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Mapping the pedagogical integration of discovery learning and STEAM in enhancing students' critical thinking skills: A systematic literature review and bibliometric analysis

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Abstract

Background: The development of students' critical thinking skills has become a central concern in 21st-century education, particularly in response to increasingly complex scientific, technological, and societal challenges. Despite the growing number of studies examining these approaches, existing research remains fragmented, and a comprehensive synthesis that maps research trends, thematic orientations, and theoretical implications is still limited.
Aims: This study aims to examine the evolution, distribution, and scholarly significance of research on Discovery Learning and STEAM in enhancing students' critical thinking skills.
Methods: A systematic literature review combined with bibliometric analysis was conducted using the Scopus database. A total of 714 documents published between 2014 and 2025 were initially identified using the keywords "Discovery Learning," "STEAM," and "critical thinking." After applying PRISMA-based inclusion and exclusion criteria, 75 peer-reviewed articles were selected for in-depth analysis. Bibliometric mapping was performed using VOSviewer to examine publication trends, country and institutional contributions, keyword co-occurrence, and thematic networks.
Results: The findings reveal a consistent growth in research on both Discovery Learning and STEAM, with a notable increase in publications over the last five years. Discovery Learning is predominantly associated with inquiry, experimentation, and metacognitive regulation, while STEAM emphasizes interdisciplinary integration, creativity, and technology-enhanced problem-solving. The analysis also indicates a strong concentration of studies in developing countries, particularly Indonesia, alongside expanding international contributions. However, limited cross-national collaboration and uneven thematic depth remain evident.
Conclusion: This review demonstrates that Discovery Learning and STEAM function as complementary pedagogical frameworks that collectively strengthen students' critical thinking through inquiry-based, interdisciplinary, and reflective learning processes. Beyond confirming their effectiveness, this study highlights the need for deeper theoretical integration, stronger empirical validation, and more globally collaborative research. By synthesizing research trends and identifying underexplored dimensions, this review provides a robust foundation for advancing sustainability-oriented, context-responsive, and future-ready educational practices.

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INTRODUCTION

The increasing emphasis on critical thinking skills in contemporary education reflects global demands for learners who can analyze information, evaluate evidence, and respond to complex real-world problems. Recent systematic reviews in STEM and STEAM education indicate that higher-order thinking has become a central learning outcome rather than a peripheral skill, particularly

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within science and mathematics learning contexts (Bielik et al., 2023; Hidayat et al., 2024). Inquiry-oriented pedagogies are widely recognized as effective approaches for fostering critical thinking because they engage students in problem formulation, investigation, and reflective reasoning, a pattern highlighted in STEAM reviews by (Leavy et al., 2023; Yim et al., 2025). Within this pedagogical landscape, Discovery Learning is frequently associated with constructivist learning processes that support metacognitive regulation and independent reasoning, as noted across inquiry-based learning syntheses by (Sam, 2024). At the same time, STEAM education has gained prominence as an interdisciplinary framework that integrates scientific inquiry with creativity and contextual problem solving, a trend emphasized in recent reviews by (Pinar et al., 2025; Zhan & Niu, 2023). The convergence of inquiry, interdisciplinarity, and creativity positions Discovery Learning and STEAM as potentially complementary approaches for developing critical thinking. However, the rapid expansion of research on these pedagogies has produced a fragmented body of literature with varied emphases and methodological orientations. Consequently, there is a growing need to synthesize existing research to clarify how Discovery Learning and STEAM collectively contribute to critical thinking development.

Despite the growing number of studies examining Discovery Learning and STEAM, existing systematic reviews tend to address these approaches separately, resulting in limited theoretical integration. Reviews of STEM and STEAM education often focus on broad instructional trends or learning outcomes without sufficiently examining the pedagogical mechanisms that underlie critical thinking development, as observed by (Kumar & Deák, 2023; Leavy et al., 2023). Similarly, Discovery Learning is frequently discussed implicitly within inquiry-based frameworks rather than being analyzed as a distinct cognitive architecture, a concern raised in syntheses by (Lombardi et al., 2021; Morris, 2025). Bibliometric and systematic analyses further reveal that many studies prioritize effectiveness comparisons while offering minimal insight into how inquiry processes shape learners' reasoning and reflection, as reported by (Chen et al., 2025; Tsakeni et al., 2025). Moreover, recent reviews highlight a strong concentration of research within specific geographical contexts, particularly developing countries, which raises questions about conceptual generalization and global relevance (Bendl et al., 2025; Tan, 2025). The lack of integrated synthesis obscures the pedagogical relationship between Discovery Learning's structured inquiry phases and STEAM's interdisciplinary design. Addressing this issue is essential for advancing theoretical clarity and informing instructional design. Therefore, a systematic literature review combined with bibliometric analysis is warranted to reconceptualize Discovery Learning and STEAM as complementary pedagogical frameworks for critical thinking development, as advocated by Christou et al. (2024).

LITERATURE REVIEW

Discovery Learning (DL) is consistently conceptualized as a constructivist instructional model that promotes active inquiry, analytical reasoning, and reflective knowledge construction. Within systematic reviews of STEM and STEAM education, inquiry-oriented pedagogies are identified as core mechanisms for developing critical thinking because learners are required to formulate problems, analyze evidence, and construct explanations through exploration, as synthesized by (Ilma et al., 2023; Liani & Redhana, 2025). The phased structure of DL aligns with constructivist learning theory, which emphasizes metacognitive regulation and independent reasoning as foundations of higher-order thinking, a pattern also highlighted in STEAM-focused reviews by (Segarra-Morales & Juca-Aulestia, 2024). Reviews of inquiry-based STEM learning further show that discovery-oriented instruction enhances students' analytical judgment more effectively than transmission-based approaches, particularly in science and mathematics education, as reported by (Syafe'i et al., 2023). However, Calheiro & Greca (2025) note that most reviews discuss DL implicitly under broad inquiry-based frameworks rather than examining it as a distinct pedagogical architecture. This lack of explicit conceptualization limits theoretical clarity regarding DL's specific role in critical thinking development. Consequently, DL remains under-positioned within the broader STEAM research landscape.

Systematic reviews also indicate that Discovery Learning becomes more effective when combined with guided inquiry, collaborative discussion, and structured cognitive scaffolding. Evidence synthesized by Segarra-Morales and Juca-Aulestia (2024) shows that hybrid discovery-oriented approaches strengthen reflective reasoning by supporting learners in organizing, verifying, and generalizing knowledge. Similarly, Ilma et al. (2023) report that inquiry-based micro-projects and problem-based tasks embedded within STEM contexts enhance scientific reasoning and evaluative thinking. Bibliometric analyses further suggest that such models benefit learners with higher cognitive engagement, while scaffolded discovery is more effective for students with emerging critical thinking skills, as discussed by Syafe'i et al. (2023). Despite these insights, Calheiro and Greca (2025) emphasize that existing reviews prioritize outcome comparisons over pedagogical mechanisms. As a result, the cognitive processes underlying discovery-based learning remain fragmented across studies. This fragmentation reveals a conceptual gap in understanding how DL functions beyond its instructional procedures.

The integration of Discovery Learning with digital and media-based environments has gained attention in recent STEAM-oriented systematic reviews, particularly in relation to sustainability-oriented education. Reviews by Ilma et al. (2023) indicate that digital platforms, interactive media, and game-based environments enhance inquiry by contextualizing abstract concepts and facilitating experiential learning. Within these contexts, discovery-based learning supports critical thinking by enabling learners to test hypotheses and reflect on real-world problems, as synthesized by Segarra-Morales and Juca-Aulestia (2024). Technology-enhanced STEAM reviews also suggest that digital discovery environments foster creativity, self-regulation, and problem-solving skills, which are closely associated with critical thinking development, according to Syafe'i et al. (2023). However, Calheiro and Greca (2025) caution that technology is often treated as an add-on rather than an integral pedagogical component. Consequently, the interaction between DL principles and digital inquiry remains weakly theorized. This indicates a methodological and conceptual gap in existing reviews.

