

Mapping the STEM-Creativity Nexus: A Bibliometric and SLR Analysis of Learning Models, Barriers, and Future Directions in Science Education

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Abstract

This study aims to review the application of the STEM approach in improving creative thinking abilities in science education, using the Systematic Literature Review (SLR) method. A total of 26 articles retrieved from Scopus and Google Scholar databases were analyzed. The data visualization process was conducted using R Studio and Microsoft Excel to map related research trends. The results of the review showed that the application of STEM approaches is growing and gaining widespread attention from lecturers, teachers, researchers and education stakeholders globally, especially in Indonesia, Taiwan, Turkey and Germany. Indonesia dominates research in this area, mainly due to the influence of national policies and curricula that support STEM implementation. Various learning methods and models such as Project-Based Learning (PjBL), Inquiry-Based Learning (IBL), and Design-Based Learning have been integrated with the STEM approach and proven effective in improving students' creative thinking ability. Key barriers include limited time, insufficient resources and challenges in adapting curricula to support STEM implementation in specific subjects. Creativity is difficult to develop with just one short intervention; it requires a supportive social environment, repeated practice and greater freedom for exploration. As an innovative step, future research may consider integrating the Clarity Learning Model (CLM) as a new element to strengthen the learning structure. These findings provide important insights for educators and researchers in designing STEM-based learning that is more effective and relevant to future needs.

Keywords: design-based learning, education literacy, educational reforms, inquiry-based learning, innovative learning, learning models, project-based learning, STEM

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1. Introduction

STEM curricula and approaches are being included into the curriculum of elementary and secondary schools in an effort to better prepare students for the demands of the STEM (science, technology, engineering, and math) workforce (Margot & Kettler, 2019). Having awareness or proficiency in STEM fields means (1) an understanding of

how science, technology, engineering, and mathematics play a part in contemporary society; (2) a grasp of some basic concepts from each discipline; and (3) basic skills in applying that knowledge e.g., the ability to critically assess science or engineering information in the media, solve common technological problems, and perform simple mathematical operations useful in daily life

(Honey et al., 2014; Laksmiwati et al., 2024). Therefore, it is recommended that education and teaching be based on STEM pedagogy through an interdisciplinary approach (EL-Deghaidy et al., 2017). This approach provides opportunities for students to connect their learning to real-life situations and prepares them for career paths in STEM fields (Margot & Kettler, 2019).

The goal of educational reforms has been to incorporate technology and engineering into the teaching of science and maths (Park et al., 2016; Setyaningsih et al., 2022). A particular way of combining multiple disciplines through a project-based approach is teaching through the engineering design process, in which students apply what they have learned to solve problems (Perignat & Katz-Buonincontro, 2019). This serves as the cornerstone of STEM education, where students gain understanding through hands-on practice and are encouraged to expand their knowledge as they hone their concepts (Martín-Páez et al., 2019). STEM serves as a catalyst in educational environments (Margot & Kettler, 2019). As STEM has grown in popularity in schools, scholars have proposed various pedagogical models and strategies to integrate the arts into STEM programs, which leads to the emergence of STEAM (Science, Technology, Engineering, Arts, and Mathematics) (Martín-Páez et al., 2019). According to empirical studies, arts education can improve students' capacity for creativity, critical thinking, innovation, teamwork, and interpersonal communication (Liao, 2016).

Over the past few years, creative thinking has become increasingly important, mostly because of the importance that new ideas play in changing the world (Alkathiri et al., 2018). To facilitate all kinds of scientific breakthroughs that enhance lives, it is essential to expand and communicate information

(Ulger, 2018). Therefore, having individuals who are able to think creatively is becoming more crucial (Solihat et al., 2024). This is evident from the growing number of educational systems in various countries that emphasize the importance of creative thinking (Alkathiri et al., 2018). Consequently, students' creative thinking ability has been used as a metric to measure their academic development over time (Jauk et al., 2014). The learning method used in the classroom has been linked to the process of acquiring these abilities (Yazar Soyadı, 2015). Terms such as creative thinking, creative problem solving, creative skill development, or simply creativity are often mentioned in articles as outcomes of STEM (Perignat & Katz-Buonincontro, 2019).

Several learning models have been integrated with STEM or STEAM approaches to help students become more creative thinkers and better prepared for the Fourth Industrial Revolution. Examples include PjBL-STEM (Mulyati et al., 2023; Yusuf et al., 2023), Digital visual classroom integrated with STEAM (Wannapiroon & Pimdee, 2022), Blended learning-STEAM (Putri et al., 2023), and Ethno-STEM project based learning (Sumarni & Kadarwati, 2020). These models are effective in improving creative thinking skills. However, although STEM education has demonstrated its effectiveness, putting it into practice is not simple. Therefore, identifying research trends in the integration of STEM in science education for the development of creative thinking skills is essential to help educators and researchers determine the next steps.

