, 2018; Gabriel et al., 2024; SSPH+ Public Health Reviews, 2023; Kale et al., 2019).

A narrative synthesis approach was adopted to summarize and integrate the findings of the included studies, as the methodological diversity—ranging from mixed-methods designs to the use of varied critical thinking assessment tools—rendered a meta-analysis inappropriate. To ensure systematic organization, the studies were first grouped according to their research design (e.g., experimental or non-experimental). A thematic synthesis was then conducted to identify recurring patterns, insights, and trends across the body of evidence. Three major thematic categories emerged. The first focused on the effectiveness of combining collaborative learning with Polya's problem-solving strategy in enhancing students' critical thinking skills, with many studies reporting notable improvements. The second theme explored the factors that influenced the success of the intervention, including variables such as instructor preparedness, students' prior knowledge, classroom environment, and institutional support. The third theme highlighted variations in critical thinking outcomes based on how the intervention was designed and implemented, pointing to differences in duration, instructional fidelity, and the integration depth of Polya's method. This synthesis approach allowed for a rich, contextual understanding of how and why the integrated instructional model impacts critical thinking.

Search Results

A total of 397 records were initially identified through database searches. After excluding 293 records that were published outside the targeted years (2021–2025), 104 records remained. Of these, 7 duplicate records were removed, resulting in 97 unique records for screening.

During the screening stage, 74 records were excluded due to one or more of the following reasons: wrong topics (n = 23), insufficient methodological Quality (n = 19), not focused on critical thinking (n = 17), or not integrating collaborative learning (CL) with Polya's problem-solving approach (n = 15). This left 23 studies for full-text eligibility assessment.

Following full-text review, 5 additional studies were excluded based on criteria reported in the supplementary materials. Ultimately, 18 studies were included in the final synthesis, incorporating both quantitative and qualitative findings. This rigorous selection process ensured that only relevant, high-quality studies addressing the integration of collaborative learning with Polya's method and its impact on students' critical thinking were included in the review.

A PRISMA flow diagram is presented in Figure 1 to illustrate the study selection process.

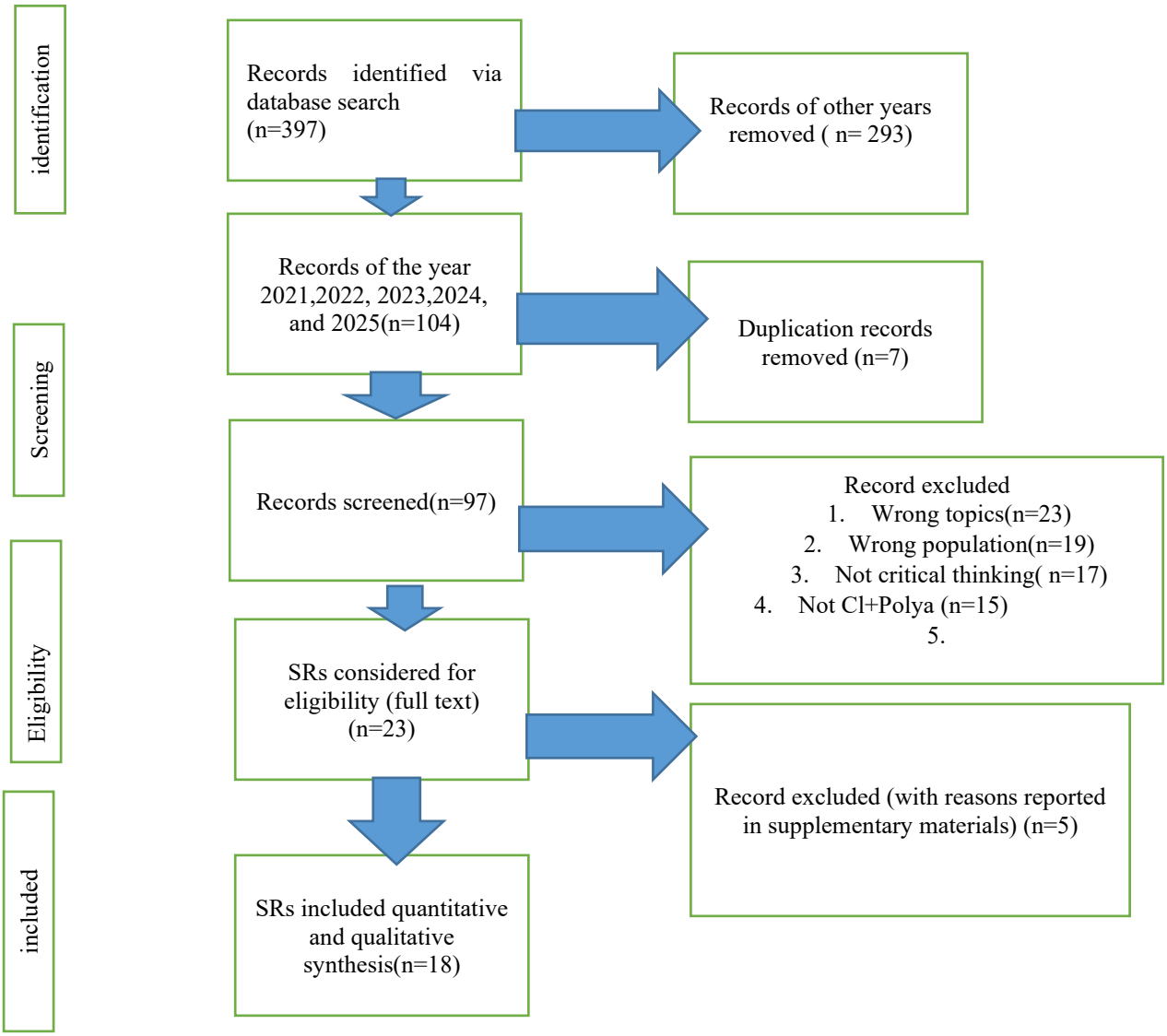

Figure 1. PRISMA Flow Diagram

Characteristics of Included Studies

The characteristics of included studies—such as study design, participant demographics, interventions, and outcomes—is essential for transparency, comparability, and contextual understanding in systematic reviews (Moher et al., 2009; Phillips et al., 2024; Cochrane EPOC, 2022; Cochrane Training, 2023). The 18 studies included in this systematic review were published between 2021 and 2025, capturing recent innovations and trends in mathematics education. Conducted across 13 different countries—namely Ghana, Nigeria, Turkey, Malaysia, Indonesia, Thailand, Ireland, Texas, China, Rwanda, Altiplano-puno, Taiwan the Philippines, and others—these studies reflect a diverse range of educational systems and instructional contexts, enhancing the generalizability of the findings. Sample sizes ranged from 28 to 1500 participants, with most studies situated in second cycle institutions and Tertiary, while a smaller subset focused on Basic institutions. The methodological approaches adopted in these studies were varied: 6 employed experimental designs, including randomized controlled trials and quasi-experimental methods; 2 utilized mixed-methods approaches that integrated both quantitative and

