Jurnal Pendidikan Progresif
e-ISSN: 2550-1313 | p-ISSN: 2087-9849
URL: https://jpp.fkip.unila.ac.id/index.php/jpp
Jounal's DOI: http://doi.org/10.23960/jpp

Vol. 16, No. 3, 2026
Article ID: 1899
Pages: 1733-1749

Research Trends and Empirical Evidence on STEM Learning for Creative Thinking: A Systematic Literature Network Analysis

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Received: 29 June 2026 *Accepted: 04 August 2026* *Published: 29 August 2026*

Abstract: The increasing emphasis on twenty-first-century competencies has positioned STEM learning as an important educational approach for fostering students' creative thinking. Although numerous studies have investigated the relationship between STEM learning and creative thinking, a comprehensive understanding of research trends, thematic developments, and empirical evidence remains limited. This study aims to analyze the development of research on STEM learning and creative thinking using a Systematic Literature Network Analysis (SLNA) that integrates bibliometric and qualitative content analyses. Bibliographic data were retrieved exclusively from the Scopus database using the search query TITLE-ABS-KEY (STEM AND Learning AND Creative AND Thinking). The initial search identified 287 publications; 248 met the criteria for bibliometric analysis, and 33 highly relevant full-text articles were selected for qualitative synthesis following the PRISMA 2020 framework. Bibliometric analysis was conducted using Biblioshiny and VOSviewer to examine publication trends, collaboration networks, and thematic structures, while qualitative content analysis synthesized research characteristics, instructional approaches, methodologies, and findings on creative thinking. The findings reveal a continuous increase in publications between 2021 and 2025, indicating growing scholarly interest in STEM learning and creative thinking. Thematic analysis identifies creative thinking, project-based learning, STEM education, and assessment as dominant research themes, while digital learning and computational thinking emerge as developing topics. The qualitative synthesis demonstrates that STEM learning consistently enhances creative thinking through project-based learning, inquiry-based learning, engineering design, robotics, and digital learning environments, particularly by promoting fluency, flexibility, originality, and elaboration. This study contributes to the literature by integrating bibliometric mapping with qualitative synthesis, providing a comprehensive overview of the current research landscape and offering directions for future research and educational practice in STEM learning and creative thinking.

Keywords: STEM learning, creative thinking, bibliometric analysis, systematic literature review, qualitative synthesis.

Article's DOI: https://doi.org/10.23960/jpp.v16i3.pp1733-1749

INTRODUCTION

The rapid advancement of science, technology, and digital innovation has transformed the competencies required for success in the twenty-first century. Educational systems are expected not only to develop students' disciplinary knowledge but also to foster higher-order thinking skills, creativity, collaboration, communication, and problem-solving abilities (Winda & Mega, 2023). Among various educational approaches, Science, Technology, Engineering, and Mathematics (STEM) education has gained widespread recognition as an interdisciplinary approach that equips students with essential competencies and prepares them to address increasingly complex real-world challenges (Muttaqiin, 2023). STEM learning encourages students to actively construct knowledge through inquiry, engineering design, and authentic problem-solving experiences, thereby promoting independent learning and innovation (Bybee, 2013).

Previous studies have consistently demonstrated the positive contribution of STEM education to improving students' twenty-first-century competencies. STEM learning has been reported to enhance problem-solving abilities, collaboration, interdisciplinary understanding, and digital literacy while preparing students for future workforce demands (Madahae et al., 2021; Churchill et al., 2018; Bal, 2022; Malathi & Gopinath, 2021). Furthermore, STEM-based instructional activities encourage students to integrate scientific concepts with technological applications and engineering design, allowing them to apply knowledge in authentic contexts (Rusminati & Juniarso, 2023). Bal (2022) found that STEM education allows students to absorb, synthesize, and apply interdisciplinary knowledge. Churchill et al. (2018) further argue that contemporary STEM education should extend beyond the integration of four disciplines by adopting a transdisciplinary perspective that incorporates inquiry-based learning and digital literacy. Collectively, these studies indicate that STEM education has evolved into a comprehensive instructional approach that supports interdisciplinary learning and innovation. Gonzalez (2012) has become a leading guide to STEM education policies and programs in the United States.

Beyond improving scientific understanding, one of the most important expected outcomes of STEM education is the development of creative thinking. Creative thinking enables students to generate original ideas, examine problems from multiple perspectives, and develop innovative solutions, making it an essential competency in science education and twenty-first-century learning (Irman et al., 2025). This ability is commonly reflected through four indicators: fluency, flexibility, originality, and elaboration. Previous empirical studies have shown that STEM-based learning environments effectively promote these dimensions of creative thinking by engaging students in authentic problem-solving, collaborative inquiry, and project-based activities (Sirajudin & Suratno, 2021). For example, STEM-oriented project-based learning has been shown to improve both conceptual understanding and creative thinking skills (Sumarni et al., 2019), while other studies have reported that STEM learning creates educational environments that encourage idea exploration, collaboration, and innovation in science classrooms (Nurcahyo & Fatmawati, 2022). In Indonesia, the implementation of STEM learning continues to expand across educational levels, encouraging educators to design interdisciplinary learning experiences that strengthen creativity and problem-solving skills (Widiyatmoko & Darmawan, 2023).