Previously, many literature review studies have been conducted, such as the use of STEAM to enhance environmental education literacy and innovation (Syahmani et al., 2021), the growing use of creative thinking in science education (Fahmi & Jumadi,

2023), the aim of Indonesian STEM education to strengthen students' 21st-century learning skills (Ilma et al., 2023), and critical thinking abilities in mathematics using the STEM/STEAM method (Nurhikmayati et al., 2024). However, none of these studies have specifically conducted a systematic literature review (SLR) focusing on trends in the use of the STEM approach to improve creative thinking skills in science education. Therefore, this SLR study was conducted as a step to examine the trend of the STEM approach in order to improve creative thinking ability in learning. This research aims to serve as a forum for the many studies that integrate STEM in improving creative thinking abilities in the scope of science, with the hope that this approach can continue to evolve in response to the demands of 21st-century education.

2. Method

As part of a systematic literature review, this study employs bibliometric research, which applies statistical and quantitative techniques to bibliographic data, including publications and citations (Rochman et al., 2024). This method collects data from publications such as scientific journals, articles, and citations, then analyzes the data to find relevant patterns (Nandiyanto et al., 2023). The findings of performance analysis and science mapping produced by programs and databases like Scopus and Google Scholar should be compiled in this study (Solihat et al., 2024). Creative thinking is essential to meet the demands of 21st-century competencies (Lamb et al., 2017), and STEM is the approach adopted by researchers to improve creative thinking ability (Yulianti et al., 2020). Therefore, bibliometric research was conducted to highlight the trend of the application of the STEM approach in fostering creative thinking ability. Three steps were

included in this bibliometric investigation: data collection, visualization, and analysis.

Data collection was conducted on October 16, 2024 through SCOPUS and Google scholar databases. The selected documents were those indexed by SCOPUS or Sinta 1 and 2, which have a high academic reputation. The document search was conducted using the following keywords: "Science" AND 'STEAM' OR 'STEM' AND 'creative thinking skills' OR 'creative thinking ability'. The search and screening process in this study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, as shown in Figure 1.

The selection procedure is depicted in Figure 1, which begins with identification and screening, focusses on years (2019–2024), and restricts the findings to publications. Since document-type articles are the most prevalent and important type of scholarly publication, they were chosen. They typically contain original research that can be effectively evaluated and compared using bibliometric techniques and metrics. Additionally, publications written in English were given additional consideration during the selection process as English is the most widely used language in global scientific communication. This decision enables access to a broader range of internationally relevant literature and facilitates the exchange of research findings among international scholars. After that, a screening procedure was carried out to eliminate duplicate titles and ensure the chosen articles were pertinent to the subject of the study. Articles were chosen based on the following criteria: they fell within the scope of science, measured creative thinking skills, and did not use the systematic literature review methodology. Lastly, before being incorporated and analysed in the bibliometric analysis, 26 articles were exported

and stored in BibTex format. The software that makes it easier to analyse the data visualization display is referred to as the format option.

In data visualization, the BibTex-formatted data was imported into Biblioshiny. To run Biblioshiny, the program must be coded in the R Studio application. A possible option for conducting and visualising bibliometric analysis data is the R application, which is based on [Aria & Cuccurullo \(2017\)](#) an open-source bibliometric program. Through the R application's program calls, researchers can do interactive bibliometric analysis using Biblioshiny, the Bibliometrix program on the web ([Aria & Cuccurullo, 2017](#)). R Studio was chosen due to its capa-

bility to perform in-depth data analysis with interactive visualizations, allowing exploration of patterns in the data through customizable graphs outputs. We also used Microsoft Excel to complete the data visualization, as it facilitates data analysis by providing basic statistical functions, data filtering and sorting capabilities, and instant visualizations that make interpretation of results easier.

For the data analysis, the bibliometric analysis results generated using the R application were analyzed and interpreted. At this point, a literature review was conducted to gather detailed information about the subject of the study: namely, creative thinking ability.