STEAM education is widely described in systematic reviews as an interdisciplinary pedagogical framework aimed at cultivating critical and creative thinking through the integration of science, technology, engineering, arts, and mathematics. Segarra-Morales and Juca-Aulestia (2024) report that STEAM-based learning environments promote higher-order thinking by encouraging multidisciplinary exploration and open-ended inquiry. Similarly, Liani and Redhana (2025) show that STEAM instruction leads to stronger critical thinking outcomes compared to traditional teaching, particularly when collaborative problem-solving is emphasized. Reviews focusing on teacher education and maker-based practices highlight the role of creative collaboration and design thinking in stimulating analytical reasoning, as discussed by Calheiro and Greca (2025). Across disciplines, STEAM is consistently associated with cognitive flexibility and evaluative judgment, as synthesized by Ilma et al. (2023). Nevertheless, most reviews conceptualize STEAM as an umbrella movement rather than unpacking the instructional models operating within it. This limits understanding of how specific pedagogical mechanisms contribute to critical thinking.

Recent STEAM literature further emphasizes that inquiry-driven, project-based, and problem-based learning activities enhance student engagement and motivation. Systematic reviews indicate that emerging technologies such as augmented reality and robotics strengthen visualization and complex reasoning within STEAM classrooms, as reported by Syafe'i et al. (2023). Teacher facilitation is also identified as a critical factor in guiding inquiry and assessing critical thinking processes, according to Segarra-Morales and Juca-Aulestia (2024). Despite these advances, existing systematic reviews rarely examine how Discovery Learning operates within STEAM contexts as a coherent cognitive framework, a concern raised explicitly by Calheiro and Greca (2025). As a result, the pedagogical intersection between DL's structured inquiry phases and STEAM's interdisciplinary design remains underexplored. This unresolved intersection constitutes a clear research gap. Addressing this gap represents the novelty of the present study by reconceptualizing Discovery Learning and STEAM as complementary pedagogical architectures for critical thinking development.

Table 1. Main Findings on Discovery Learning and STEAM in Enhancing Critical Thinking

No.	Discovery Learning and STEAM in Enhancing Critical Thinking	References
1	Integrating mathematics with science, technology, engineering, and the arts (STEAM) consistently enhances student engagement and promotes critical thinking through interdisciplinary problem solving.	Liani & Redhana, 2025; Segarra-Morales & Juca-Aulestia, 2024; Ilma et al., 2023
2	STEAM-based activities bridge disciplinary knowledge, such as chemistry and statistics, enabling students to apply analytical reasoning in meaningful and authentic learning contexts.	Segarra-Morales & Juca-Aulestia, 2024; Calheiro & Greca, 2025
3	STEAM education fosters critical thinking by engaging learners in constructivist, creative, and problem-based learning experiences that encourage multiple perspectives.	Ilma et al., 2023; Liani & Redhana, 2025; Syafe'i et al., 2023
4	Discovery Learning activities that involve observing phenomena, formulating problems, and drawing conclusions strengthen reasoning and evidence-based thinking.	Syafe'i et al., 2023; Segarra-Morales & Juca-Aulestia, 2024
5	Digital and technology-enhanced learning environments, including interactive and immersive tools, support critical thinking by fostering active engagement and inquiry.	Ilma et al., 2023; Calheiro & Greca, 2025
6	Critical thinking is developed through activities that require analyzing information, synthesizing evidence, and making justified judgments within inquiry-based learning.	Liani & Redhana, 2025
7	Discovery Learning functions as a core element of active and inquiry-based learning, emphasizing reflection, rational reasoning, and openness to diverse viewpoints within STEAM contexts.	Segarra-Morales & Juca-Aulestia, 2024; Syafe'i et al., 2023
8	Inquiry-based discovery activities engage students in investigating relevant topics, thereby enhancing critical thinking through exploration and reflection.	Ilma et al., 2023; Calheiro & Greca, 2025
9	Educational robotics and technology-integrated STEAM activities foster critical thinking through collaborative design, programming, and problem-solving processes.	Segarra-Morales & Juca-Aulestia, 2024; Syafe'i et al., 2023
10	Discovery Learning lesson designs that follow structured inquiry phases support systematic reasoning and conceptual generalization.	Syafe'i et al., 2023; Ilma et al., 2023
11	Guided discovery and culturally contextualized STEAM approaches enhance critical thinking by integrating inquiry, collaboration, and socio-cultural relevance.	Calheiro & Greca, 2025; Liani & Redhana, 2025
12	Design-based and challenge-based learning approaches aligned with STEAM promote analytical reasoning and reflective thinking.	Segarra-Morales & Juca-Aulestia, 2024
13	Arts-integrated STEAM learning encourages creativity and critical reflection through expressive and interpretive inquiry processes.	Calheiro & Greca, 2025
14	Integrating arts within STEAM breaks disciplinary boundaries, enriches learning experiences, and strengthens problem-solving and critical thinking skills.	Segarra-Morales & Juca-Aulestia, 2024; Ilma et al., 2023
15	Inquiry-based laboratory and experimental learning grounded in discovery principles significantly enhances students' critical thinking abilities.	Syafe'i et al., 2023
16	STEAM project-based learning fosters critical thinking by engaging students in authentic problem solving and reflective evaluation of outcomes.	Liani & Redhana, 2025
17	Modules integrating STEM or STEAM approaches with Discovery Learning encourage learners to construct knowledge through inquiry and exploration.	Ilma et al., 2023; Calheiro & Greca, 2025
18	Discovery Learning is particularly effective for students with higher cognitive engagement, while scaffolded inquiry supports learners with emerging critical thinking skills.	Syafe'i et al., 2023; Segarra-Morales & Juca-Aulestia, 2024
19	Contextualized STEAM learning in science education enhances students' critical thinking by linking inquiry with real-world applications.	Ilma et al., 2023; Liani & Redhana, 2025

No.	Discovery Learning and STEAM in Enhancing Critical Thinking	References
20	STEAM learning performance positively influences sustainable inquiry behavior and long-term critical thinking development.	Nong et al., 2022
21	Discovery Learning promotes inductive reasoning and active problem solving, which are essential for developing critical thinking.	Syafe'i et al., 2023
22	Integrating STEAM, particularly arts-focused approaches, into engineering education strengthens interdisciplinary problem solving and critical thinking.	Calheiro & Greca, 2025
23	Interactive technologies enhance creativity, collaboration, and critical thinking, leading to improved STEAM learning outcomes.	Ilma et al., 2023; Syafe'i et al., 2023

Table 1 synthesizes key findings from Scopus-indexed studies that examine the roles of Discovery Learning and STEAM in enhancing students' critical thinking skills across diverse educational contexts. Rather than presenting isolated empirical results, the table organizes the literature thematically to illustrate recurring pedagogical patterns that support inquiry, reasoning, and reflective learning. The evidence summarized in the table indicates that STEAM-based instruction consistently enhances critical thinking by engaging students in interdisciplinary problem solving, where concepts from science, mathematics, technology, and the arts are integrated to address authentic challenges. In parallel, Discovery Learning is shown to function as a cognitive mechanism that structures inquiry through observation, problem formulation, data analysis, and generalization, thereby fostering evidence-based reasoning. The table also highlights the growing importance of technology-enhanced environments, such as digital media, robotics, and interactive tools, in amplifying inquiry processes and supporting active student engagement. Importantly, several references appear across multiple thematic categories, reflecting the multifaceted nature of systematic reviews that address inquiry, interdisciplinarity, and technology integration simultaneously. This thematic overlap underscores that Discovery Learning and STEAM should not be viewed as separate pedagogical approaches but as complementary frameworks that jointly contribute to critical thinking development. Overall, the table reinforces the study's argument that integrating Discovery Learning within STEAM-oriented instructional designs offers a coherent and theoretically grounded pathway for cultivating higher-order thinking skills in contemporary education.

METHOD

Research Design

This study employed a systematic literature review integrated with bibliometric analysis to examine how Discovery Learning and STEAM contribute to the development of critical thinking skills in educational contexts. This design was selected to synthesize fragmented empirical findings while simultaneously mapping the intellectual structure of the field, as recommended in recent STEAM-focused review studies by (Chen & Hitt, 2021). A systematic review approach allows for rigorous evidence synthesis, while bibliometric techniques provide insight into research trends and conceptual clustering (Marzi et al., 2025; Walsh & Rowe, 2023). The integration of these methods enables the identification of both pedagogical mechanisms and thematic patterns underlying inquiry-based learning, consistent with methodological arguments advanced by (Chen & Chen, 2025). Unlike conventional reviews that prioritize outcome comparison, this design emphasizes interpretive synthesis to reveal how instructional processes support critical thinking, following the orientation outlined by (Depraetere et al., 2021; Stoyanov & Kirschner, 2023). Bibliometric mapping complements this process by visualizing keyword relationships and research concentration areas. The combined design directly supports the study's novelty by linking Discovery Learning with STEAM through a cognitive–pedagogical lens. Overall, this research design aligns with the journal's focus on theory-informed and methodologically rigorous educational research.