Although previous studies have extensively examined the implementation of STEM learning and its influence on creative thinking, several limitations remain. Existing reviews have generally focused on specific educational levels, particular instructional models, or individual empirical interventions. Bibliometric studies have primarily described publication trends and research networks, whereas systematic reviews have often emphasized instructional effectiveness without integrating publication patterns and thematic developments. Consequently, there remains limited evidence that combines bibliometric analysis with qualitative synthesis to provide a comprehensive understanding of research trends, thematic structures, dominant instructional approaches, and empirical findings in STEM learning and creative thinking. Addressing this gap is important for identifying emerging research directions and providing a broader evidence base for researchers, educators, and policymakers.

This study aims to systematically analyze research on STEM learning and creative thinking using a Systematic Literature Network Analysis

(SLNA) that integrates bibliometric analysis with qualitative synthesis. This study investigates publication trends, thematic structures, collaboration patterns, and empirical evidence on the implementation of STEM learning to develop creative thinking skills. The findings are expected to provide a comprehensive overview of current research developments, identify existing research gaps, and offer evidence-based recommendations for future STEM education research and practice. Based on these objectives, this study addresses the following research questions:

RQ1. What are the publication trends and bibliometric characteristics of research on STEM learning and creative thinking published between 2021 and 2025?
RQ2. What are the dominant thematic structures, collaboration patterns, and emerging research topics identified through bibliometric analysis?
RQ3. What learning approaches, research methods, and major findings can be synthesized from empirical studies regarding the contribution of STEM learning to the development of creative thinking?

■ METHOD

Research Design

This study employed a Systematic Literature Review (SLR) integrated with bibliometric and qualitative content analyses, commonly referred to as a Systematic Literature Network Analysis (SLNA), to investigate research trends in STEM learning and creative thinking published between 2021 and 2025. The bibliometric analysis was conducted to identify publication performance, collaboration networks, keyword co-occurrence, thematic evolution, and emerging research trends. Subsequently, qualitative content analysis was performed on selected full-text articles to synthesize research characteristics, instructional approaches, methodologies, and empirical findings related to STEM learning and creative thinking. The integration of bibliometric and qualitative analyses enabled both a macro-level overview of the research landscape and a deeper understanding of the evidence reported in empirical studies.

The bibliographic data were obtained exclusively from the Scopus database, one of the largest international databases of peer-reviewed scientific publications. Scopus was selected because it provides comprehensive and reliable bibliographic metadata suitable for bibliometric studies, including information on publications, citations, authors, affiliations, and keywords. The literature search was conducted on July 16, 2025, using publication metadata, including title, abstract, and keyword fields.

Search Strategy

The literature search was performed using the following search query: TITLE-ABS-KEY (STEM AND Learning AND Creative AND Thinking). The initial search identified 287 publications. To ensure the dataset's relevance and consistency of the dataset, several filters were applied, including publication year (2021-2025), document type (Article and Conference Paper), and language (English). After applying these criteria, 248 publications were retained and used as the dataset for the bibliometric analysis.

Inclusion and Exclusion Criteria

The literature selection was conducted in two stages to establish separate datasets for bibliometric analysis and qualitative synthesis. For the bibliometric analysis, publications were included if they were indexed in the Scopus database, published between 2021 and 2025, written in English, classified as an article or conference paper, and contained the search terms in the title, abstract, or author keywords. Based on these criteria, 248 publications were included in the bibliometric analysis. For the qualitative content analysis, a second screening was performed using the full-text articles. Articles were included if they explicitly discussed the implementation of STEM learning, examined creative thinking as one of the research outcomes, clearly described the research methodology and findings, and provided empirical evidence or systematic review findings relevant to the objectives of this study. Following the eligibility assessment, 63 articles met the inclusion criteria. Subsequently, 33 articles with the highest relevance and complete information were selected for qualitative synthesis and comparative analysis.