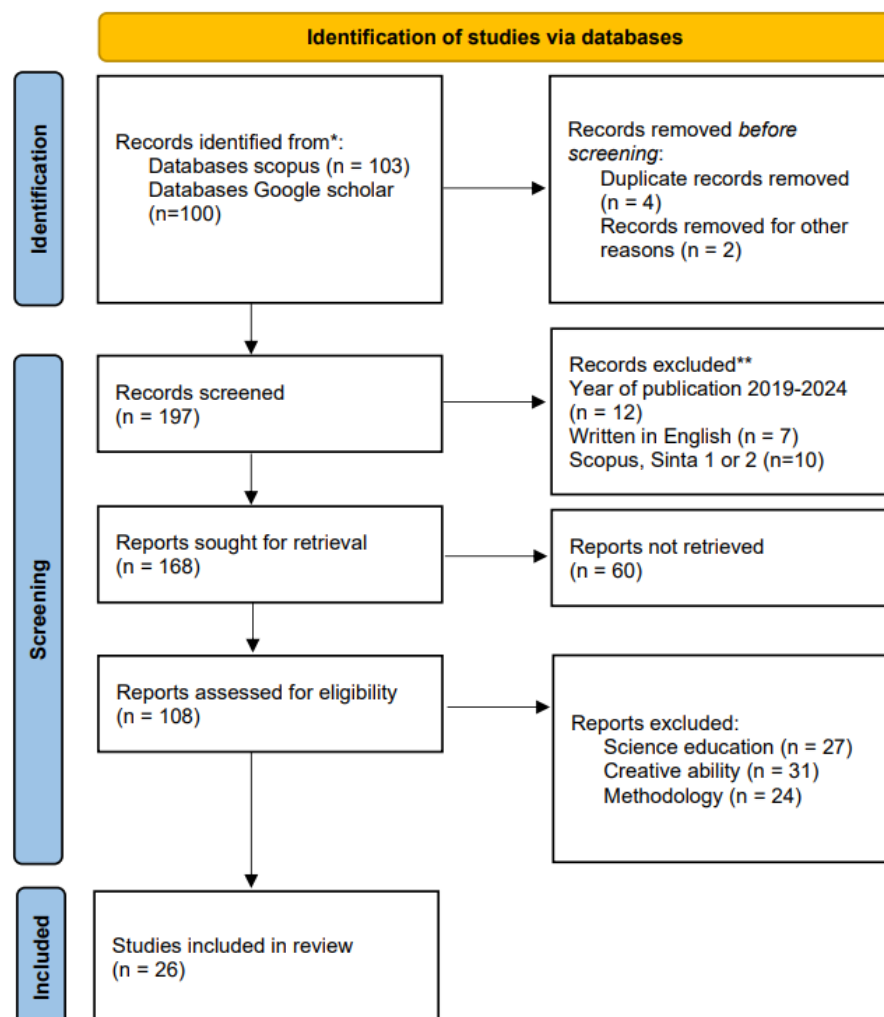


Figure 1. The Process of Article Selection

3. **Result and Discussion**

a. **General Characteristics of Qualifying Studies**

1) **Yearly Trend of Publication Numbers**

Our review presently includes 26 articles that were published between 2019-2024 in internationally indexed journals (Scopus) and nationally indexed journals (Sinta 1 and 2). Figure 2 illustrates the development of publications related to STEM in improving creative thinking skills in science education. It shows the growth and variations in research production by displaying the annual publication trend from 2019 to 2024. There is a consistent rise in publications from 2019

to 2021, rising from 3 documents in 2019 to 7 documents in 2021, the highest throughout the period, which may indicate increased research activity or interest in those years. However, the 2021-2022 period shows a decline, to 4 documents in 2022. However, this upward trend declined in 2022, with only 4 documents published. In 2023, the number of publications rose slightly to 5, followed by a drop to 3 documents in 2024. Notwithstanding these variations, the general pattern indicates that this research area is still expanding, with sporadic rises probably due to changes in the focus of study.