Participants

In systematic literature review research, participants are defined as published scholarly articles rather than individual learners or educators. The analytical corpus consisted of peer-reviewed journal articles indexed in the Scopus database, which was selected due to its comprehensive coverage of international research in science, mathematics, and interdisciplinary education, as discussed by Crosthwaite et al. (2023). Scopus indexing ensures consistent quality control and reliable metadata, which supports bibliometric and thematic analyses, as noted by Liani and Redhana (2025). Articles were treated as units of analysis to enable systematic comparison across instructional models and disciplinary contexts. Inclusion criteria required explicit discussion of Discovery Learning, STEAM education, or critical thinking skills within formal educational settings, following procedures outlined by Segarra-Morales and Juca-Aulestia (2024). Studies that addressed STEM education without inquiry-oriented or critical thinking components were excluded to maintain conceptual focus. This selection strategy ensured alignment between the dataset and the study's theoretical objectives (Barthakur et al., 2022; Chen et al., 2022). As a result, the included articles collectively represent current research on inquiry-based and interdisciplinary approaches to critical thinking development.

Instrument

The instruments used in this study consisted of structured search strategies, screening protocols, and analytical tools for data extraction and synthesis. A PRISMA-based screening framework was applied to ensure transparency and replicability in article selection, following international standards for systematic reviews described by (Stracke et al., 2023; Wanaguru et al., 2025). Bibliometric analysis was conducted using VOSviewer to visualize keyword co-occurrence networks, publication trends, and thematic clusters, as commonly employed in STEAM education reviews by Hsu et al. (2024). A thematic coding framework was developed to categorize instructional approaches, inquiry processes, and cognitive outcomes associated with Discovery Learning and STEAM, drawing on conceptual guidance from Calheiro and Greca (2025). Data extraction templates were used to systematically record bibliographic information and pedagogical characteristics, as suggested by (Campos et al., 2024; Chalmers et al., 2024). The combination of bibliometric and thematic instruments enabled methodological triangulation. Visual outputs such as network maps and synthesis tables were generated to support analytical interpretation. These instruments collectively enhanced the validity and clarity of the review findings.

Data Analysis Plan

Data analysis was conducted through a two-stage process integrating bibliometric mapping and thematic synthesis. In the first stage, bibliometric analysis was used to identify publication growth, dominant keywords, and thematic clusters related to Discovery Learning, STEAM, and critical thinking, following analytic approaches described by (Leavy et al., 2023; Marín-Marín et al., 2021). Keyword co-occurrence analysis was applied to detect conceptual linkages between inquiry-based learning and interdisciplinary instruction, as recommended by Segarra-Morales and Juca-Aulestia (2024). In the second stage, thematic synthesis was conducted to interpret how Discovery Learning and STEAM function as pedagogical mechanisms that foster critical thinking, consistent with interpretive strategies outlined by Calheiro and Greca (2025). Studies were grouped into thematic categories based on instructional design, learning activities, and reported cognitive processes. The synthesis table presented in the Results section was developed from this thematic clustering process. Cross-validation between bibliometric patterns and thematic interpretations was conducted to enhance trustworthiness (Marzi et al., 2025; Verma et al., 2024). This integrated analysis enabled the identification of conceptual gaps and intersections. Through this approach, the data analysis plan directly operationalized the study's research gap and novelty.

Article Selection Procedure (Integration of Figure 1)

The article selection process followed a PRISMA-based procedure, as illustrated in Figure 1. The initial search was conducted via the Scopus database on October 18, 2025, using article titles, abstracts, and keywords related to Discovery Learning, STEAM, and critical thinking skills, yielding 714 records. Keyword refinement was then applied to enhance conceptual relevance, resulting in 347 articles for screening, consistent with systematic review practices outlined by Page et al. (2021). Studies unrelated to Discovery Learning, STEAM, or critical thinking were excluded at this stage, leading to the removal of 367 records. Additional exclusions were applied based on document type, eliminating book chapters, conference papers, review articles, and retracted publications to ensure peer-reviewed quality, as recommended by Ilma et al. (2023). Language filtering retained only English-language publications, excluding studies in Spanish and Lithuanian. Open-access screening further refined the dataset to enhance transparency and accessibility. As a result of this process, 75 articles were included for bibliometric mapping and thematic synthesis.

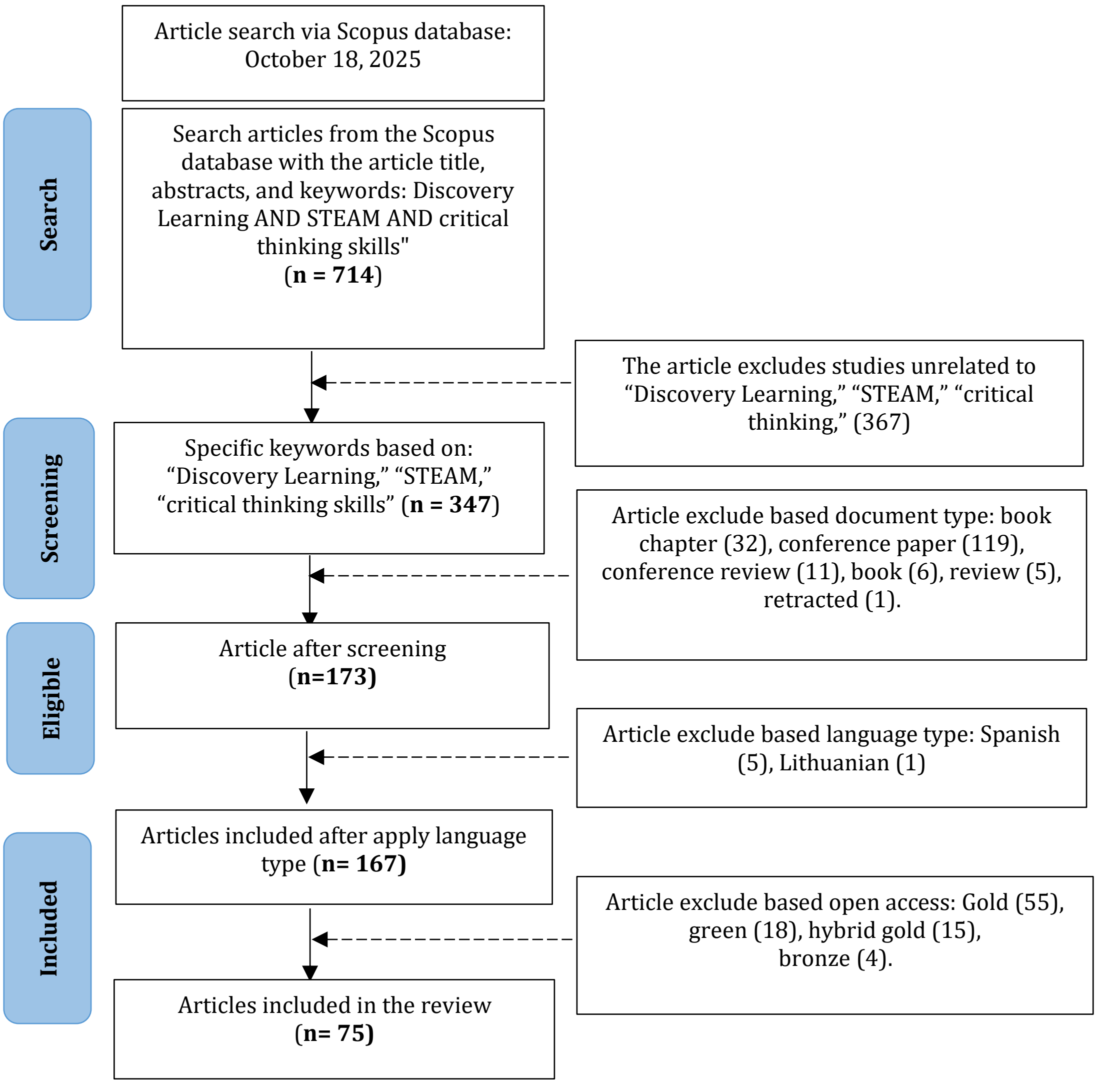


Figure 1. PRISMA-based flow diagram of the article identification, screening, eligibility, and inclusion process.