qualitative data collection and analysis; and 10 were qualitative case studies offering detailed contextual insights. The prevalence of qualitative case studies among the reviewed studies is particularly significant within the Ghanaian educational context and reflects broader trends in educational research. In Ghana, where systemic educational reforms such as the National Teacher Education Curriculum Framework (NTECF) are being implemented, qualitative research plays a crucial role in uncovering how these changes are experienced in real classroom environments. These methods provide rich, descriptive insights into teaching practices, student engagement, and contextual challenges—elements that are often difficult to quantify but are essential for informed policy and practice.

Qualitative approaches also offer a flexible framework for exploring the complexities of integrating pedagogical strategies like collaborative learning and Polya's problem-solving method, especially in settings where standardized interventions are not yet uniformly adopted. This is critical in Ghana, where variability in resources, teacher preparedness, and student backgrounds across urban and rural areas demands context-sensitive inquiry.
More broadly, in educational research, qualitative methods are essential for theory development, needs assessment, and generating grounded explanations of educational phenomena. They help bridge the gap between policy intentions and classroom realities by capturing voices, attitudes, and behaviors that shape learning processes. Thus, in both the Ghanaian setting and the wider research landscape, qualitative case studies are not merely an alternative to experimental research—they are an indispensable tool for deepening our understanding of how and why educational innovations succeed or falter.

The participants across the reviewed studies were students engaged in mathematics learning at various educational levels, from early childhood through to tertiary education. This broad representation supports the review's emphasis on examining how the integration of collaborative learning and Polya's problem-solving method fosters critical thinking across different stages of mathematical development. Overall, the range in study designs, participant demographics, and geographical distribution provides a rich and multifaceted evidence base for understanding the impact of integrating collaborative learning with Polya's problem-solving approach in calculus education.

Quality of Evidence

The quality of evidence in systematic reviews—often through structured frameworks like the GRADE approach—is essential for ensuring transparent, reliable, and actionable conclusions that guide both research and practice (Guyatt et al., 2011; Balshem et al., 2011; Brozek et al., 2009; Wu & Meerpohl, 2022; Kane et al., 2016; Fleming et al., 2014). Using the CASP Qualitative Checklist Table and Comparative Matrix for RCTs is a critical exercise in ensuring the rigor, transparency, and trustworthiness of a systematic review. This structured approach allows researchers to systematically evaluate and compare the quality of multiple studies based on consistent criteria, such as randomization, blinding, ethical considerations, and the precision of treatment effects. It ensures that the included studies are not only relevant but also methodologically sound, which strengthens the overall conclusions drawn from the review. In the Ghanaian context, where research utilization in educational decision-making is gaining momentum, such appraisal tools are especially important. They help filter out weak evidence, promote

evidence-based educational reforms, and guide policy and practice grounded in credible, high-quality research. Given that studies on pedagogical innovations like integrating collaborative learning with Polya's problem-solving approach are still emerging in Ghana, applying CASP enhances the credibility and applicability of findings to the local educational. Table 3, 4, 5 and 6 represented the CASP Checklist.

Table 3. CASP Qualitative Checklist

CASP Questions	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6	Study 7	Study 8	Study 9	Study 10
1. Was there a clear statement of the research aims?	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
2. Is a qualitative methodology appropriate?	Low	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
3. Was the research design appropriate to address the aims?	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
4. Was the recruitment strategy appropriate?	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
5. Was the data collected in a way that addressed the research issue?	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
6. Has the relationship between researcher and participants been considered?	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
7. Have ethical issues been taken into consideration?	Cann ot tell	Low risk	Connot tell	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
8. Was the data	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

CASP Questions	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6	Study 7	Study 8	Study 9	Study 10
analysis sufficiently rigorous?	risk	risk	risk	risk	risk	risk	risk	risk	risk	risk
9. Is there a clear statement of findings?	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk
10. How valuable is the research?	Cann ot tell	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk

Table 4. Author, Year and Database

Study	**Author/year**	**Database**
Study 1	Satoshi Kusakaa and Jean Claude Habimana(2025), Rwanda	Tylor & Francis group
Study2	Sevda Dolapcioglu & Ahmet Doğanay, 2022, Turkey	Tylor & Francis group
Study3	Oben Kanbolat(2023)	Eric
Study4	In Hi. Abdullah1, Hery Suharna1 & Mustafa AH. Ruhama1(2024)	Eric
Study5	1Epifani Putri Mariana & 2Yosep Dwi Kristanto(2023)	Eric
Study6	Aidan Fitzsimons & Eabhnat Ní Fhloinn, 2024, Ireland	Eric
Study7	Yulianti Yusal1)*, Andi Suhandi2), Wawan Setiawan3), Ida Kaniawati2), 2023 and Indonesia	Sage
Study8	Mohamad Ikram Zakaria1, Nik Abdul Hadi Noor Nasran2, Abdul Halim Abdullah3, Najua Syuhada Ahmad Alhassora4, Rasidi Pairan5, Wanda Nugroho Yanuarto6(2024)	Eric
Study9	Hobri, Herry Agus Susanto, Alvi Hidayati, Susanto, Warli(2021)	Eric
Study10	Rizqiana Azizah Saraswatia), Sumbaji Putrantob), Caturtunggal, 2021	Tylor & Francis group

Use this matrix to compare multiple Randomised Controlled Trials (RCTs) across CASP criteria. Each column represents a different study; each row is a CASP question.