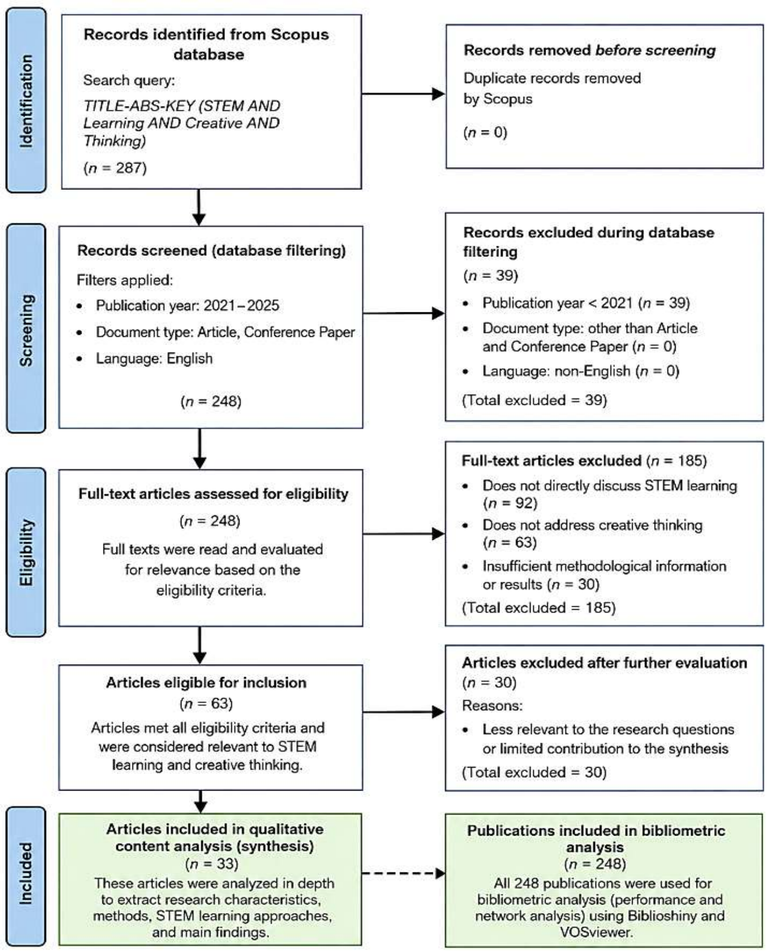

Figure 1. PRISMA 2020 flow diagram illustrating the literature selection process for bibliometric analysis and qualitative synthesis.

Articles were considered less relevant when they (1) did not explicitly investigate STEM learning implementation, (2) did not examine creative thinking as a primary or secondary outcome, (3) lacked sufficient methodological information for qualitative synthesis, or (4) focused on unrelated educational topics despite containing STEM-related keywords. The literature selection process followed the Preferred Reporting Items for Systematic Reviews and

Meta-Analyses (PRISMA 2020) framework. The review consisted of four sequential stages.

1. Identification, in which 287 publications were retrieved from the Scopus database using the predefined search strategy.
2. Screening, in which publications were filtered according to publication year (2021–2025), document type (Article and Conference Paper), and language (English), resulting in 248 publications.
3. Eligibility, full-text articles were assessed based on their relevance to STEM learning and creative thinking as well as the completeness of methodological and empirical information. This process identified 63 eligible articles.
4. Included, finally, 33 full-text articles were selected for qualitative content analysis, while all 248 publications remained part of the bibliometric analysis.

The bibliographic records were exported from Scopus in CSV and RIS formats. The CSV file was used for descriptive bibliometric analysis using Biblioshiny, whereas the RIS file was imported into VOSviewer for bibliometric network visualization. The extracted metadata included publication year, document title, authors, affiliations, countries, source titles, abstracts, author keywords, and cited references. For the qualitative content analysis, the selected 33 full-text articles were examined in greater depth. Information extracted from each article included research objectives, research design, participants, STEM learning approaches, research methods, creative thinking indicators, and principal findings. The extracted information was subsequently organized into a synthesis matrix to facilitate cross-study comparison.

Data Analysis

The study employed two complementary analytical approaches, bibliometric analysis and qualitative content analysis. The bibliometric analysis was conducted using the dataset of 248 publications to examine publication trends, research productivity, collaboration networks, keyword co-occurrence, and thematic development in STEM learning and creative thinking research. Bibliometric analysis is widely used to identify the intellectual structure and evolution of scientific literature through quantitative analysis of bibliographic metadata (Hakim, 2020). Two software packages were employed. Biblioshiny, the web interface of the Bibliometrix R package, was used to analyze annual scientific production, productive authors, journals, institutional affiliations, country contributions, and thematic evolution (Watrianthos et al., 2023). VOSviewer was used to construct and visualize bibliometric networks, including keyword co-occurrence, author collaboration, and thematic relationships among research topics. The software generates network, overlay, and density visualizations that facilitate the interpretation of scientific knowledge structures (Van Eck & Waltman, 2020).

Following the bibliometric analysis, the 33 selected full-text articles were analyzed qualitatively to synthesize research characteristics, including research design, participants, STEM learning approaches, research methods, creative thinking indicators, and principal findings. The qualitative synthesis complemented the bibliometric findings by providing an in-depth interpretation of how STEM learning has been implemented to foster creative thinking across different educational contexts.

RESULT AND DISCUSSION

Publication Trends and Bibliometric Characteristics (RQ1)

Main information bibliometric (MIB)

A total of 248 publications from 145 publication sources met the inclusion criteria for bibliometric analysis. These publications included 30 single-authored and 756 co-authored documents, indicating a high level of research collaboration in studies of STEM learning and creative thinking. The bibliometric profile provides an overview of the growth and characteristics of research within this field during the 2021–2025 period.