Figure 1 illustrates the systematic procedure used to identify, screen, and select articles included in this review. The process began with an initial search of the Scopus database, which yielded 714 records based on the predefined keywords related to Discovery Learning, STEAM, and critical thinking skills. Keyword refinement was subsequently applied to ensure conceptual relevance, resulting in 347 articles that proceeded to the screening stage. During screening, studies that did not address inquiry-based learning, interdisciplinary instruction, or critical thinking were excluded to maintain alignment with the research objectives. Further eligibility assessment was conducted by excluding non–peer-reviewed document types, including book chapters, conference papers, review articles, and retracted publications. Language criteria were then applied to retain only English-language studies, ensuring consistency in academic discourse. An additional open-access filtering step was used to enhance transparency and accessibility of the reviewed literature. Through this systematic and transparent process, a final set of 75 articles was selected for bibliometric analysis and thematic synthesis.

Additional Methodological Rigor

To further strengthen methodological rigor, transparency and reflexivity were applied throughout the review process. Clear inclusion and exclusion criteria were used to minimize selection bias, as advocated by Page et al. (2021). The integration of bibliometric analysis and thematic synthesis provided methodological triangulation, enhancing credibility, in line with recommendations by Calheiro and Greca (2025). Reflexive interpretation was applied during thematic analysis to avoid overgeneralization across educational contexts. Limitations related to database scope were acknowledged to maintain analytical integrity, as discussed by Segarra-Morales and Juca-Aulestia (2024). Documentation of each review stage supports replicability. This approach aligns with best practices in international educational research. Consequently, the methodological framework provides a robust foundation for interpreting the study's findings.

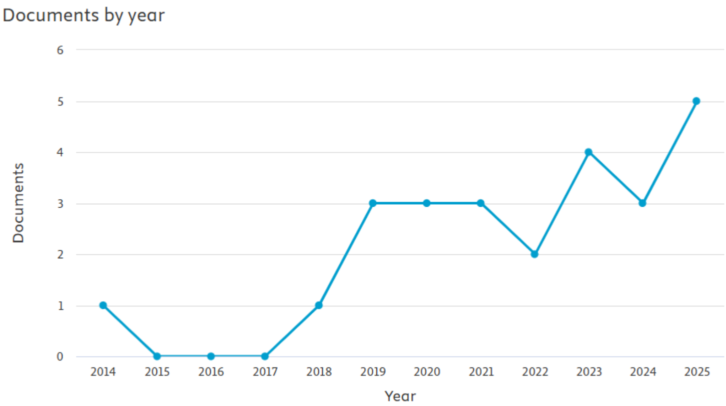
RESULTS AND DISCUSSION

The results of this study focus on findings from 75 selected articles retrieved from the Scopus database related to Discovery Learning, STEAM, and critical thinking skills. The data were analyzed based on the number of publications, yearly distribution, and journal sources. In addition, this study highlights the most influential elements within this research domain, including prominent authors, institutional affiliations, and countries that have contributed to the development of Discovery Learning and STEAM-based approaches for enhancing students' critical thinking skills.

RQ1: Is the exploration of Discovery Learning and STEAM-based approaches a subject that continues to hold significance for future *educational research on critical thinking skills?*

Based on the analysis of data obtained from the Scopus database covering the years 2014–2025 (refer to Figure 2), studies examining the role of Discovery Learning as a pedagogical model for strengthening students' critical thinking skills have demonstrated a steady upward trajectory over the past decade. Research output, which was relatively scarce between 2014 and 2016, began to rise noticeably in 2018, reflecting increasing scholarly attention to the effectiveness of Discovery Learning in cultivating higher-order thinking among learners.

The consistent publication trend during 2019–2021, followed by a marked growth from 2023 to 2025, indicates that Discovery Learning is gaining broader recognition as a 21st-century instructional approach that supports analytical, creative, and reflective dimensions of thinking (Ilma et al., 2023; Segarra-Morales and Juca-Aulestia, 2024; Calheiro and Greca, 2025; Liani and Redhana, 2025; Syafe'i et al., 2023). This overall trend underscores that Discovery Learning remains a highly relevant and promising focus for future educational research, reaffirming its essential contribution to advancing both theoretical understanding and practical implementation of critical thinking-oriented pedagogy.

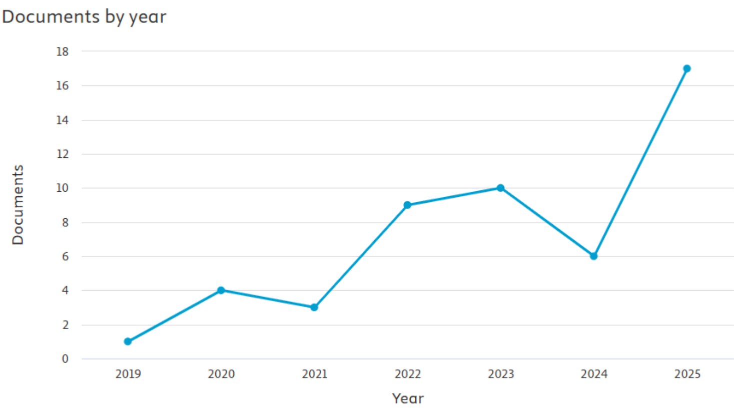


Source: Scopus database

Figure 2. Trend of research publications on Discovery Learning and critical thinking skills from scopus database (2014–2025)

Following the analysis of research trends on Discovery Learning, this section further examines the development of studies focusing on the STEAM approach and its role in enhancing students' critical thinking skills. Based on the analysis of data from the Scopus database covering the period 2019–2025 (refer to Figure 3), research on the implementation of the STEAM approach (Science, Technology, Engineering, Arts, and Mathematics) in fostering students' critical thinking skills has shown a sharp and consistent upward trend. The number of publications, which initially stood at only one article in 2019, rose significantly to 17 articles in 2025, indicating a growing scholarly interest in the effectiveness of STEAM as an integrative educational approach.

Recent studies highlight that STEAM-based learning strengthens students' critical thinking by integrating scientific reasoning, artistic creativity, and cross-disciplinary collaboration (Ilma et al., 2023; Segarra-Morales and Juca-Aulestia, 2024; Calheiro and Greca, 2025; Liani and Redhana, 2025; Syafe'i et al., 2023). This upward trend confirms that STEAM has evolved beyond a mere interdisciplinary concept into a transformative framework for 21st-century learning. Moreover, its growing prominence underscores STEAM's essential role in advancing higher-order thinking skills while opening new pathways for future research and pedagogical innovation in education.



Source: Scopus database

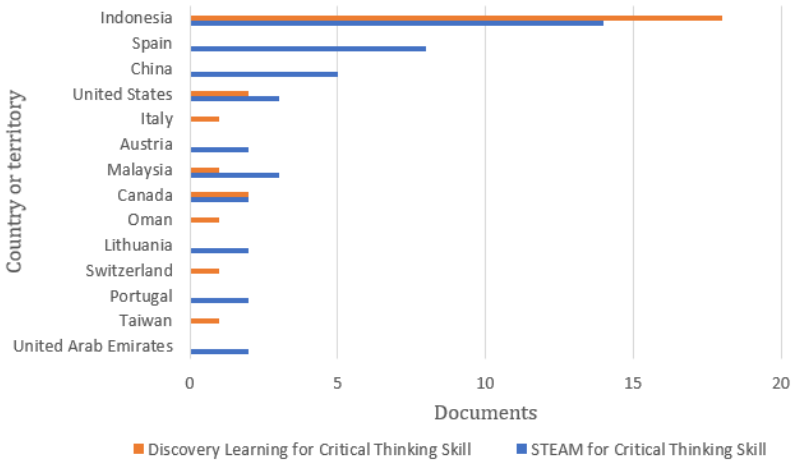
Figure 3. Trend of research publications on STEAM and critical thinking skills from scopus database (2019–2025)

RQ2: What is the current allocation and thematic distribution of research investigations related to Discovery Learning, STEAM education*, and critical thinking skills?*

Based on the analysis of data from the Scopus database, publications on the application of Discovery Learning to foster students' critical thinking skills are predominantly contributed by Indonesia, with a total of 18 articles (refer to Figure 4). This number far exceeds those from other countries such as Canada, the United States, Belgium, France, Italy, Malaysia, Oman, Switzerland, and Taiwan, each contributing only two articles. The dominance of Indonesia reflects a strong commitment to developing innovative discovery-based learning aligned with the Merdeka Curriculum policy, which emphasizes the enhancement of higher-order thinking skills. Meanwhile, the limited contributions from other countries suggest that research on the effectiveness of Discovery Learning for critical thinking development remains an open area for further exploration, particularly through cross-national collaborations and diverse educational contexts.