Table 5. Represent Comparative Matrix – CASP RCT Appraisal

CASP Question	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6	Study 7	Study 8
1. Did the trial address a clearly focused issue?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2. Was the assignment of participants to interventions	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

CASP Question	Study 1	Study 2	Study 3	Study 4	Study 5	Study 6	Study 7	Study 8
randomized?								
3. Were all participants who entered the trial properly accounted for at its conclusion?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4. Were participants, staff, and study personnel 'blind' to treatment?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
5. Were the groups similar at the start of the trial?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
6. Aside from the experimental intervention, were the groups treated equally?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
c7. How large was the treatment effect?	Large Positive Effect size	Large Positive Effect size	Large Positive Effect size	Cannot tell	Large Positive Effect size	Large Positive Effect size	Large Positive Effect size	Large Positive Effect size
8. How precise was the estimate of the treatment effect?	High level precision	High level precision	High level precision	Cannot tell	High level precision	High level precision	High level precision	High level precision
9. Can the results be applied to the local population/context?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
10. Were all clinically important outcomes considered?	Partially	Partially	Partially	Partially	Partially	Partially	Partially	Partially
11. Are the benefits worth the harms and costs?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table 6. Author, Year and Database

Study	**Author/Year**	**Database**
Study1	Al-Jehada B. Gulam 1, * and Joel C. Arenas 2(2024)	Google Scholar
Study2	Dwi Yulianto *, Moh Rizal Umami, Randa Sarah Mony(2024)	Google Scholar

Study	Author/Year	Database
Study3	Lei Xie Suwisa ratkamolpong Supawadee Kanjanakate, 2025,	Google Scholar
Study4	JeffreyA. Phillips,Katharine W. Clemmer,JeremyE. B. McCallum, and Thomas M. Zachariah (2025)	JSTOR
Study5	Dongdong Zhou a, Hui Li a, YuWei Sima a, Yaqing Hanb and Fan Shi c(2025)	Tylor &Francis
Study6	Yulianti Yusal1)*, Andi Suhandi2), Wawan Setiawan3), Ida Kaniawati2), 2023 and Indonesia	Sage
Study7	Afiqah Bari'ah Emran1, Masitah Shahrill2 and Daniel Asamoah2(2023)	Sage
Study8	Ludfiahtul Habibah1, Suratno2, Mochammad Iqbal3, 2023 and Jalan	Tylor & Francis

The table incorporating Author, Year, and Database, alongside the CASP Qualitative Checklist Table and the Comparative Matrix for RCTs, serves as a comprehensive framework for evaluating and presenting the methodological quality of included studies in a systematic review. The Author, Year, and Database section ensures clear traceability and transparency in study selection, helping to identify the origin, recency, and source credibility of each study. The CASP Qualitative Checklist Table provides a structured appraisal of qualitative studies, ensuring that issues such as clarity of aims, appropriateness of methodology, and ethical rigor are critically examined. Similarly, the Comparative Matrix for RCTs allows for side-by-side assessment of randomized controlled trials across key CASP domains such as randomization, blinding, and outcome reporting. Together, these three components promote methodological rigor, enhance comparability, and support the selection of high-quality evidence—particularly crucial in the Ghanaian educational context, where decisions based on robust evidence can greatly influence teaching innovations and policy reforms.

Results

Summary of Key Findings

The following key findings highlight critical gaps in the existing literature—areas that have received limited attention yet are essential for a comprehensive understanding and advancement of the field.

1. There is a noticeable lack of precise empirical research examining the effect of integrating collaborative learning with Polya's problem-solving method on the development of critical thinking skills among pre-service teachers.
2. While the integrated model has been applied in studies focusing on other educational outcomes such as academic performance, engagement, and motivation, its specific influence on critical thinking remains under-investigated.
3. Critical thinking is an underexplored construct within mathematics education literature, particularly in relation to instructional strategies aimed at pre-service teacher training.
4. Critical thinking is primarily emphasized at the senior high school and tertiary education levels.

Interpretations of Major Findings in the Review

In the Ghanaian context, the findings of this systematic review underscore a pressing concern for the future of mathematics teacher education. The lack of empirical studies integrating collaborative learning with Polya's problem-solving method to enhance critical thinking skills directly contradicts the goals outlined in the National Teacher Education Curriculum Framework (NTECF, 2018), which advocates for inquiry-based, learner-centered instruction. Ghana's education system is actively seeking to move away from rote memorization and passive learning, yet without research-backed instructional models that develop critical thinking, this transition remains theoretical and difficult to implement effectively. Pre-service teachers in Ghana are at a pivotal stage in their professional development and must be equipped not just with content knowledge, but with cognitive strategies that promote reasoning, reflection, and problem-solving. The integrated approach discussed in the review offers such potential. However, without local evidence demonstrating its effectiveness, educational institutions may hesitate to adopt it, perpetuating traditional methods that fail to prepare teachers for the demands of modern classrooms. Furthermore, in a country where high-stakes examinations often shape instructional priorities, the absence of critical thinking-focused pedagogies means that students—and by extension, their teachers—may continue to prioritize memorization over understanding. This misalignment between policy goals and classroom realities highlights the urgent need for Ghanaian-specific research to guide teacher training programs. By filling this gap, educators and policymakers can ensure that the curriculum reforms translate into meaningful pedagogical practices, ultimately improving teaching quality and student learning outcomes nationwide.

Building upon this concern, the under exploration of critical thinking within studies employing collaborative and problem-solving instructional models points to a significant missed opportunity in the Ghanaian educational landscape. While existing research has effectively applied these models to improve academic achievement, motivation, and engagement, their capacity to foster critical thinking—an essential 21st-century skill—remains largely untapped. This gap is particularly concerning given Ghana's ongoing efforts to shift from procedural teaching to conceptual understanding, as emphasized in current education reforms. In most Ghanaian mathematics classrooms, instruction continues to be shaped by high-stakes assessments that prioritize correct answers over reasoning processes. This results in limited emphasis on cognitive skills such as analysis, evaluation, and independent thinking. The integration of collaborative learning and Polya's problem-solving strategy holds strong promise in changing this paradigm by encouraging student-led inquiry and deeper comprehension. However, the scarcity of studies applying this model to critical thinking indicates a reluctance—or perhaps a lack of readiness—within the system to adopt instructional frameworks that demand both pedagogical innovation and a rethinking of assessment norms. Additionally, the limited use of this approach likely reflects systemic constraints such as inadequate teacher training, lack of professional development opportunities, and a gap between curriculum intentions and actual classroom practice. For Ghana to fully realize the benefits of its curriculum reforms, it must invest in empirical research that supports instructional strategies capable of promoting higher-order thinking. Equipping teachers with both the tools and confidence to implement these models will be crucial to transforming mathematics education into a platform for cognitive empowerment, not just examination success.