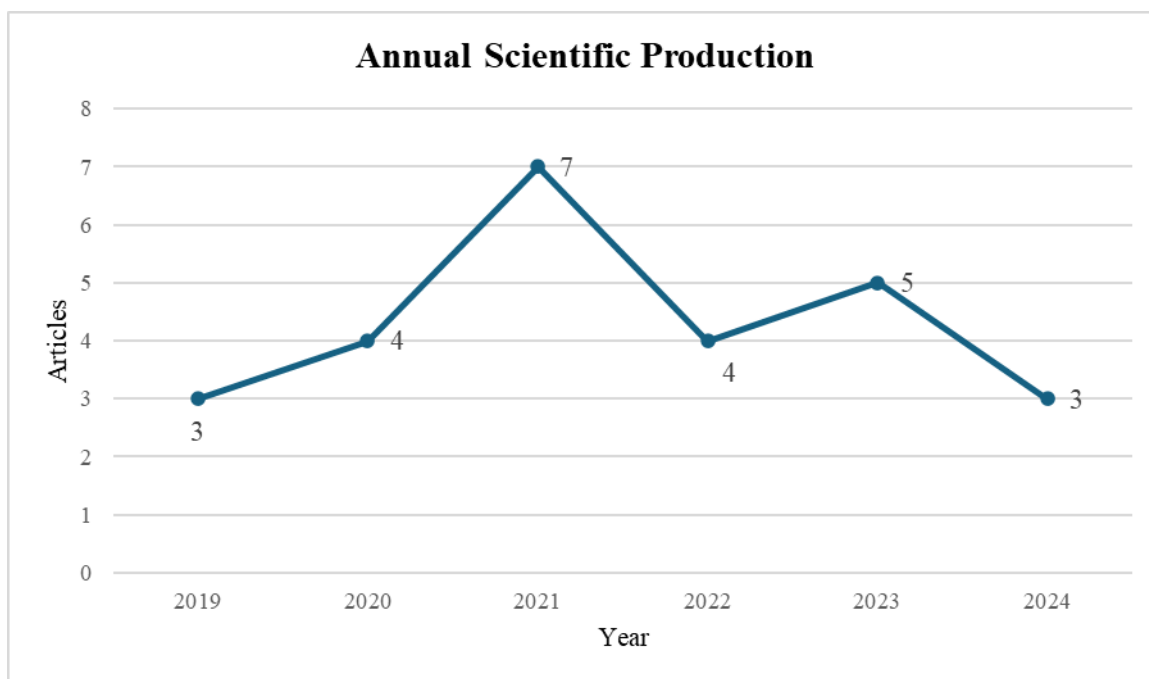


Figure 2. Annual Scientific Productions

In addition, research on creative thinking is very important because it helps to understand how individuals analyze information in depth (Rahmawati et al., 2019) and generate innovative solutions (Purnamasari et al., 2020), which is crucial in facing complex challenges and improving the quality of learning (Jantassova et al., 2022). Research related to creative thinking has been conducted especially in the development of problem-

solving skills within STEAM fields (Rahmawati et al., 2019; Wannapiroon & Pimdee, 2022). This research also supports better decision-making and encourages the creation of new ideas that are relevant in various life contexts. In the educational context, creativity-based approaches not only help students develop innovative solutions but also enhance their cognitive flexibility in problem solving (Kaufman & Sternberg, 2019). Thus,

further exploration of methods and strategies that support the development of creative thinking is crucial, especially in the face of increasingly complex and dynamic global challenges.

2) Distribution of Article Publications on the STEM Approach in Enhancing Creative Thinking Ability in Science Learning from 2019–2024

To get a comprehensive picture of the distribution of the improvement of creative thinking skills in science education through the STEM approach, a breakdown by country and the corresponding percentage of articles is presented, as shown in Figure 3. The distribution of research outputs by country is depicted in Figure 3, with the number of documents produced by each country indicated in brackets. With nine documents, or 34.62% of the total research output, Indonesia is clearly in the lead, as seen in Fig. 3. This is followed by the United States, Taiwan, Turkey, and Germany, each contributing 11.54% with three documents. Other countries such as Thailand (7.69%), along with Italy, Austria, Slovakia, United Arab

Emirates, Hungary, and Malaysia (each contributing 3.85%), also played an important role, despite this, their efforts paled in comparison to those of Indonesia. Indonesia ranks highest because national curriculum (Khalil et al., 2023) and policies appear to be the two most significant in integrating STEM (Azhari et al., 2023). This distribution implies that, even though certain nations lead the world in research output, contributions from various regions continue to grow, reflecting international collaboration and sustained interest in this field. In addition, these trends highlight the importance of institutional support and funding in driving STEM research in different countries. Furthermore, international collaboration is increasingly becoming key in accelerating innovation and knowledge dissemination. Much of the research in STEM fields involves collaboration between scholars from different countries, which not only enriches scientific perspectives but also strengthens cross-cultural relationships in the development of science (Contreras Aguirre & Gonzalez, 2021).