First, following the analysis of publication distribution on Discovery Learning, the next focus examines the global dissemination of research on the STEAM approach and its relationship with the development of critical thinking skills. Based on data retrieved from the Scopus database, studies related to the implementation of STEAM (Science, Technology, Engineering, Arts, and Mathematics) in fostering critical thinking show a diverse geographical distribution. Indonesia and Spain lead with 14 publications each, followed by China with six articles, and Malaysia and the United States with three articles each (refer to Figure 4). Other countries, including Austria, Canada, Lithuania, Portugal, and the United Arab Emirates, also contribute to this field, though in smaller numbers, with two articles respectively.

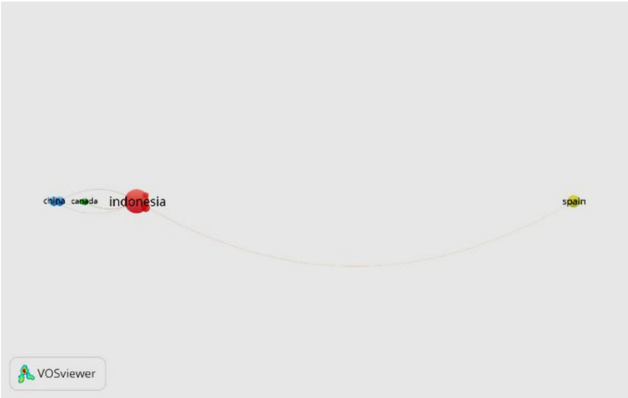
This distribution suggests that research interest in STEAM as a pedagogical framework for strengthening critical thinking has expanded globally and is no longer concentrated only in developed countries. The dominance of Indonesia and Spain reflects a growing commitment among educational institutions to adopt innovative, interdisciplinary, and creativity-based learning models. Meanwhile, the participation of other countries indicates an increasing openness to international research collaboration and the cross-disciplinary integration of science, technology, engineering, and the arts in education. Overall, this trend highlights STEAM's emerging role as a transformative approach for cultivating students' critical and creative thinking skills, positioning it as a vital component in 21st-century education research and practice.



Source: Adapted from scopus database

Figure 4. Number of articles by country or territory related to Discovery Learning and STEAM for enhancing critical thinking skills

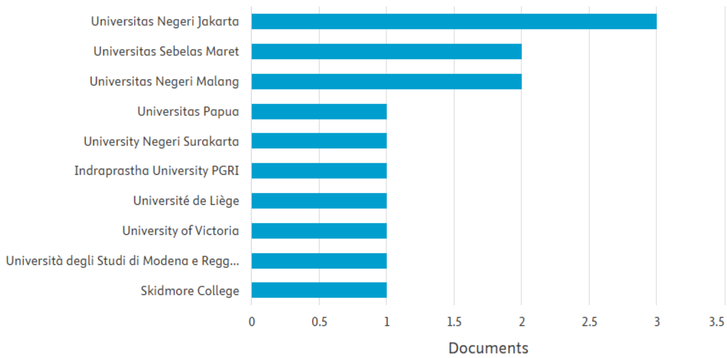
The bibliometric network visualization indicates that research on Discovery Learning and STEAM in enhancing students' critical thinking skills is predominantly concentrated in Indonesia, which occupies the most central position in the global network, reflecting a strong national emphasis on educational innovation. Indonesia's dominance demonstrates its commitment to integrating inquiry-based and interdisciplinary approaches within the curriculum to strengthen higher-order thinking skills (see Figure 5). Limited collaborations are observed with countries such as China and Canada, forming a small regional cluster, whereas Spain appears as an isolated node, suggesting independent but thematically aligned research activity. This pattern implies that although global interest in the topic is increasing, the research landscape remains fragmented with minimal cross-national cooperation. Strengthening international collaboration is therefore crucial to developing broader theoretical perspectives and comparative evidence on how Discovery Learning and STEAM can effectively cultivate critical thinking across diverse educational contexts.



Source: Output VOSviewer software

Figure 5. Network country visualization

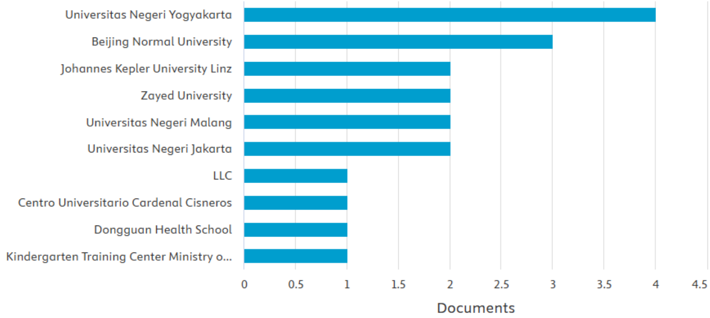
Second, the allocation of scholarship focusing on Discovery Learning as a means to enhance students' critical thinking skills is largely concentrated in Indonesian institutions (see Figure 6). Universitas Negeri Jakarta (Indonesia) leads with 3 documents, followed by Universitas Sebelas Maret (Indonesia) and Universitas Negeri Malang (Indonesia), each contributing 2 documents. Other contributors, including Universitas Papua (Indonesia), Universitas Negeri Surakarta (Indonesia), and Indraprastha University PGRI (Indonesia), produced 1 document each. A smaller number of studies originated from international institutions such as Université de Liège (Belgium), University of Victoria (Canada), Università degli Studi di Modena e Reggio Emilia (Italy), and Skidmore College (United States), each with 1 document. This distribution suggests that research demonstrating the role of Discovery Learning in fostering critical thinking is predominantly driven by Indonesian scholars, with limited yet emerging contributions from global academia.



Source: Scopus database

Figure 6. Top research institutions on Discovery Learning and critical thinking skills

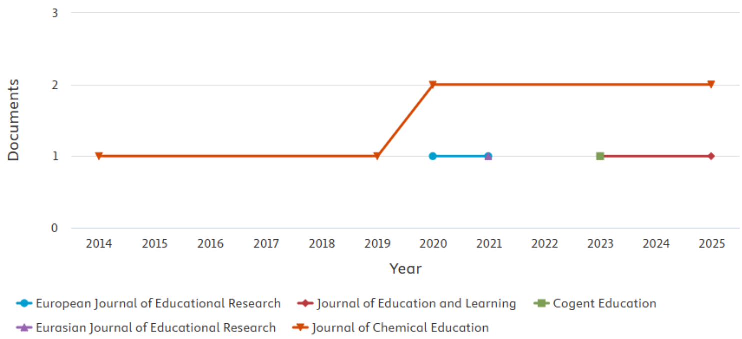
Following the discussion on Discovery Learning, the analysis then turns to studies focusing on the implementation and impact of STEAM-based learning in developing students' critical thinking skills. The distribution of research in this area shows broader international participation compared to Discovery Learning studies. Universitas Negeri Yogyakarta (Indonesia) leads with four documents, followed by Beijing Normal University (China) with three. Johannes Kepler University Linz (Austria), Zayed University (United Arab Emirates), and Universitas Negeri Malang (Indonesia) each contributed two documents. Additional contributions come from Universitas Negeri Jakarta (Indonesia), Centro Universitario Cardenal Cisneros (Spain), Dongguan Health School (China), Kindergarten Training Center Ministry of Education (China), and LLC, each with one document (see Figure 7). This pattern demonstrates that research on STEAM implementation for fostering critical thinking has achieved global recognition, engaging both Asian and European institutions. The findings reaffirm that STEAM-based pedagogical practices effectively cultivate critical thinking through interdisciplinary integration, inquiry-driven learning, and experiential engagement across diverse educational contexts.