In light of these issues, it is important to emphasize that the marginal presence of critical thinking in mathematics

education research across sub-Saharan Africa—Ghana included—is both striking and concerning. Although national education policies repeatedly identify critical thinking as a foundational skill for 21st-century learners, the lack of empirical inquiry into how this competence is developed through everyday teaching practices reveals a disconnect between policy intentions and educational realities. This shortfall undermines efforts to equip pre-service teachers with the instructional tools and cognitive habits necessary for fostering analytical reasoning in their future classrooms. Given this context, it is both urgent and necessary for future research in Ghana to pursue intervention-based studies that rigorously test the integration of collaborative learning and Polya's problem-solving strategy as a means of developing critical thinking among pre-service mathematics teachers. Such investigations would provide evidence-based insights into effective teaching methodologies while helping to shape more relevant, responsive, and transformative teacher education programs. Ultimately, prioritizing this line of inquiry is not only an academic exercise but a national imperative. It aligns directly with Ghana's aspirations for curriculum transformation, educational equity, and the cultivation of a critically minded citizenry capable of navigating complex challenges in an increasingly knowledge-driven world.

In the Ghanaian context, the finding that critical thinking is taught largely at the second-cycle (senior high school) and tertiary levels suggests that students are often not introduced to structured critical thinking skills during the foundational stages of education—such as in basic schools (primary and junior high). This implies a missed opportunity to develop essential reasoning, problem-solving, and analytical abilities early in students' academic journeys. As a result, many learners may struggle with independent thinking and decision-making when they reach higher levels of education, where such skills are expected. This highlights the need to integrate critical thinking instruction across all educational levels in Ghana to build a stronger cognitive foundation from an early age.

Interpretations of other Findings Addressing the Review Objectives

Objective 1: Effectiveness of Integrating Collaborative Learning with Polya's Problem-Solving Approach on pre-service' Critical Thinking

The review revealed substantial evidence supporting the effectiveness of integrating collaborative learning with Polya's problem-solving approach in enhancing pre service teachers' critical thinking skills, particularly in mathematics education. Across the reviewed studies, students who participated in this integrated instructional model demonstrated improved abilities in logical reasoning, argumentation, reflective judgment, and solution analysis compared to those in traditional lecture-based settings. Several quasi-experimental and intervention-based studies reported statistically significant gains in critical thinking assessments post-intervention. These gains were especially evident when the learning environment promoted student dialogue, peer questioning, and step-by-step heuristic problem-solving based on Polya's stages (understanding the problem, devising a plan, carrying out the plan, and looking back). This suggests that the integration of collaborative learning and Polya's method not only facilitates content mastery but also promotes higher-order thinking.

Objective 2: Instructional Conditions or Contexts that Influence Its Impact

The review identified several key instructional conditions that influenced the success of integrating collaborative

learning with Polya's problem-solving approach. Notably, classroom cultures that encouraged collaboration, guided inquiry, and reflective dialogue significantly enhanced students' engagement and cognitive development. Studies showed that teacher facilitation quality, group composition, and the structure of problem-solving tasks affected outcomes (Hidayati, Susanto, & Warli, 2021). Classrooms where teachers were trained in facilitating both collaborative learning and Polya's method tended to report stronger results. Additionally, the integration was more effective in contexts where students had moderate to high prior knowledge, suggesting that foundational understanding may mediate the effectiveness of this combined approach. Technology use, instructional time allocation, and institutional support were also found to moderate the impact of the integration across various educational settings.

Objective 3: Gaps in the Current Literature to Inform Future Research

Despite the promising evidence, the review highlighted notable gaps in the current literature. Few studies examined the long-term impact of integrating collaborative learning with Polya's problem-solving approach on students' critical thinking beyond the intervention period. There was also a scarcity of research from low-resource contexts, particularly in sub-Saharan Africa, where cultural and infrastructural factors may influence instructional implementation. Additionally, limited attention has been given to how individual learner differences—such as gender, motivation, and prior knowledge—interact with the integration. Most studies relied on quantitative measures, with minimal use of qualitative insights that could deepen understanding of classroom dynamics and student experiences (Arabaçı, & Kanbolat, 2023). These gaps indicate the need for more diverse, context-sensitive, and longitudinal research to fully understand the potential and limitations of collaborative learning combined with Polya's problem-solving method in various educational settings.

Discussion

One significant finding identified in the literature is the limited availability of rigorous empirical research that explores the impact of integrating collaborative learning with Polya's problem-solving strategy on the critical thinking development of pre-service teachers. Although both collaborative learning and Polya's method are widely acknowledged as effective instructional strategies (Dolapcioglu & Doğanay, 2022; Kusakaa & Habimana, 2025), most existing studies zero in on general student outcomes such as academic achievement, engagement, or motivation (Kanbolat, 2023). The specific intersection of these approaches as a means to develop critical thinking in teacher education programs, particularly in mathematics, remains largely overlooked.

Although critical thinking is recognized globally as a core competency for the 21st century (OECD, 2018), it continues to fly under the radar within mathematics education research—particularly in the context of instructional strategies for pre-service teachers. Much of the existing literature focuses on mathematical content knowledge and procedural fluency, often leaving out essential dimensions such as analytical reasoning, reflective judgment, and cognitive flexibility (Olanrewaju & Adebayo, 2023). This narrow emphasis reflects a longstanding belief that mastery of content should come before higher-order thinking, despite evidence suggesting that critical thinking and conceptual understanding should go hand in hand (Gillies, 2016).