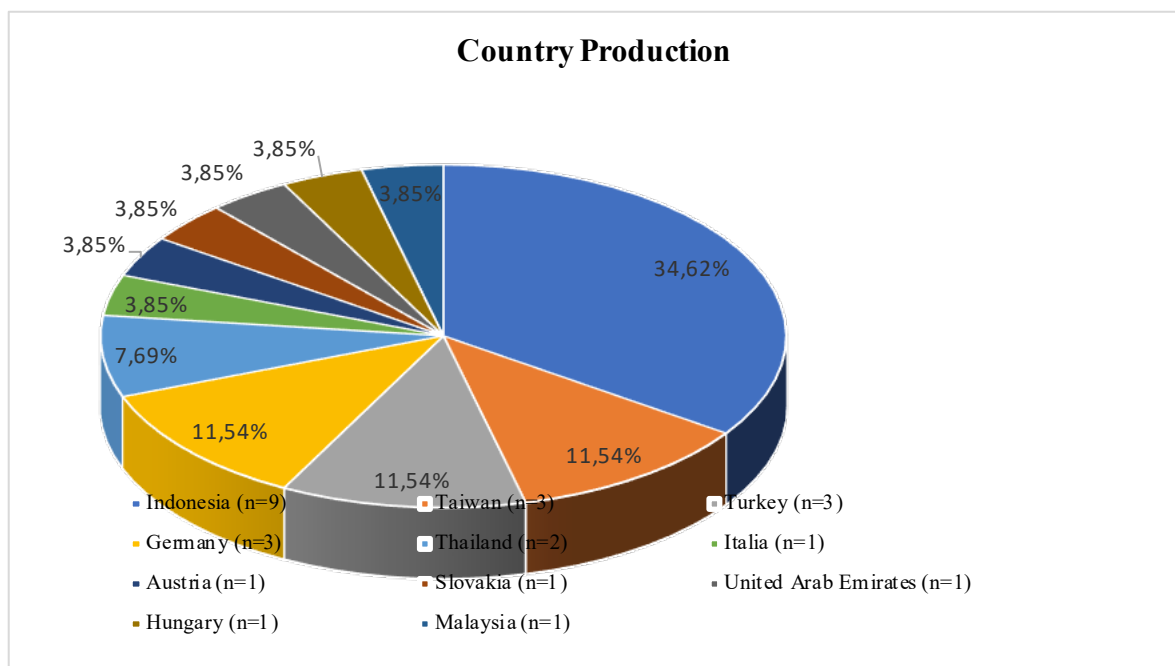


Figure 3. Country Production Over Time.

3) Distribution of Articles Based on Research Methods

The research approaches carried out by researchers of the selected studies are shown in Figure 4. Figure 4 shows that there are various approaches to conducting research related to the role of STEM in enhancing creative thinking skills in science education. The majority of the studies used a quantitative approach ($n=17$). Additionally, the quantity of mixed-methods research ($n = 3$), R&D research ($n = 4$), and qualitative studies ($n = 2$) was almost equal. This is in line with Harris & De Bruin (2018), which noted that STEM education has placed a strong emphasis on creativity and recommended conducting experimental research to identify strategies for fostering creativity in STEM education. In this study, quantitative research that uses experiments is widely conducted, such as research from (Siew & Ambo, 2020) and (Dotson et al., 2020). The dominance of quantitative approaches in STEM research focused on improving creative thinking skills suggests that this method is considered effective in objectively measuring the impact of interventions. Experimental methods in quantitative research allow researchers to isolate specific variables and identify causal relationships, thus providing strong empirical evidence. Meanwhile, mixed methods, R&D, and qualitative research continue to play an important role in exploring the factors that

influence creativity in STEM education from different perspectives. Thus, the combination of these approaches provides a more holistic insight into understanding how STEM can support the development of creative thinking skills.

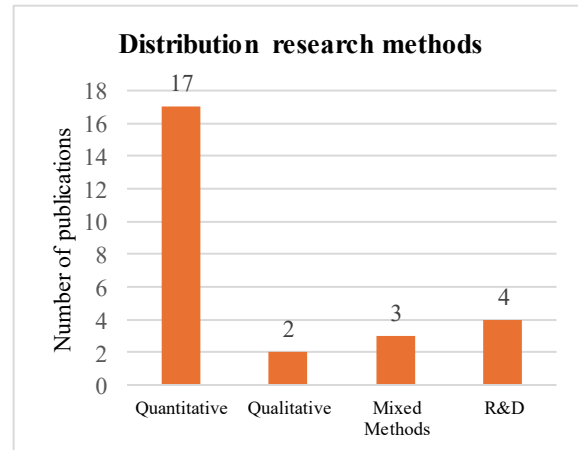


Figure 4. Distribution of Articles Based on Research Methods

4) Top 10 Most Cited Papers

The top 10 most cited papers during the analysis period are presented in Table 1, highlighting key information such as the most cited authors, the journals in which these articles were published, total citation counts, and the proportion of citations relative to the top ten cited publications overall. These articles, which focus on STEM and STEAM education in fostering creative thinking abilities within the framework of science education, are listed in the ranking, as shown in Table 1.

Table 1. Top 10 Most Cited Paper

Author	Journal	Total Citations	TC per year	Normalized TC
(Sumarni & Kadarwati, 2020)	Jurnal Pendidikan IPA Indonesia	370	74	2.55
(Conradty & Bogner, 2019)	Creativity Research Journal	143	23.83	1.04
(Rahmawati et al., 2019)	Journal of Physics: Conference Series	133	22.17	0.96
(Altan & Tan, 2021)	International Journal of Technology and Design Education	128	32	2.75
(Wannapiroon & Pimdee, 2022)	Education and Information Technologies	119	39.67	1.78