Annual scientific production

Figure 2 illustrates the annual distribution of publications from 2021 to 2025. Overall, there is a noticeable upward trend in document production from 2021 through 2024, followed by a sharp decline in 2025. Starting with 7 documents in 2021, the number increased significantly to 16 in 2022, suggesting a substantial growth in productivity or publication activity. Although there was a slight decrease in 2023 to 14 documents, the figure rose again in 2024, peaking at 22, the highest in the past five years. In 2025, however, the document count dropped drastically to only 4, likely because the was still in progress an not all data had been recorded yet

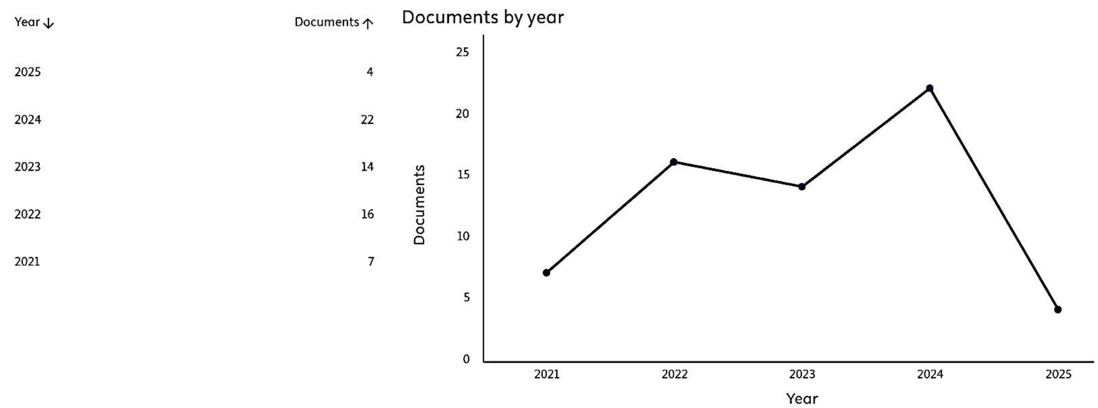

Figure 2. Total documents by year

The annual publication trend shows a steady increase in research output from 2021 to 2024, peaking in 2024. The lower number of publications recorded in 2025 is likely attributable to the ongoing indexing process, as the database had not yet fully captured publications for that year. This upward trend reflects increasing global interest in integrating STEM learning with the development of creative thinking as an essential twenty-first-century competency.

Most relevant sources

The most influential scientific publications in STEM that demonstrate creative thinking were identified through analyses of Scopus and Biblioshiny. The most relevant sources for this research are the AIP Conference Proceedings and the Journal of Physics Conference Series (Figure 2). The bibliometric analysis indicates that AIP Conference Proceedings and Journal of Physics: Conference Series are the dominant publication outlets. This finding suggests that STEM learning and creative thinking continue to be actively discussed in conference proceedings and science education journals, reflecting rapid dissemination of educational innovations.

Subject area

The distribution of documents by subject area, Social Sciences dominate the chart, accounting for 40.5% of the documents, followed by Computer Science at 13.8%. Other fields collectively make up 12.9%. Psychology (7.8%), Engineering (6.9%), and Mathematics (6.0%) also contribute significantly. Smaller portions include Health Professions (3.4%), Decision Sciences and Materials Science (each 2.6%), and both Chemistry and Chemical Engineering (each 1.7%). This distribution indicates a strong emphasis on Social Sciences, with substantial representation from technical and scientific disciplines as well. Social Sciences constitute the largest research domain, followed by Computer Science, Psychology, Engineering, and Mathematics. This multidisciplinary distribution demonstrates that STEM learning and creative thinking have evolved beyond science education and are increasingly investigated from educational, technological, psychological, and engineering perspectives.

Country and institutional contributions

Research on STEM learning and creative thinking was contributed by authors from multiple countries. Indonesia recorded the highest publication output (17 documents), followed by Thailand (8), while Malaysia, Taiwan, and the United States each contributed five publications (Figure 3). At the institutional level, Universitas Negeri Malang was the most productive affiliation. These findings suggest that Southeast Asia, particularly Indonesia, has become a major region contributing to research on STEM learning and creative thinking during the study period. The geographical distribution further reflects the growing international interest in this research area.

The number of documents published by various academic institutions, with Universitas Negeri Malang leading significantly with 5 papers. Following this, Universiti Kebangsaan Malaysia has 3 documents. At the same time, several institutions, including the Chinese University of Hong Kong, Universidad de Málaga, the University of Auckland, King Mongkut's Institute of Technology, National Taiwan Normal University, Auckland University of Technology, Curtin University, and Universitas Negeri Semarang, each contributed 2 documents. This distribution highlights Universitas Negeri Malang's prominent role in scholarly contributions among the listed affiliations.