Despite the growing body of research demonstrating the effectiveness of collaborative learning and Polya's problem-solving strategy in enhancing student outcomes such as academic performance, motivation, and engagement (Gillies, 2016; Olanrewaju & Adebayo, 2023), their specific influence on critical thinking remains off the radar. Much of the literature tends to prioritize measurable outcomes like test scores or student satisfaction, often at the expense of investigating deeper cognitive skills such as analysis, evaluation, and inference—core components of critical thinking (Olanrewaju & Adebayo, 2023). This oversight results in an incomplete pedagogical picture, glossing over the full potential of integrating these strategies in mathematics instruction.

It was also revealed that, in many education systems—including Ghana's—critical thinking instruction is largely geared toward the senior high and tertiary levels, leaving early educational stages underdeveloped in this regard (NTECF, 2018). This fragmented approach ignores critical periods of cognitive development during the primary and junior high school years, when foundational reasoning skills, problem-solving habits, and curiosity should be intentionally cultivated (Vygotsky, 1978). Waiting until later stages to emphasize analytical thinking not only cuts off cumulative intellectual growth but also puts undue pressure on students to suddenly adopt complex thinking habits with little preparatory support.

This delayed focus has practical consequences in Ghanaian classrooms. Many students arrive at senior high school or university with little experience in justifying solutions, posing problems, or engaging in abstract reasoning—yet they are expected to keep up with complex mathematics curricula that presuppose these very abilities. For both students and educators, this misalignment results in low confidence, disengagement, and persistent underperformance, particularly in mathematics assessments (WAEC, 2022). Early and systematic integration of critical thinking into mathematics instruction, starting from teacher education through basic education, is crucial to breaking the cycle. By equipping future teachers with strategies that foster reasoning and inquiry from the foundational level, Ghana can create a stronger, more coherent learning trajectory.

The lack of empirical precision was also identified as a concern, given that pre-service teachers are expected to become facilitators of problem-solving and analytical reasoning in their future classrooms. Without firsthand experience of instructional models that explicitly cultivate critical thinking, teacher trainees may fall short in promoting these skills in their students. As Vygotsky (1978) emphasized, learning is a socially mediated process, and instructional strategies that draw on social interaction and guided discovery—like collaborative learning coupled with problem-solving—can provide powerful scaffolding for developing higher-order thinking skills. If this issue is not addressed, it may come back to haunt future educational outcomes. After all, "you cannot give what you don't have." Thus, it is vital that teacher education programs step up efforts to embed such evidence-based practices.

In the Ghanaian context, this research finding has serious implications. Ghana's National Teacher Education Curriculum Framework (NTECF, 2018; Doğanay, & Doğanay, 2022) calls for a shift toward competency-based teacher education, stressing the importance of critical thinking, reflective practice, and learner-centered instruction. Yet, in the absence of context-specific studies that back up and validate the integration of proven instructional strategies, policy reform and pedagogical innovation remain on shaky ground. This not only drags

down the quality of mathematics instruction in colleges of education but also risks producing teachers who are ill-equipped to bring out critical, analytical learners—an outcome at odds with Ghana's broader educational goals. The implications of this research gap are particularly serious for Ghana, where students frequently fall short in applying higher-order thinking in mathematics assessments and classroom problem-solving tasks (Anamuah-Mensah et al., 2021; Zakaria, Noor Nasran, Abdullah, Ahmad Alhassora, Pairan, & Yanuarto, 2024). Without empirical validation of the impact of collaborative-Polya integration on critical thinking, educators may continue to focus disproportionately on procedural knowledge and rote learning, driven by examination-oriented goals rather than the development of conceptual understanding and reasoning. This trend runs counter to Ghana's ongoing educational reforms, which emphasize the cultivation of 21st-century skills, including critical thinking, creativity, and problem-solving (NTECF, 2018; Emran, Shahrill, & Asamoah, 2023). "You learn how to cut down trees by cutting them," and without digging into strategies that build reasoning, progress in education may remain superficial.

To get to the root of this gap, there is an urgent need for empirical studies that explore how collaborative learning frameworks—especially when guided by structured heuristics like Polya's four-step method—can meaningfully influence pre-service teachers' critical thinking capacity, both in Ghana and similar low- and middle-income contexts. After all, "a child who does not travel thinks his mother is the best cook." Without localized evidence to guide practice, Ghana risks missing the mark on much-needed educational transformation.

The findings of this systematic review are strongly supported by existing literature, reinforcing the pedagogical value of integrating collaborative learning with Polya's problem-solving strategy in mathematics education. Collaborative learning has long been recognized for its role in promoting dialogic reasoning, social interaction, and the co-construction of knowledge (Ciddi, 2025; Emran, Shahrill, & Asamoah, 2023; Vygotsky, 1978). When learners engage in group-based problem solving, they are encouraged to articulate their thought processes, negotiate meaning, and reflect on alternative perspectives—processes that are central to the development of critical thinking.

Simultaneously, Polya's four-step problem-solving model—understand the problem, devise a plan, carry out the plan, and look back—provides a structured cognitive framework that supports systematic and reflective mathematical thinking (Polya, 1957). When applied within a collaborative setting, this structure enhances students' capacity to analyze problems more deeply, consider multiple solution strategies, and justify their reasoning with peer input and feedback. As such, the integration of these two approaches creates a powerful synergy: collaborative interaction stimulates metacognition, while Polya's method provides cognitive scaffolding that enables students to navigate complex tasks more effectively.

This combined approach aligns with the findings of previous studies. For instance, (Hobri, Susanto, Hidayati, Susanto, & Warli, 2021; Zakaria et al., 2024) demonstrated that integrating metacognitive instruction with problem-solving strategies significantly improved students' higher-order thinking and mathematical reasoning. Similarly, (Arabaçı, & Kanbolat, 2023; Doğanay, & Doğanay, 2022; Kusaka, & Habimana, 2025) found that students taught using a combination of collaborative learning and structured problem-solving techniques

outperformed their peers in both achievement and critical reasoning tasks. These studies, along with the current review's findings, suggest that the traditional, teacher-centered approach—which often prioritizes procedural fluency over conceptual understanding—may be insufficient for fostering deep mathematical reasoning.