Author	Journal	Total Citations	TC per year	Normalized TC
(Hebebe & Usta, 2022)	Participatory Educational Research	64	21.33	0.96
(Vidákovich et al., 2021)	Journal of Physics: Conference Series	58	14.5	1.25
(Siew & Ambo, 2020)	Problems of Education in the 21st Century	52	10.4	0.36
(Ahmad et al., 2021)	Jurnal Pendidikan IPA Indonesia	45	11.25	0.97
(Tran et al., 2021)	Frontiers in Education	33	8.25	0.71

Based on Table 1, the importance and influence of each study in its respective field are reflected through the variations in total citations, annual citation counts, and normalized citation scores. A study by [Sumarni & Kadarwati \(2020\)](#) investigated how integrating STEAM into chemistry education might help students enhance their capacity for critical and creative thinking. According to all measurements, the results showed that ethno-STEM project-based learning may enhance typical students' capacity for creative and critical thinking, which initially ranged from low to medium ([Sumarni & Kadarwati, 2020](#)). Similarly, a study by [Rahmawati \(2019\)](#) investigated the role of STEAM integration in developing students' capacity for critical and creative thinking. The findings demonstrated that students were able to develop creativity and critical thinking ability ([Rahmawati et al., 2019](#)).

These studies demonstrate that STEM can enhance creative thinking skills, although significant challenges remain. In the research of [Tran et al., \(2021\)](#), it was found that a STEAM-based approach that integrates arts in STEM can improve students' scientific creativity. However, their study also revealed that not all STEAM implementations yield the same outcomes, and some students still struggle to develop their creativity. Similarly, [Sumarni & Kadarwati \(2020\)](#) highlighted the Ethno-STEM Project-Based Learning (PBL) approach which in-

corporates local wisdom into STEM learning. Their study shows that this method is effective in improving students' creative thinking skills, yet challenges persist in its implementation. One of the main obstacles found is the dominance of rote-based learning in schools, which hinders exploration and creative problem solving. In addition, students often struggle to answer "why" questions due to limited exposure to learning methods that encourage exploration and critical thinking. These findings suggests that innovative learning designs are necessary to ensure the effectiveness of STEM in improving students' creative thinking skills ([Muliya-ti et al., 2023](#)).

These findings consistently underscore the importance of integrating STEM or STEAM in developing students' creative thinking skills. The goal of STEAM education is to increase students' interest in all subjects by improving their creativity, expressiveness, and aesthetic sensibility ([Hsiao & Su, 2021](#)). STEM is now a national priority for all secondary school levels in the US, according to the National Science Foundation ([Wannapiroon & Pimdee, 2022](#)). The goal is to equip students with critical thinking skills that can transform them into innovative problem solvers who can eventually be used in the workplace ([Hebebe & Usta, 2022](#)).

b. Learning Model/Media Integrated with STEM or STEAM

As indicated in Table 2, various learning methods and media associated with the STEM (Science, Technology, Engineering,

Mathematics) or STEAM (Science, Technology, Engineering, Arts, Mathematics) approaches have been developed to enhance students' creative thinking abilities.

Table 2. Learning Model/Media Integrated with STEM or STEAM

Author	Learning Model/Media Integrated with STEM or STEAM
(Altan & Tan, 2021)	Design based learning
(Conradty & Bogner, 2019); (Kırıcı & Bakırcı, 2021)	Inquiry
(Mulyati et al., 2023) and (Yusuf et al., 2023)	PJBL
(Putri et al., 2023)	Blended learning
(Khalil et al., 2023)	Curriculum STEM
(Supahar et al., 2024)	Audio Biostimulation
(Haim & Aschauer, 2024)	FOCUS
(Mou, 2024)	Visual story telling
(Supahar et al., 2024)	IOT
(Wannapiroon & Pimdee, 2022)	Digital virtual classroom
(Yulianti et al., 2022)	SCRATCH
(Wannapiroon & Pimdee, 2022)	Conceptual model
(Yulianti et al., 2020); (Mulyati et al., 2023); (Dermawan & Andartiani, 2022)	Worksheet
(Shukri et al., 2020)	Module
(Siew & Ambo, 2020)	Project-based cooperative
(Sumarni & Kadarwati, 2020)	Ethno-PjBL
(Tran et al., 2021)	Curriculum STEAM
(Vidákovich et al., 2021)	STEM-E (Ethnomathematics)

Table 2 presents various models and media integrated with the STEAM or STEM approaches. Problem-Based Learning (PBL) and Project-Based Learning (PJBL) encourage students to solve real-world problems and complete complex projects that require in-depth analysis and innovative solutions (Purnamasari et al., 2020; Mulyati et al., 2023). Blended Learning, on the other hand, combines online and face-to-face learning, providing flexibility for students to learn concepts independently while practicing critical analysis (Putri et al., 2023). The use of E-Module and Digital Virtual Classroom also provides flexibility and supports students' independent exploration, thus improving their creative thinking ability (Purnamasari et al., 2020; Wannapiroon & Pimdee, 2022).