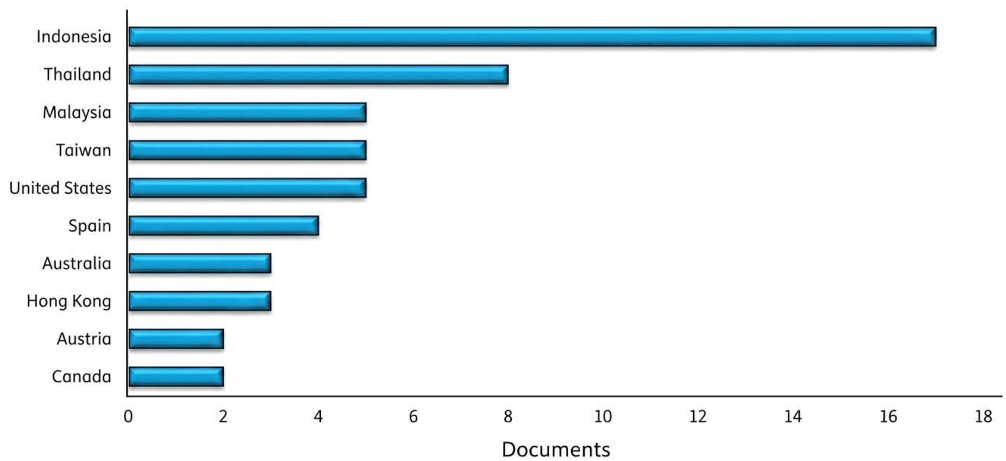

Figure 3. Authors' country of origin regarding research

The integration of STEM (Science, Technology, Engineering, and Mathematics) with creative thinking is an effective strategy for enhancing students' ability to solve complex and real-world problems in innovative ways. Integrated STEM not only strengthens scientific literacy but also responds to emerging challenges in learning environments by supporting meaningful, technology-supported education (Hilyana et al., 2023). When students engage in STEM-based activities that emphasize exploration and creativity, they are encouraged to generate original ideas, elaborate on possible solutions, and connect interdisciplinary concepts. Indonesia emerged as the leading contributor to publications in this field, followed by Thailand, Malaysia, Taiwan, and the United States. Among higher education institutions, Universitas Negeri Malang recorded the highest number of publications. These findings indicate that Southeast Asia has become a major contributor to STEM education research, particularly in studies focusing on creativity and twenty-first-century learning.

Research Networks and Thematic Structures (RQ2)

The keyword co-occurrence analysis generated using VOSviewer version 1.6.20 provides an overview of the intellectual structure of research on STEM learning for creative thinking (Figure 4). A minimum keyword occurrence threshold of two was applied, resulting in 33 of the 236 author keywords being included in the network visualization, using the full counting method. The network reveals STEM as the central node connecting multiple research themes, indicating that STEM learning serves as the primary conceptual framework linking various educational approaches and learning outcomes.

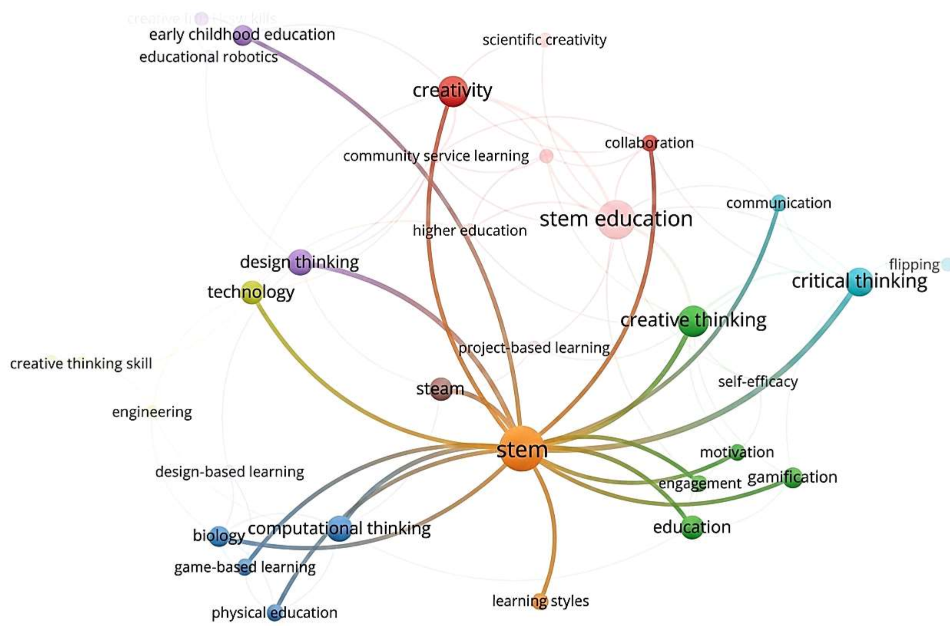

Figure 4. Keyword co-occurrence network of STEM learning for creative thinking

The network demonstrates that creative thinking and creativity are among the most prominent themes associated with STEM learning, reflecting the increasing emphasis on creativity as a major educational outcome of interdisciplinary learning. These themes are closely connected with collaboration, communication, critical thinking, and motivation, suggesting that recent STEM research increasingly conceptualizes creative thinking as part of a broader set of twenty-first-century competencies rather than as an isolated cognitive ability. This finding is consistent with previous studies reporting that STEM learning promotes collaboration, inquiry, and authentic problem-solving experiences that simultaneously foster creativity and other higher-order thinking skills (Sirajudin & Suratno, 2021; Sumarni et al., 2019; Nurcahyo & Fatmawati, 2022).

Another notable feature of the network is the emergence of design thinking, computational thinking, technology, and gamification as interconnected themes. These keywords indicate an expansion of STEM research beyond traditional science instruction toward technology-enhanced learning environments that encourage innovation and creative problem solving. The presence of design thinking suggests greater attention to engineering design processes and human-centered problem-solving. In contrast, computational thinking integrates algorithmic reasoning and digital competencies within STEM education. Likewise, gamification and motivation reflect growing interest in creating engaging learning environments that foster creativity through interactive, technology-supported instructional strategies (Widiyatmoko & Darmawan, 2023; Irman et al., 2025).