Source: Scopus database

Figure 7. Top research institutions on STEAM and critical thinking skills

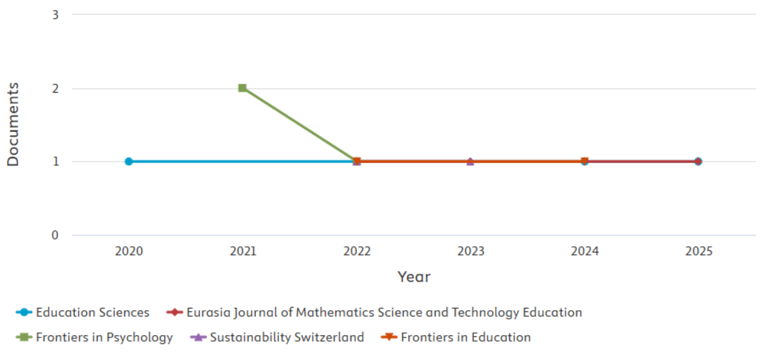
Third, the distribution of research articles on the implementation of *Discovery Learning* focusing on enhancing students' critical thinking skills shows a diverse range of publication sources. As illustrated in Figure 8, the Journal *of Chemical Education* dominates with two articles, followed by the *European Journal of Educational Research*, *Eurasian Journal of Educational Research*, *Journal of Education and Learning*, and *Cogent Education*, each contributing one article. This distribution indicates that the topic of *Discovery Learning* as an instructional model for fostering critical thinking has gained recognition across various international journals in the fields of education and science. The dominance of education- and chemistry-based journals reflects that discovery-oriented pedagogical approaches are perceived as effective for promoting higher-order thinking skills through inquiry, experimentation, and conceptual reflection in the learning process (see Figure 8).



Source: Scopus database

Figure 8. Number of articles on Discovery Learning and critical thinking skills by source (top 5 journals)

Based on the analysis of data from the Scopus database presented in Figure 9, publications on the implementation of STEAM as a learning approach in fostering critical thinking skills demonstrate contributions from various international journals. Education Sciences published one article in 2020, followed by Frontiers in Psychology in 2021 with two articles. In addition, the Eurasia Journal of Mathematics, Science and Technology Education, Sustainability (Switzerland), and Frontiers in Education each published one article between 2022 and 2024. This distribution indicates that the STEAM approach is increasingly recognized as an effective and adaptive educational framework, as it can be integrated with other learning models such as inquiry-based, problem-based, and project-based learning to enhance students' higher-order thinking skills (see Figure 9).

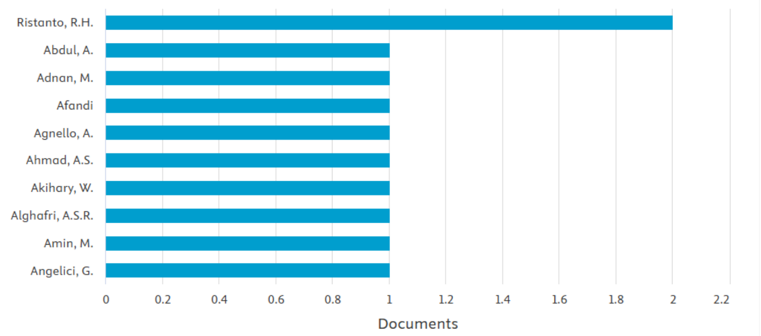


Source: Scopus database

Figure 9. Number of articles on STEAM and critical thinking skills by source (top 5 journals)

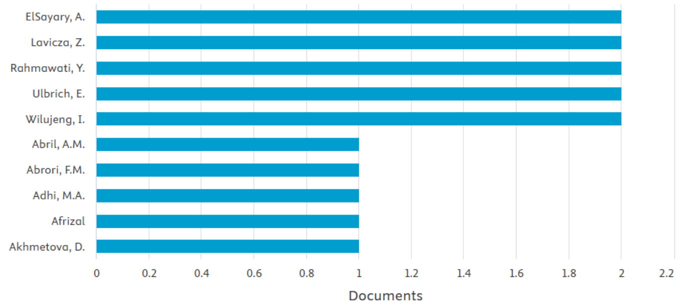
Fourth, based on the analysis of data from the Scopus database presented in Figure 10, the distribution of research related to Discovery Learning and its application in fostering critical thinking skills shows relatively balanced contributions among authors, with no significant dominance observed. Among the top ten authors, only Ristanto, R.H. has published two articles, while other contributors such as Abdul, A., Adnan, M., Afandi, Agnello, A., Ahmad, A.S., Akihary, W., Alghafri, A.S.R., Amin, M., and Angelicci, G. have each produced one publication. This distribution suggests that research on Discovery Learning for enhancing critical thinking remains collaborative and widely distributed across various institutions, with no single researcher emerging as a dominant contributor. Furthermore, this pattern indicates that the topic continues to offer substantial opportunities for future exploration and holds strong potential to evolve into a more prominent area of educational research (see Figure 10).

An analysis of the Scopus database, as illustrated in Figure 11, reveals that research on STEAM as a learning approach for fostering critical thinking skills shows a balanced distribution among authors, with no clear dominance observed. Among the top ten authors, ElSayary, A., Lavicza, Z., Rahmawati, Y., Ulbrich, E., and Wilujeng, I. each contributed two publications, while Abril, A.M., Abrori, F.M., Adhi, M.A., Afrizal, and Akhmetova, D. each authored one article. This pattern illustrates that research on STEAM as a learning approach for developing critical thinking skills has been highly collaborative and globally distributed, involving scholars from diverse institutional and geographical backgrounds. The active participation of Indonesian researchers such as Rahmawati, Y. and Wilujeng, I. highlights the growing prominence of STEAM studies in Indonesia, while contributions from international scholars like ElSayary, A. and Lavicza, Z. reflect the strengthening of global research networks. Overall, these findings emphasize that STEAM as a learning approach continues to evolve as a dynamic and integrative field of educational research, promoting synergy between local and international academics in advancing 21st-century learning aimed at enhancing students' critical thinking (see Figure 11).



Source: Scopus database

Figure 10. Distribution of publications on Discovery Learning and critical thinking skills by author (top 10 authors)



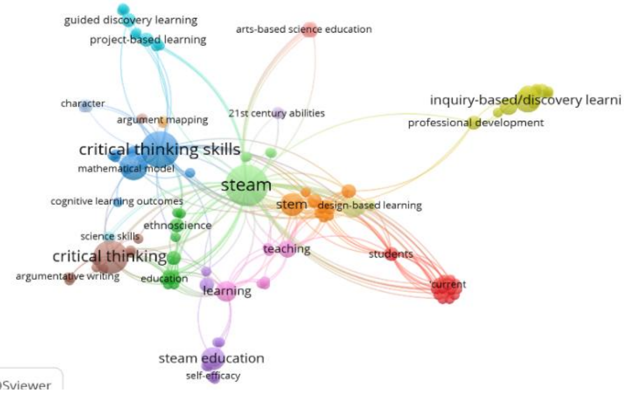
Source: Scopus database

Figure 11. Distribution of publications on STEAM and critical thinking skills by author (top 10 authors)

RQ3: What theoretical insights and practical recommendations emerge from previous studies on Discovery Learning and STEAM for fostering critical thinking in future educational research and practice?

The analysis was conducted on a collection of publications retrieved from the Scopus database using VOSviewer to identify the theoretical and practical implications of studies discussing Discovery Learning and STEAM as a learning approach in developing students' critical thinking skills. The metadata analysis revealed that both approaches make a significant contribution to 21st-century educational innovation, particularly in strengthening students' higher-order thinking abilities. The bibliometric analysis also indicated several recurring research themes, such as the integration of discovery learning, inquiry-based learning and project-based learning, along with areas that remain underexplored namely, the implementation of the integrated Discovery Learning model oriented toward the STEAM approach within local contexts and digital learning environments. From a practical perspective, the findings of this review provide a foundation for educators and researchers to design learning models that are more contextual, collaborative, and exploration-oriented, thereby enhancing students' critical thinking skills in future educational practices.