The Inquiry model prioritizes student exploration and inquiry to understand concepts and find creative solutions independently (Prayogi et al., 2024). Meanwhile, innovations such as Audio Biostimulation contribute to students' focus and concentration during learning activities (Supahar et al., 2024). The FOCUS program integrates creativity and innovation with sustainability principles, training students to create solutions that promote sustainable development (Haim & Aschauer, 2024). Conceptual Models and Worksheets facilitate deep conceptual understanding through a logical and systematic approach (Mulyati et al., 2023).

Learning with STEM education, STEM project-based learning, for example, equips the upcoming generation of engineers, math-

emicians, and technologists to meet the demands of the twenty-first century (Yusuf et al., 2023). The integration of technology, engineering, and design principles through STEM inquiry-based learning, can foster creative thinking (Khalil et al., 2023). However, STEM education does not necessarily enhance students' ability to elaborate on, provide details for, or clarify complex concepts. A key element of creative thinking is elaboration, which calls for the expansion and development of concepts in order to produce thorough and specific responses (Khalil et al., 2023). To further improve the results of creative thinking, future studies should investigate how STEM education can better support the development of elaboration skills. Over the next decade, knowledge in science, engineering, and technology will continue to evolve due to the impact of the Industrial Revolution 4.0. As a result, students worldwide must intensify their efforts to strengthen their scientific knowledge base, as the complexity of modern-day challenges demands the ability to think creatively.

The distribution of publications on STEM approaches in enhancing creative thinking skills in science education reveals various challenges and opportunities relevant to educational innovation. One of the main challenges found in various publications is the lack of systematic STEM curriculum in formal education settings (Tran et al., 2021). Although creativity is considered an important aspect of 21st century learning, there is still a lack of curriculum design that specifically targets the development of creativity through STEM approaches (Sapounidis et al., 2024). There is also uncertainty regarding how to effectively integrate science subjects with technology, engineering and math in K-12 education (Khut & Shimizu, 2023). This creates barriers to the effective implementation of integrated STEM education

(Khut & Shimizu, 2023). Additionally, research on STEM education is often suffers from inconsistencies inconsistent and limited duration, which limits the ability to generalize findings and develop systematic curricula (Tselegkaridis & Sapounidis, 2022). Therefore, in the coming decade, effective curriculum development for STEM education is essential. The industrial revolution 4.0 will drive the transition of science, engineering, and technology knowledge, and students worldwide must accelerate efforts to strengthen their scientific foundations, as the complexity of contemporary challenges increasingly requires individuals capable of creative thinking.

c. Trend Analysis of Findings in STEM and Creative Thinking research

STEM or STEAM is generally effective in improving creative thinking skills but its effect on creativity depends on the duration of the intervention and project design. Research conducted by Sumarni & Kadarwati (2020) found that Ethno-STEM PjBL has a positive impact on improving students' creative thinking skills, but the originality indicator shows the lowest results, indicating that generating complex and original ideas remains a challenge. Similar results were reported in Altan & Tan's (2021) research with the application of STEM based on Design-Based Learning (DBL) effectively increasing the fluency indicator (i.e., the number of ideas) but less in originality (i.e., the uniqueness of ideas). This indicates that while students are capable of generating multiple solutions, they often struggle to develop innovative ones. This limitation may stem from students' lack of exposure to open-ended questions and unfamiliarity with project-based learning (Sumarni & Kadarwati, 2020), the same reason found in Rahmawati et al's research (2019) so that some students have diffi-

culty in working independently and collaboratively. However, different results in Siew et al.'s research (2017) showed that a supportive environment, such as project-based learning, can facilitate the development of more unique and flexible ideas. This is closely related to the engineering aspect, which is often the dominant element in STEM implementation, especially through prototyping. The engineering aspect plays an important role in increasing student creativity and can be further optimized in incorporating the art aspect, thus transforming STEM into STEAM (Sickler-Voigt, 2023). In the engineering aspect, students go through several stages known as the engineering design process (EDP) (Jolly, 2017), which consist of the following stages: 1) define the problem, 2) research, 3) imagine, 4) plan, 5) Create, 6) test and evaluate, 7) redesign, and 8) communicate (Jolly, 2017). Typically, a design challenge begins with a real-world problem, requiring students to use their creativity to identify the best solution, build a prototype, and test it (Fatihatussaadah et al, 2024). The final stage, communication, involves students presenting their ideas and discoveries to peers and receiving feedback (Altan & Tan, 2021). For example, research of (Mulyati et al., 2023), students engaged in the creation of mini solar car, and solar-powered wind turbines. The aim of STEM education is to improve maths and science learning by combining engineering and technology (Hebeci & Usta, 2022).