The network also highlights the connection between STEM learning and diverse educational contexts. Keywords such as early childhood education, biology, physical education, and higher education demonstrate that research on STEM learning for creative thinking has expanded across multiple educational levels and disciplinary settings. This diversity suggests that creativity is increasingly recognized as a transferable competency that can be developed through interdisciplinary STEM learning regardless of subject area or educational level. Rather than concentrating exclusively on science classrooms, recent studies have explored how STEM principles can be integrated into broader educational contexts to promote creativity, innovation, and meaningful learning experiences (Nurcahyo & Fatmawati, 2022; Widiyatmoko & Darmawan, 2023).

Overall, the keyword co-occurrence network demonstrates that the research landscape has evolved from investigating the effectiveness of STEM learning toward exploring how STEM learning fosters creative thinking through collaborative, technology-supported, and interdisciplinary learning environments. The thematic relationships identified in the network are consistent with the qualitative synthesis presented in the following section, where project-based STEM learning, inquiry-based instruction, engineering design, robotics, digital learning, and contextual STEM approaches emerge as the dominant instructional strategies for developing creative thinking. This convergence between the bibliometric network and the qualitative synthesis strengthens the evidence that STEM learning has become an increasingly comprehensive pedagogical framework for cultivating creativity alongside other higher-order competencies required in twenty-first-century education.

Trends in research topics related to these articles show that many people continued to research creative thinking during 2021 – 2025. Meanwhile, STEM was widely researched in 2023. Currently, research on active learning remains infrequent. Trend-topic analysis indicates that creative thinking has remained a consistent research focus throughout 2021–2025, whereas STEM education experienced a substantial increase beginning in 2023. In contrast, active learning appears to be an emerging but relatively underexplored topic, suggesting opportunities for future investigation.

Qualitative Synthesis of Empirical Evidence (RQ3)

Characteristics of included studies

Table 1 summarizes the characteristics of the 33 empirical studies included in the qualitative synthesis. Unlike a conventional literature summary, the table presents a synthesis matrix that compares the research objectives, research designs, participants, research instruments, and principal findings of each study. This comparative structure facilitates the identification of common research patterns and provides the empirical basis for the thematic synthesis presented in the following sections. Overall, the reviewed studies represent diverse educational settings ranging from preschool to higher education and employ various research methodologies, including experimental, quasi-experimental, mixed-methods, qualitative, research and development, and systematic literature review designs. Despite this methodological diversity, all studies investigated STEM learning as a means of developing creative thinking or related higher-order competencies. Therefore, the synthesis matrix provides a comprehensive overview of the current empirical evidence concerning STEM learning for creative thinking available in suplementary files.

STEM learning approaches

The qualitative synthesis revealed that project-based STEM learning was the most frequently implemented instructional approach among the selected studies. Variations of this approach included STEM Project-Based Learning (STEM-PjBL), STEAM Project-Based Learning, project-oriented problem-based learning (PoPBL), and project-based digital learning. These approaches were consistently applied across elementary, secondary, vocational, and higher education settings and demonstrated positive outcomes in developing students' creativity and other higher-order thinking skills (Lu et al., 2022; AlAli, 2024; Oanh & Dang, 2025; Yusuf et al., 2023; Pramasdyahsari et al., 2023). Project-based STEM learning typically engaged students in authentic problem-solving, collaborative teamwork, iterative design processes, and product development, thereby creating meaningful learning experiences that fostered creative thinking.

Beyond project-based learning, several studies implemented inquiry-based and scientific STEM learning, emphasizing scientific investigation, experimentation, and evidence-based reasoning (Chen & Chen, 2021; Astawan et al., 2023; Sutaphan & Yuenyong, 2023). Other instructional approaches included case-based STEM learning supported by mobile simulations (Nurita et al., 2024), Ethno-STEM, which integrated local culture into STEM instruction (Izzah et al., 2023), and context-based STEM learning, where real-life contexts such as water resources and chemistry applications were used to promote meaningful learning (Utmeemang & Buaraphan, 2024). These approaches shared a common emphasis on contextual problem-solving and interdisciplinary knowledge integration.

The review also identified an increasing diversity of innovative STEM learning environments. Several studies incorporated engineering design, design thinking, and robotics-based learning to promote creativity through iterative design challenges (Huang et al., 2024; Kijima et al., 2021; Siper Kabadayi & Sönmez, 2024). In parallel, advances in educational technology have encouraged the integration of digital STEM learning, including Scratch programming, IoT-based learning media, virtual classroom environments, electronic modules, and digital teaching materials (Yulianti et al., 2022; Hamimi et al., 2024; Asrizal et al., 2022; Asrizal et al., 2024; Wannapiroon & Pimdee, 2022). Collectively, these findings indicate that STEM learning has evolved beyond traditional classroom instruction toward technology-enhanced, student-centered, and interdisciplinary learning environments that actively support the development of creativity.