Instead, the reviewed studies emphasize the importance of active student participation, peer interaction, and metacognitive reflection, all of which are essential components of critical thinking (Habibah, Suratno, & Iqbal, 2023; Emran, Shahrill, & Asamoah, 2023). The integration model's strength lies in its ability to bridge the gap between procedural rigor and cognitive engagement, providing learners with the opportunity to explore problems collaboratively while adhering to a logical problem-solving process. This balance not only enhances critical thinking but also supports long-term retention and transfer of mathematical knowledge—key goals in 21st-century education.

Strengths and Limitations

This systematic review presents several notable strengths that enhance the credibility, depth, and relevance of its findings. Foremost among these is the rigorous and transparent methodology, which followed established systematic review protocols, including clearly defined eligibility criteria, comprehensive database searches, and a dual-reviewer screening process. Such methodological precision significantly reduced selection bias and ensured the inclusion of relevant and high-quality studies, consistent with best practices outlined by the PRISMA guidelines (Page et al., 2021). The inclusion of diverse research designs—quantitative, qualitative, and mixed-methods—is another key strength, as it allowed for a holistic and context-rich synthesis of evidence. This integrative approach provided a nuanced understanding of both measurable outcomes and the pedagogical processes underlying the success of the intervention.

Moreover, the use of thematic synthesis enabled the identification of patterns and insights that may not have been immediately evident within individual studies. By grouping findings according to emerging themes such as critical thinking gains, instructional design, and contextual influences, the review was able to generate practically meaningful conclusions that extend beyond individual contexts. This thematic approach aligns with the recommendations of (Page et al., 2021), who emphasize its value in educational research for synthesizing complex, heterogeneous data. However, the review is not without limitations. A major constraint is the language restriction—only studies published in English were included. This may have excluded valuable insights from non-English literature, introducing language bias and potentially limiting the cultural diversity of perspectives represented. Additionally, while the majority of included studies reported positive outcomes, there was considerable variability in intervention duration, instructor competence, and student demographic characteristics, which could influence the fidelity and impact of the instructional approach. Such heterogeneity makes it challenging to generalize findings across all educational contexts.

Furthermore, the absence of a meta-analytic synthesis—necessitated by methodological differences across the studies—means that the review cannot offer precise, pooled effect size estimates. Although narrative synthesis allows for rich thematic exploration, it lacks the statistical power of meta-analysis for quantifying intervention

effectiveness. As Page et al., (2021) caution, such limitations underscore the need for caution in interpreting the magnitude of the intervention's impact. In sum, while this review offers a comprehensive and insightful synthesis of the literature, future work could strengthen the evidence base by including non-English studies, standardizing intervention reporting, and, where possible, conducting meta-analyses on more homogeneous subsets of studies to better quantify effect sizes.

Conclusion

This systematic review offers compelling evidence that the integration of collaborative learning with Polya's problem-solving strategy is a highly effective instructional approach for enhancing critical thinking skills in mathematics education. Drawing from studies conducted across a variety of educational levels and cultural contexts, the review demonstrates that this combined pedagogical model fosters deeper conceptual understanding, enhanced logical reasoning, and reflective thought processes. Students engaged in this approach not only improve their ability to solve complex mathematical problems but also develop essential metacognitive skills that support both academic performance and lifelong learning.

The review also reveals that, although the implementation strategies varied—ranging from short-term interventions to semester-long programs—the positive outcomes were consistent, especially when the integration was intentionally designed and delivered by well-prepared instructors. These findings underscore the importance of structured scaffolding, where collaborative tasks are aligned with Polya's systematic problem-solving framework, allowing students to internalize strategic thinking through peer interaction and guided reflection.

Importantly, the review underscores that fostering critical thinking should never be left to chance. It must be purposefully nurtured from the earliest stages of education by embedding it into instructional design through a deliberate blend of collaborative learning and structured thinking processes. When introduced early and reinforced consistently, students are not only better prepared to tackle mathematical tasks but are also more likely to apply these advanced reasoning skills across disciplines and in everyday life problem-solving contexts.

Recommendations

For Educational Practice

Mathematics educators, especially those teaching calculus, are encouraged to adopt instructional strategies that deliberately merge collaborative learning techniques with Polya's structured problem-solving framework. This integration supports both conceptual mastery and the development of critical thinking. To ensure effective implementation, instructors should undergo targeted professional development focused on facilitating collaborative group work and guiding students through Polya's four-step problem-solving process. Additionally, assessment practices should extend beyond traditional testing to include diverse tools that evaluate both the cognitive processes and the performance-based problem-solving abilities of students, thereby providing a more comprehensive picture of critical thinking development.

For Policy and Curriculum Development

Curriculum designers at both national and institutional levels should consider revising mathematics syllabi to formally include collaborative, problem-solving-based instructional models, particularly at the senior high school and tertiary levels. These revisions should prioritize methods that foster active learning, peer engagement, and structured reasoning. Likewise, teacher education programs must embed training that equips future educators with skills in collaborative learning facilitation and structured problem-solving, ensuring that they are fully prepared to implement and sustain these approaches in the classroom.

For Future Research

There is a pressing need for longitudinal studies to investigate the sustained impact of this integrated instructional model on students' critical thinking and overall academic performance over time. In addition, future research should explore how this approach performs in culturally diverse and resource-constrained environments, such as in sub-Saharan Africa and rural educational settings, where contextual factors may influence outcomes. Finally, with the growing role of technology in education, further studies should evaluate the model's effectiveness within digital and blended learning environments, to better inform pedagogical strategies that respond to evolving instructional contexts.

Acknowledgement

I sincerely acknowledge the support and contributions of all individuals, databases and institutions that played a role in the completion of this paper. I extend my gratitude to the participating Professor Yarhands Dissou Arthur, Dr. Emmanuel Akwerty and teachers for their cooperation and valuable insights. I also appreciate the guidance and feedback received from academic mentors and colleagues throughout the writing process. Their input greatly enriched the quality.