From Figure 12, the occurrences of critical thinking skills (13), critical thinking (11), STEAM (17), learning (4), and teaching (3) appear as the most dominant keywords, reflecting the central focus of recent research in this field. Other frequently occurring terms include inquiry-based/discovery learning (6), project-based learning (2), guided discovery learning (2), and STEM (5), which highlight the integration of multiple instructional approaches within STEAM-oriented frameworks. Additional related keywords such as argument mapping (1), cognitive learning outcomes (1), self-efficacy (1), ethnoscience (2), 21st century abilities (1), and arts-based science education (1) indicate the broad scope of research emphasizing interdisciplinary learning, creativity, and higher-order thinking. Finally, the ten most frequently co-occurring keywords are summarized in Table 3, illustrating the interconnectedness of Discovery Learning, STEAM, and critical thinking within contemporary educational research.



Source: Output VOSviewer software

Figure 12. Co-occurrence framework and representation of key terms

Table 2. Keyword by authors

Rank	Keyword	Total link strength
1	STEAM	121
2	Critical thinking skills	64
3	Critical thinking	53
4	STEM	41
5	Learning	37
6	Students	35
7	Inquiry-based/discovery learning	34
8	Teaching	33
9	Computational thinking	29
10	Discovery learning	26

Source: Output VOSviewer software

Based on the visual mapping results using VOSviewer and the analysis of publications indexed in the Scopus database; it can be concluded that Discovery Learning and STEAM have both theoretical and practical contributions to the development of students' critical thinking skills. Theoretically, Discovery Learning has been proven to be a flexible instructional model that can be integrated with various learning approaches, where the selection of such strategies strengthens students' metacognitive abilities to analyze, reason, and solve problems independently (Ilma et al., 2023; Segarra-Morales and Juca-Aulestia, 2024). Meanwhile, the STEAM approach plays a crucial role in creating holistic learning experiences by integrating science, technology, engineering, arts, and mathematics within real-world contexts, thereby fostering students' analytical, reflective, and creative capacities (Calheiro and Greca, 2025). Practically, these findings emphasize that the synergy between Discovery Learning and STEAM can serve as a strategic direction for developing 21st-century learning that is more contextual, collaborative, and oriented toward the enhancement of higher-order thinking skills, particularly critical thinking.

The findings from the reviewed studies on Discovery Learning and STEAM reveal that both approaches play a pivotal role in cultivating students' critical thinking skills through inquiry, experimentation, collaboration, and reflection. Based on the synthesis of previous research, the conceptual framework presented below illustrates the interrelated activities and learning strategies within Discovery Learning and STEAM that collectively foster critical thinking skills in educational contexts (see Figure 13).

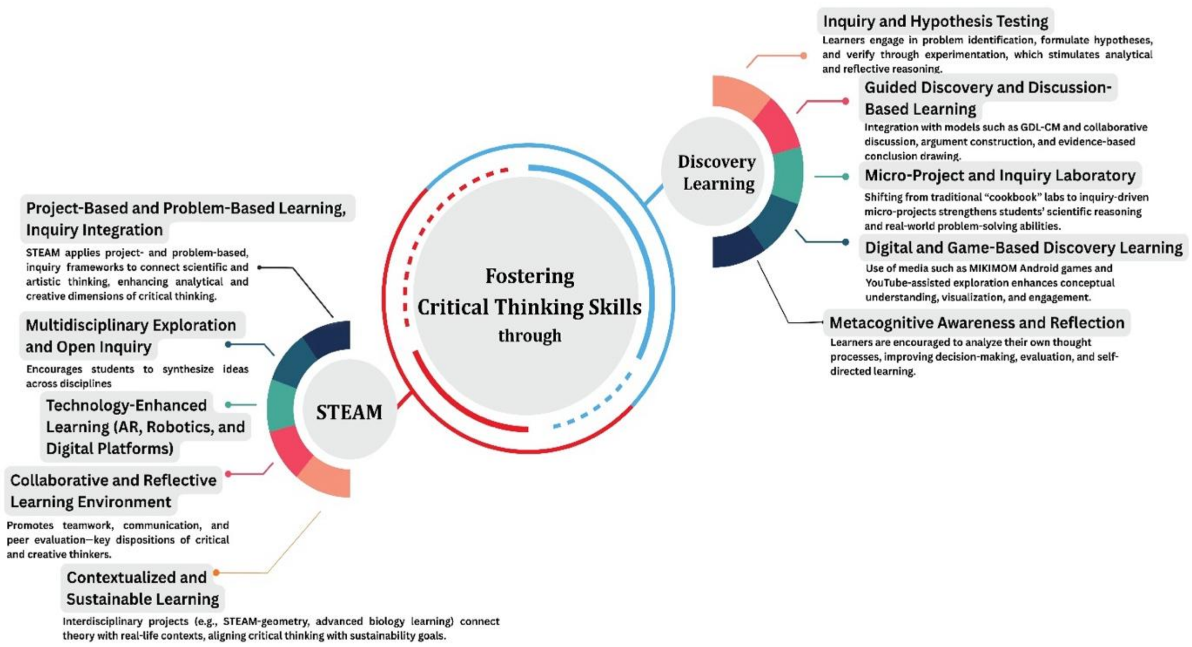


Figure 13. Conceptual Framework of Fostering Critical Thinking Skills through Discovery Learning and STEAM

The conceptual framework integrates Discovery Learning (DL) and STEAM (Science, Technology, Engineering, Arts, and Mathematics) as complementary approaches to foster critical thinking through inquiry, creativity, and interdisciplinary engagement. Discovery Learning, rooted in constructivist theory, emphasizes students' active participation in hypothesis formulation, investigation, data interpretation, and reflection, promoting analytical, critical, and creative thinking as well as decision-making and problem-solving abilities, as evidenced in recent studies on inquiry-oriented pedagogy and higher-order thinking development (Chusni et al., 2020; Hatch, 2023). STEAM education, on the other hand, provides a holistic learning experience by merging scientific inquiry with artistic creativity and technological innovation, encouraging interdisciplinary collaboration, hands-on experimentation, and real-world problem-solving within authentic learning contexts (Bassachs et al., 2020; Liao, 2016). Its practical applications, such as robotics, coding, and digital simulations, have been widely reported to support the development of analytical reasoning and creative problem-solving, while integrative instructional models such as inquiry-oriented STEAM further enhance critical thinking processes (Evangelia & Argyrakou, 2025; Tassilova et al., 2025). Although challenges related to instructional readiness and contextual implementation remain, this integrated framework offers a robust pedagogical synergy aligned with the objectives of 21st-century education by empowering learners to think critically, act creatively, and address complex problems across diverse educational settings (Abuhassna et al., 2024; González-Pérez & Ramírez-Montoya, 2022).

Conceptual Framework: The Role of Discovery Learning in Fostering Critical Thinking Skills

Discovery Learning (DL) is a constructivist learning framework that positions students as active participants in building knowledge through inquiry, exploration, and reflection. It develops independent reasoning and problem-solving abilities by engaging learners in meaningful investigations that require interpretation, analysis, and evaluation of evidence. Central to DL is inquiry and hypothesis testing, where students identify problems, formulate hypotheses, and verify them through systematic exploration, a process shown to strengthen analytical and reflective reasoning (Chusni et al., 2020). Through continuous interaction with data and concepts, learners are encouraged to draw logical conclusions and refine their understanding, reinforcing higher-order cognitive engagement.

Guided discovery and discussion-based learning further enhance these outcomes by combining structured instructional scaffolding with collaborative knowledge construction. In guided discovery settings, learners receive strategic support that helps them navigate complex concepts and apply conceptual understanding to problem-solving tasks (Loibl & Rummel, 2014). Discussion-based approaches complement this process by fostering analytical reasoning through dialogue, argumentation, and the evaluation of multiple perspectives, thereby strengthening evidence-based judgment and reflective thinking (Chen et al., 2016; Reznitskaya et al., 2009). These collaborative interactions support the development of critical communication skills that are essential for deep learning and reasoning.

Micro-projects and inquiry-oriented learning activities extend the potential of Discovery Learning by bridging theoretical understanding with real-world application. Inquiry-driven projects encourage learners to design investigations, collect and interpret data, and apply findings to contextual problems, which promotes scientific reasoning, creativity, and perseverance (Thumlert et al., 2018). Such experiences contribute to sustained critical thinking development by situating learning within meaningful and authentic contexts.

Digital and interactive discovery learning environments further enhance student engagement and conceptual understanding. The use of simulations and interactive media supports learners in visualizing abstract concepts and exploring problem-solving scenarios through iterative feedback and experimentation, which has been shown to strengthen analytical reasoning and conceptual clarity (Chao, 2016; Daryanes et al., 2023; Wang et al., 2013). These digital modalities encourage strategic thinking and adaptability in navigating complex learning tasks.