The synthesis matrix presented in Table 1 further indicates that project-based STEM learning represents the most frequently adopted instructional approach across the reviewed studies, followed by inquiry-based STEM learning, digital or technology-enhanced STEM learning, engineering design and robotics, and context-based STEM learning. This pattern demonstrates a growing emphasis on authentic, interdisciplinary, and student-centered learning experiences that promote creativity through active problem solving and collaborative knowledge construction.

Research methodologies

The methodological analysis showed that quasi-experimental and experimental designs dominated empirical research on STEM learning. Most intervention studies employed pretest-posttest, posttest-only, or control-group experimental designs to examine the effectiveness of STEM-based instructional approaches on students' learning outcomes (Bambang et al., 2022; Nurita et al., 2024; Astawan et al., 2023; Chen & Chen, 2021; AlAli, 2024). This predominance reflects the strong emphasis on evaluating the causal effects of STEM learning interventions, particularly regarding creative thinking and other higher-order cognitive skills.

Several studies adopted mixed-methods designs, combining quantitative measures with qualitative data such as interviews, classroom observations, portfolios, or reflective journals to obtain a more comprehensive understanding of students' learning experiences (Evans et al., 2021; Kijima et al., 2021; Siper Kabadayi & Sönmez, 2024; Huang et al., 2022). In addition, qualitative approaches, including interpretive and case studies, were employed to investigate the development of creativity, engineering identity, and classroom interactions in authentic learning settings (Simpson et al., 2023; Sutaphan & Yuenyong, 2023; Othman et al., 2022).

A smaller number of studies focused on educational development and model construction, employing research and development (R&D), instructional design, or model validation methodologies to create innovative STEM learning environments (Utmeemang & Buaraphan, 2024; Wang, 2022; Wannapiroon & Pimdee, 2022; Hamimi et al., 2024). Furthermore, one study adopted a Systematic Literature Review approach to compare the effects of STEM and STEAM on computational thinking (Syafe'i et al., 2023). Overall, the diversity of research methodologies indicates that research on STEM learning has expanded beyond intervention-effectiveness studies to encompass broader investigations into instructional design, implementation processes, and educational innovation.

Empirical evidence of STEM learning for creative thinking

The qualitative synthesis of the 33 selected empirical studies provides consistent evidence that STEM learning positively contributes to students' creative thinking across diverse educational levels and disciplinary contexts. Although the instructional approaches and research methodologies varied considerably, nearly all empirical studies reported improvements in creativity-related outcomes following the implementation of STEM-based learning. These findings indicate that creative thinking has become one of the most consistently investigated educational outcomes in contemporary STEM research.

Across the reviewed studies, project-based STEM learning emerged as the most frequently implemented instructional approach. Learning activities involving authentic projects, engineering design challenges, collaborative problem-solving, and iterative product development encouraged students to generate multiple ideas, explore alternative solutions, and continuously improve their products through reflection (Lu et al., 2022; Oanh & Dang, 2025; Yusuf et al., 2023; AlAli, 2024). Similarly, inquiry-based STEM learning, scientific investigation, and context-based STEM instruction promoted creative thinking by engaging students in experimentation, evidence-based reasoning, and real-world problem solving (Chen & Chen, 2021; Astawan et al., 2023; Nurita et al., 2024; Sutaphan & Yuenyong, 2023; Izzah et al., 2023).

The synthesis further indicates that recent STEM research has increasingly incorporated technology-enhanced learning environments to foster creativity. Digital learning platforms, Scratch programming, robotics, Internet of Things (IoT)-

based learning media, electronic modules, and virtual learning environments have been successfully integrated into STEM instruction to support creativity, innovation, and student engagement (Yulianti et al., 2022; Hamimi et al., 2024; Asrizal et al., 2022; Asrizal et al., 2024; Siper Kabadayi & Sönmez, 2024; Wannapiroon & Pimdee, 2022). Likewise, engineering design and design-thinking approaches encouraged students to develop creative confidence and innovative problem-solving skills through iterative design processes (Kijima et al., 2021; Huang et al., 2024; Mou, 2024).

Beyond creativity, many studies consistently reported improvements in broader higher-order competencies, including critical thinking, computational thinking, communication, collaboration, innovation, conceptual understanding, and twenty-first-century skills (Bambang et al., 2022; Huang et al., 2022; Syafe'i et al., 2023; Zainil et al., 2024; Pramasdyahsari et al., 2023). These findings suggest that creative thinking does not develop in isolation but evolves alongside other higher-order competencies through authentic interdisciplinary learning experiences. Consequently, the empirical evidence synthesized in this review supports the view that STEM learning functions as a comprehensive pedagogical framework for developing creativity alongside the competencies required for twenty-first-century education.