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Appendix. Studies used for the Systematic Review

Name of Journal	Author/ Year/Country	Focus of study	Study design	Intervention Or not	Population Or not	Statistical analysis
ERIC						
Anatolian Journal of Education	Damar Rais, Zhao Xuezhi, 2023, China	the difficulties in the teaching process of programming occur from teaching perspectives	experimental	Python Programming	grade XI	parametric test analysis of variance
Southeast Asia Mathematics Education Journal	1Epifani Putri Mariana & 2Yosep Dwi Kristanto, 2023 and Indonesia	Many Students' still have low creative thinking skills.	Descriptive qualitative method.	Integrating STEAM Education and Computational Thinking	eighth-grade students	Qualitative analysis(narrative analysis)
Journal of Education and Learning (EduLearn)	Kanyarat Sonsupap, Kanyarat Cojorn, 2024 and Thailand	Bolster teaching competence and facilitate professional growth.	qualitative approach	using the potential of two intertwined strategies CoP and lesson study as powerful tools	Teachers	Content analysis and interpretation of the data.
Journal of Education and Learning;	Lalita Yapatang1 & Titiworada Polyiem, 2022 and Thailand	instructing mathematical problem-solving ability	experimental	Cooperative Learning and Polya's Problem-Solving	grade 9 students	one-sample t-test, paired-samples t-test,
European Journal of Science and Mathematics Education,	Mark Applebaum, 2025, , ISRAEL	creative and critical thinking	design of learning games	math games, particularly Bachet's game,	Pre service teacher	Qualitative analysis
Asian Journal of Contemporary Education	Lei Xie Suwisa ratkamolpong Supawadee Kanjanakate, 2025, Thailand.	students' problem-solving and teamwork skills in mathematics	A quasi - experimental	Constructing an integrated problem-based and collaborative learning model	Grade 4 students	a paired sample t-test analysis
Mathematics Teaching Research Journal	Arif Hidayatul Khusna1,2, Tatag Yuli Eko Siswono1*, Pradnyo Wijayanti, 2024 and Indonesia	Students' Critical Thinking Skills in Collaborative Problem Solving	Not explicit	Mathematical Problem Design	Not explicit	Narrative analysis
T&F						
Higher Education Research & Development	Gonçalo Cruz Helena Silva a,d*, Rita Payan-Carreira c,e and Felicidade Morais b*, Caroline Dominguez c,f a,d, 2021 and Portugal	studies dealing with employers' perceptions on CT meaning and envisioning in the workplace are scarce	qualitative	No intervention	employers	Using Facione's framework for data analysis
Teachers and Teaching theory and practice	Jina Ro, South Korea and 2023	yet there has been little effort to clarify its(CT) meaning and significance at	Mixed method	No intervention	No	From a combination of quantitative and qualitative

Name of Journal	Author/ Year/Country	Focus of study	Study design	Intervention Or not	Population Or not	Statistical analysis
		the policy level.				content analyses on pertinent policy documents,
Irish Educational Studies	Aidan Fitzsimons & Eabhnat Ní Fhloinn, 2024, Ireland	collaborative problem-solving in mathematics	qualitative	The cops model	post-primary school students	thematic analysis
Journal of College Science Teaching	Christa Evangelisto, 2023 and Texas.	Overcoming Obstacles and Finding Support for Teaching Critical Thinking in STEM	qualitative	No intervention	teachers	Thematic analysis
International Journal of Mathematical Education in Science and Technology	Sevda Dolapcioglu & Ahmet Doğanay, 2022, Turkey	Development Of critical thinking	qualitative research pattern which includes systematic data collection for analysis of an existing problem,	Authentic learning	34 fifth graders	Using excel for frequency
Reflective Practice International and Multidisciplinary Perspective	Von Christopher Chua, 2021, Philippines	Improving learners' productive disposition	action research design,	realistic mathematics education, a teacher's critical reflection of personal pedagogy	tenth grade learners	thematic analysis
Investigations in Mathematics Learning	Thomas Roberts, Cathrine Maiorca, Christa Jackson & Margaret Mohr Schroede, 2022	Problem-Solving Practices	No explicit	Integrated STEM	no	no
International Journal of Science Education	Dongdong Zhou, Hui Li, YuWei Sima, Yaqing Han & Fan Sh, 2025 and china	Improving middle school students' collaborative problem- solving competence in project-based learning	Mixed method	instant feedback in science curriculum*	ninth grade	Mixed analysis
The Journal of educaTional research	Satoshi Kusakaa and Jean Claude Habimanab, 2025 Rwanda	Metacognitive skills	Qualitative	collaborative problem solving	seventh-grade students	Framwork analysis
Cogent Education	Bright Asare, Yarhands Dissou Arthur & Benjamin Adu Obeng, 2025, Ghana	examining the moderating effect of problem-solving skills on the bond between mathematical self-	cross-sectional design	the role of problem-solving skills	university students	Quantitative analysis

Name of Journal	Author/ Year/Country	Focus of study	Study design	Intervention Or not	Population Or not	Statistical analysis
		belief and mathematical creativity				
Computer Science Education	Ugur Kale, Jiangmei Yuan & Abhik Roy, 2023	CT has been highlighted in recent coding initiatives	qualitative	A relational analysis approach	3 rd rd grade	content analysis to
Research in Science & Technological Education	Xiaoyong Hu, Wanyi Li, Xingyu Geng & Li Zhao, 2024 and China	students' creativity in STEM education	method of quasi-experimental research	Exploring the effects of different interventions of the problem-oriented teaching mode	STEM students	independent samples t tests
EURASIA Journal of Mathematics, Science and Technology Education	Muslim Muslim 1,2 , Toto Nusantara 1* , Sudirman Sudirman 1 , Santi Irawati 1, 2024 and INDONESIA	The causes of changes in student positioning in group discussions	Qualitaive	Polya's problem-solving and commognitive approaches	mathematics education students	Narrative analysis
African Scholar Publications & Research International www.africanscholarpub.com	*Mukhtar Sunusi Hassan; & **Usman Abdullahi Sani, 2025 and Nigeria	Exploring the Effectiveness of Cooperative Learning Strategies in Secondary Mathematics Education	quasi-experimental design	Using Polya' sProblem Solving Method	SHS students	Quantitative analysis
Jurnal eScience Humanity 5	Mohammad Edy Nurtamam1, Ana Naimatul Jannah2, 2024 and Indonesia	there is a gap in understanding how much PBL affects students' ability to effectively implement all stages of Polya, which is the focus of this study		PBL		meta-analysis a
Union: Jurnal Ilmiah Pendidikan Matematika	Dwi Yulianto *, MohRizal Umami, Randa Sarah Mony,2024 and Indonesia	Fostering critical thinking and self-efficacy in mathematics students	a Quasi-Experimental Design method	Exploring the impact of contextual learning and problem-based learning as well as direct instruction	eighth-grade students	Quantitative analysis
Advances in Social Science, Education and Humanities Research,	Lia Budi Tristanti1,* Toto Nusantara2	Students' Mathematical Argument	experimental research	CIRC-Typed and Problem-Based Cooperative Learning Models	undergraduate students	Quantitative analysis
World Journal of Advanced Research and Reviews	Al-Jehada B. Gulam 1, * and Joel C. Arenas 2024, Philippines	The uncertainty of performance in problem-solving skills	pretest-posttest design	using Polya's four step method in problem solving	g Grade nine (9) students	Quantitative analysis
Journal of	Lalita Yapatang1 &	Development of the	n experimental	Cooperative	grade 9	Quantitative