The duration of the intervention is very important in the STEM or STEAM approach. Research conducted by Conradty & Bogner (2019) examined how a STEAM approach based on Inquiry-Based Science Education (IBSE) a four-hour STEAM module. Their findings revealed that while there was a temporary increase in Flow scores among female students after the intervention, there were no

significant long-term improvements in creative thinking skills. This study found that creativity does not improve with just one intervention and concluded that creativity requires repeated training within a supportive social environment to achieve sustainable growth. This is evidenced by the research of Rahmawati et al (2019) who conducted a two-year longitudinal study on high school students' chemistry learning by integrating the PjBL learning model with STEAM. The results show that creative thinking skills increase through the exploration of real-world problems, as the STEAM approach encourages students to connect chemical concepts with the real-world contexts (Rahmawati et al., 2019). This shows that STEAM is more effective if applied in the long term with repeated practice. However, this study also found that STEAM integration is not always straightforward, especially in disciplines such as chemistry, which are often taught separately from the art aspect. Challenges in managing time and resources in STEAM projects have also been identified in other studies, indicating the need for more flexible curriculum approaches (Khalil et al., 2023), as well as STEM implementation outcomes varying depending on the duration of the program and the depth of the intervention. In addition, the sequence of learning in the STEM approach also affects its effectiveness in enhancing creativity (Tran et al., 2021). Studies show that students who were first exposed to exploratory challenges through STEM projects before being exposed to theoretical concepts have higher levels of creativity compared to those who learned theoretical concepts first (Tran et al., 2021). This confirms the importance of appropriate teaching strategies within STEM education to maximize its impact on creative thinking.

STEAM can also be used in virtual learning environments, such as research conduc-

ted by Wannapiroon & Pimdee (2022), which shows that the STEAM approach in a virtual environment is very effective for developing creative thinking skills. The STEAM approach that added art aspects to STEM provided better results in developing students' creative thinking skills compared to the STEM approach alone (Wannapiroon & Pimdee, 2022). The art element proved to be a catalyst in improving creative thinking skills, allowing students to explore more innovative solutions. However, some students still have difficulty connecting art with science concepts (Rahmawati et al., 2019), suggesting that this approach needs to be further developed.

The application of STEM in improving creative thinking skills in science learning can be applied at various levels of education as previous studies have effectively improved creative thinking skills at the university level (Wannapiroon & Pimdee, 2022), senior high school (Altan & Tan, 2021), junior high school (Hebebcı & Usta, 2022), and elementary school (Conradty & Bogner, 2019). This shows that all levels of education can benefit from STEM approaches. Integrated STEM approaches are proven to be more effective than traditional approaches that separate disciplines (Hebebcı & Usta, 2022). The integrated approach allows students to develop a more holistic understanding of the interrelationships between science, technology, engineering and math. However, implementing STEM in learning is not easy, so teachers need more training in connecting science concepts with STEM in order to guide students more effectively. The STEM approach helps students understand the interconnectedness of disciplines, which is often not taught in the traditional education system. STEAM integrated with various learning models is more effective in enhancing creativity than conventional methods, but its effec-

tiveness largely depends on the learning design, and their involvement in the exploration of real-world problems.

4. Conclusion

This systematic literature review shows that the application of the STEM approach to enhancing creative thinking ability in science education shows continuous growth. Increasingly, teachers, researchers, lecturers, and other educational stakeholders worldwide are paying more and more attention to STEM in scientific education as a means of fostering ability to think creatively. The majority of STEM-creative thinking initiatives in science education have been conducted in countries such as Indonesia, Taiwan, Turkey and Germany. STEM-creative thinking in science education is most prevalent in Indonesia for various reasons, such as national policy and curriculum appear to be the two most important. Moving forward, STEM-based approaches to enhancing creative thinking in science education are expected to expand further, driven by the growing awareness of their benefits. Through considering the existing curriculum, there is much room and advancement so that future teachers can specifically teach STEM subjects. Various models and medias are integrated with STEM approaches, including PjBL, Inquiry, and design based learning, where these studies are effective in improving creative thinking ability. However, several challenges persist. These include limited instructional time, insufficient resources, and difficulties in adapting curricula to support STEM within specific subjects. Creativity is difficult to develop with just one short intervention; it requires a supportive social environment, repeated practice and greater freedom in exploration. Teachers still tend to act as instructors rather than facilitators, so students' creativity is not optimally developed. As an innovative step,

further research can integrate the Clarity Learning Model (CLM) with the STEAM approach as a novelty in the development of learning models, CLM adds elements of clarity of instruction and a more systematic structure to help students understand learning steps more purposefully. This approach is expected to be a relevant new strategy to improve creative thinking ability.

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