Metacognitive awareness and reflective practices play a crucial role in consolidating critical thinking within Discovery Learning environments. Reflective activities allow learners to evaluate their reasoning processes, identify misconceptions, and refine learning strategies, fostering self-regulated and autonomous learning behaviors. Through these interconnected inquiry, collaboration, digital exploration, and reflection processes, Discovery Learning supports the development of analytical, evaluative, and metacognitive skills essential for success in 21st-century education (Chusni et al., 2020).

Conceptual Framework: The Role of STEAM in Fostering Critical Thinking Skills

STEAM (Science, Technology, Engineering, Arts, and Mathematics) education provides an interdisciplinary learning approach that integrates multiple domains to cultivate critical thinking, creativity, and problem-solving competencies. As a pedagogical paradigm, STEAM encourages learners to engage in inquiry, collaboration, and authentic problem-solving activities that connect knowledge with real-world applications, thereby strengthening analytical reasoning and innovative thinking (Bassachs et al., 2020). Its holistic orientation supports the development of higher-order thinking skills aligned with the demands of contemporary education.

Project-based and problem-based learning strategies serve as central instructional mechanisms within STEAM pedagogy. By engaging students in interdisciplinary projects that address authentic challenges, STEAM-based learning promotes reasoning, inference, and conceptual integration across scientific and creative domains (Corrigan et al., 2025). These learning experiences enhance students' ability to analyze complex problems and propose evidence-based solutions.

Inquiry integration is fundamental to STEAM instruction, as it promotes questioning, investigation, and synthesis of knowledge across disciplines. Inquiry-oriented STEAM activities encourage learners to test ideas, interpret data, and justify conclusions, thereby strengthening analytical flexibility and critical evaluation skills (Kotsis, 2025). Multidisciplinary exploration further supports critical thinking by linking scientific reasoning with creative expression and collaborative engagement.

Technology-enhanced learning environments within STEAM, including digital simulations and interactive tools, transform traditional classrooms into adaptive spaces that support visualization, experimentation, and iterative learning. These technological applications have been shown to foster computational thinking and creative problem-solving by enabling learners to design, test, and refine solutions collaboratively (Ji & Wong, 2025; Turchi et al., 2019). Such environments promote higher-order reasoning through continuous feedback and reflection.

Collaborative and reflective learning practices are integral to effective STEAM implementation. Group-based learning encourages students to exchange ideas, evaluate diverse perspectives, and construct shared understanding, while reflective activities support metacognitive awareness and self-regulation (Khosa & Volet, 2014). Through contextualized and interdisciplinary learning experiences, STEAM education equips learners with the critical, creative, and analytical capacities required to navigate complex challenges in the 21st century (Ismiati, 2024).

Implications

The findings of this study provide several important implications for educational theory, instructional practice, and future curriculum development. From a theoretical perspective, the bibliometric evidence confirms that Discovery Learning and STEAM are not isolated pedagogical trends but interconnected frameworks that jointly support the development of critical thinking skills through inquiry, integration, and reflection. This reinforces constructivist learning theory by demonstrating how inquiry-based and interdisciplinary approaches function synergistically in contemporary educational research. From a pedagogical standpoint, the increasing integration of Discovery Learning and STEAM suggests that educators should move beyond single-model instruction toward more flexible and hybrid learning designs.

Teachers are encouraged to design learning environments that promote student exploration, cross-disciplinary problem-solving, and reflective reasoning rather than procedural task completion alone. The findings also imply that STEAM-oriented discovery activities can be particularly effective in fostering higher-order thinking when learning tasks are contextualized and aligned with real-world challenges. At the policy and curriculum level, the dominance of research output from specific regions highlights the need for institutional support in scaling inquiry-based and interdisciplinary pedagogies. Educational stakeholders may use these findings as empirical justification to integrate Discovery Learning and STEAM into curriculum frameworks aimed at strengthening 21st-century competencies, especially critical thinking and creativity.

Limitations

Despite its contributions, this study has several limitations that should be acknowledged. First, the bibliometric analysis relied exclusively on articles indexed in the Scopus database, which may have excluded relevant studies published in other reputable databases or regional journals. As a result, some valuable research outputs on Discovery Learning and STEAM may not be fully represented in the dataset. Second, this study focused on publication trends, authorship patterns, and thematic mapping rather than empirical effect sizes or learning outcomes. Consequently, the findings illustrate the research landscape and intellectual structure of the field but do not directly measure the magnitude of impact of Discovery Learning or STEAM on students' critical thinking skills.

Third, the analysis was limited to articles published between 2014 and 2025, which may not capture earlier foundational studies that influenced the theoretical development of inquiry-based and interdisciplinary learning. Additionally, bibliometric tools such as VOSviewer rely on keyword co-occurrence and citation relationships, which may oversimplify complex pedagogical constructs. These limitations should be considered when interpreting the scope and generalizability of the findings.

Suggestions for Future Research

Based on the findings and identified gaps, several directions for future research are recommended. First, empirical studies are needed to investigate the effectiveness of integrated Discovery Learning–STEAM models across diverse educational levels and cultural contexts. Experimental and quasi-experimental designs could provide stronger causal evidence regarding how these approaches influence students' critical thinking development. Second, future research should explore the implementation of Discovery Learning and STEAM within digital and hybrid learning environments, particularly in response to the growing role of educational technology. Investigating how digital inquiry tools, simulations, and collaborative platforms support critical thinking within STEAM-oriented discovery learning could offer valuable insights for modern classrooms.

Third, cross-national and cross-institutional collaboration is strongly encouraged to address the current geographical concentration of research. Comparative studies involving multiple countries would enrich theoretical perspectives and enhance the global relevance of findings. Finally, future reviews may incorporate mixed-method approaches or meta-analytical techniques to complement bibliometric findings and deepen understanding of pedagogical effectiveness.

CONCLUSION

This study provides a comprehensive bibliometric synthesis of research on Discovery Learning and STEAM in relation to the development of students' critical thinking skills. The findings demonstrate that scholarly interest in both pedagogical approaches has increased consistently over the past decade, indicating their sustained relevance in contemporary education research. Discovery Learning is shown to remain a robust inquiry-based model that supports analytical, reflective, and higher-order thinking through structured exploration and reasoning. At the same time, STEAM has evolved into a transformative interdisciplinary framework that integrates scientific inquiry, creativity, and real-world problem-solving. The convergence of these approaches highlights a growing emphasis on student-centered, inquiry-driven, and integrative learning environments. The bibliometric trends further reveal that research on Discovery Learning and STEAM is distributed across diverse journals, institutions, and geographical regions, with notable contributions from emerging educational contexts. This diversity reflects the adaptability of both approaches to different curricular goals and educational systems. Overall, the results confirm that Discovery Learning and STEAM represent essential pedagogical foundations for advancing critical thinking as a core 21st-century competency.

Beyond mapping publication trends, this study contributes theoretically and practically by clarifying the intellectual structure and research directions within the field. The analysis reveals that Discovery Learning and STEAM are increasingly integrated with inquiry-based, project-based, and technology-enhanced learning models, strengthening their impact on critical thinking development. However, the findings also indicate that research remains concentrated in specific regions, suggesting the need for broader international collaboration and comparative studies. From a theoretical perspective, the synergy between Discovery Learning and STEAM reinforces constructivist and interdisciplinary learning paradigms that prioritize reasoning, creativity, and reflection. Practically, the results offer evidence-based guidance for educators and policymakers in designing learning environments that foster critical thinking through inquiry and integration. The proposed conceptual framework further illustrates how both approaches can be aligned to support sustainable and meaningful learning experiences. Despite certain limitations related to data scope and methodological focus, this study establishes a strong foundation for future empirical and comparative research. In conclusion, Discovery Learning and STEAM hold significant promise as complementary approaches for cultivating critical thinking skills and addressing the evolving demands of 21st-century education.

AUTHOR CONTRIBUTION STATEMENT

TFS : conceptualized the study, conducted the systematic literature review and bibliometric analysis, and drafted the manuscript.
ES : provided theoretical guidance and reviewed the research design and analysis.
Ra : assisted in data analysis and interpretation of bibliometric findings.
ASI : contributed to the discussion, provided international perspectives, and revised the manuscript.

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