Name of Journal	Author/ Year/Country	Focus of study	Study design	Intervention Or not	Population Or not	Statistical analysis
Education and Learning	Titiworada Polyiem1, 2022 and Thailand	Mathematical Problem-Solving Ability	design.	Learning and Polya's Problem-Solving Process	students	analysis
International Journal of Religion	Fredy Sosa-Gutierrez1, Henry Mark Vilca Apaza2, Silvia Verónica Valdivia-Yábar3 and Wido Willam Condori-Castillo4, 2023, Altiplano – Puno.	Assessing critical thinking is a difficult task	non-experimental (correlational design)	No intervention	no	Inferential statistics were used using the SPSS statistical package.
Mathematics Teaching Research Journal	Arif Hidayatul Khusna1,2, Tatag Yuli Eko Siswono1*, Pradnyo Wijayanti1, Indonesia and 2024	Problems related to quadratic functions	experimental	Non-routine problem	high school students.	Analysis students' work
International Electronic Journal of Mathematics Education	Nurfirzanah Muhamad Fadzil 1 , Sharifah Osman 1*, MALAYSIA and 2025	the insufficient understanding of how the three methods–TAPPS, jigsaw, and fishbowl–differ in their impact on cognitive skills, subtle aspects of student behavior, and students' learning styles and abilities	non-empirical design	No intervention		systematic analysis
International Research Journal of Education and Sciences	Siew Nyet Moi and Katherine Anak Sipang, Malaysia and 2023	However, most of the students who take IQT find it difficult to describe the real situation in each question.	qualitative	How Jigsaw's Cooperative Learning Method and Polya's Problem Solving Model	Bachelor's students	thematic analysis approach
Indonesian Journal of Mathematics Education	Rizqiana Azizah Saraswatia), Sumbaji Putrantob), Caturtunggal, 2021	researchers are interested in studying critical thinking skills in solving mathematical problems in terms of students' cognitive styles, especially Field-Independent (FI) and Field Dependent (FD)	qualitative approach	no	Islamic senior high school	Thematic analysis

Name of Journal	Author/ Year/Country	Focus of study	Study design	Intervention Or not	Population Or not	Statistical analysis
		cognitive styles.				
International Journal Of Multidisciplinary: Applied Business And Education Research	Ana Laigue Viado1, Jo A. Espiritu Department, 2023, Philippines	Improving the Critical Thinking Skills of Secondary Students in the Philippines	"single subject experimental design"	The Collaborative-Individual Learning	Secondary Students	item analysis to identify the most and least learned items in the pre-test/post-test. Frequency and percentage distribution were employed to analyze the distribution of students' scores.
international Journal of Research and Review	Ludfiahtul Habibah1, Suratno2, Mochammad Iqbal3, 2023 and Jalan	Critical Thinking Ability and Mastery of Biology Concept of High School Students in Coffee Plantation Area	quasi experimental,	Collaborative Learning Model Combined with Problem Solving	High School Students	ANCOVA to test
Jurnal Pendidikan Fisika	Yulianti Yusal1)*, Andi Suhandi2), Wawan Setiawan3), Ida Kaniawati2), 2023 and Indonesia	to Improve the Pre-service Physics Teachers' Critical Thinking Skills	pretest-posttest design.	Collaborative Problem-solving Using Decision-making Problems	physics teacher	Thematic analysis
Sage						
Journal of Educational Computing Research	Ching-Yi Chang1□, Intan Setiani2□, and Jie Chi Yang2,3, 2025 and Taiwan	Enhancing Students' Learning Achievement, Collaboration Awareness, Learning Motivation and Problem-Solving Skill	A quasi-experimental study	An Escape Room-Based Computer-Supported Collaborative Learning Approach	nursing students	descriptive and inferential statistical methods
Asian Journal for Mathematics Education	Tin Lam Toh Abstract and Puay Huat Chu, 2025, Singapore.	How is problem posing presented at each of the four levels of the mathematics curriculum?		problem posing		review
Asian Journal for Mathematics Education	Bing Hiong Ngu1 ,HuyP. Phan1, Kian Sam Hong2, and Hasbee Usop, 2023 and Australia	learning linear equations	cross-cultural experimental study	Is the inverse method more effective than the balance method	students	univariate analysis of variance (ANOVA) testing,
Asian Journal for Mathematics	Afiqah Bari'ah Emran1, Masitah Shahrill2 and	Improving students' problem-solving	experimental	,little is known about the		

Name of Journal	Author/ Year/Country	Focus of study	Study design	Intervention Or not	Population Or not	Statistical analysis
Education	Daniel Asamoa, 2023,	skills in ratios.		effectiveness of mnemonic strategies such a KNOWS		
JSTOR						
Journal of College Science Teaching	JeffreyA. Phillips, Katharine W. Clemmer, Jeremy E. B. McCallum, and Thomas M. Zachariah (2025)	develop and evaluate a problem-solving framework	experimental	instructional model incorporating explicit classroom activities around the ACE-M	undergraduate students	