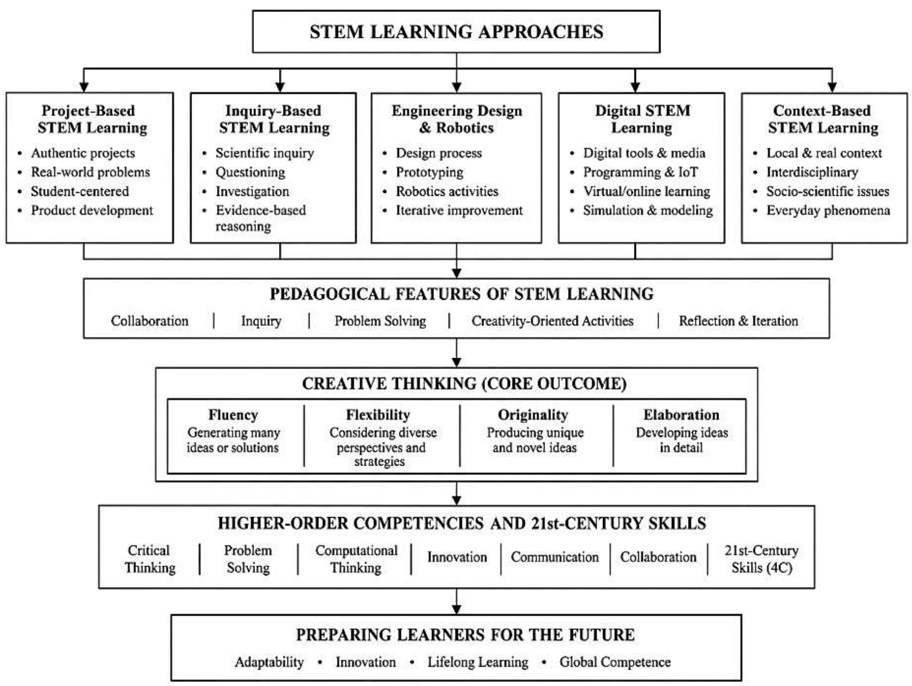

Figure 5. Thematic framework of STEM learning for developing creative thinking

Figure 5 synthesizes the pedagogical patterns identified across the 33 empirical studies and illustrates how diverse STEM instructional approaches collectively contribute to the development of creative thinking. The framework demonstrates that project-based learning, inquiry-based STEM learning, engineering design, robotics, digital STEM learning, and context-based STEM learning converge to create authentic learning experiences characterized by problem-solving, collaboration, inquiry, experimentation, engineering design processes, reflection, and real-world learning contexts. These shared pedagogical characteristics provide students with opportunities to construct knowledge actively while applying interdisciplinary concepts to meaningful problems (Chen & Chen, 2021; Astawan et al., 2023; Lu et al., 2022; AlAli, 2024).

The framework further illustrates that authentic STEM learning experiences consistently support the development of the four dimensions of creative thinking: fluency, flexibility, originality, and elaboration, which subsequently contribute to broader higher-order learning outcomes. The reviewed studies consistently demonstrate that improvements in creative thinking are accompanied by gains in critical thinking, computational thinking, communication, collaboration, innovation, and other twenty-first-century competencies. Therefore, the thematic framework complements the bibliometric findings presented in Figure 5 by integrating empirical evidence from the qualitative synthesis and providing a comprehensive conceptual representation of how STEM learning contributes to the development of creative thinking across diverse educational settings.

CONCLUSION

This study employed a Systematic Literature Network Analysis (SLNA) integrating bibliometric analysis and qualitative synthesis to examine research trends and empirical evidence on STEM learning for creative thinking published between 2021 and 2025. The bibliometric findings indicate a growing body of international research on integrating STEM learning with creative thinking and other twenty-first-century competencies. The publication trend demonstrates increasing scholarly interest in interdisciplinary STEM education, with research expanding across various educational levels and disciplinary contexts. The bibliometric network analysis further reveals that STEM learning serves as the central conceptual framework linking creative thinking to related themes, including critical thinking, computational thinking, design thinking, collaboration, communication, motivation, and technology-enhanced learning. These interconnected themes illustrate that contemporary STEM research has evolved beyond evaluating instructional effectiveness toward exploring comprehensive pedagogical strategies that integrate authentic learning experiences, interdisciplinary problem-solving, and digital technologies to foster higher-order thinking competencies. The qualitative synthesis of the 33 selected empirical studies provides strong evidence that STEM learning consistently contributes to students' creative thinking. Project-based STEM learning, inquiry-based STEM learning, engineering design, robotics, digital STEM learning, and context-based STEM instruction emerged as the dominant instructional approaches supporting creative thinking through authentic learning experiences. Across the reviewed studies, improvements were consistently reported in the four dimensions of creative thinking: fluency, flexibility, originality, and elaboration, while simultaneously promoting broader competencies, including critical thinking, computational thinking, communication, collaboration, innovation, and twenty-first-century skills. The integration of bibliometric analysis and qualitative synthesis constitutes the principal contribution of this study, linking macro-level research trends to micro-level empirical evidence. This combined approach provides a more comprehensive understanding of how STEM learning has evolved conceptually and pedagogically to support the development of creative thinking. Therefore, the findings offer valuable implications for educators, curriculum developers, and policymakers seeking to design interdisciplinary STEM learning environments that effectively cultivate creativity and other higher-order competencies. Future research is recommended to expand the literature search by incorporating additional databases beyond

Scopus, investigate the longitudinal impacts of STEM learning across diverse educational contexts, and explore integrating emerging technologies, such as artificial intelligence and immersive learning environments, to further strengthen the development of creative thinking.

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