Journal Evaluation in Education (JEE)
Vol. 7, No. 1, January 2026, pp. 256~269
ISSN: 2716-4160, DOI: 10.37251/jee.v7i1.2711

Research Article

The Potential of Creative Thinking in STEAM Based Science Learning: Supporting Factors and Implementation Challenges

Dini Fatrisia Hasniati[1,*], Raharjo[1], Elok Sudibyo[1], Muhammad Satriawan[1]
[1] Departement of Mathematics and Natural Science, Universitas Negeri Surabaya, Jawa Timur, Indonesia

Article Info

Article history:

Received Nov 21, 2025
Revised Dec 23, 2025
Accepted Jan 28, 2026
OnlineFirst Jan 31, 2026

Keywords:

Critical Thinking Ability
Literature Reviews
Science Learning
STEAM

ABSTRACT

Purpose of the study: This study aim to examine the factors causing low creative thinking skills in STEAM-based science learning, including indicators of creative thinking and various challenges in its implementation.

Methodology: The research method used is a systematic literature review (SLR). Data collection uses the PRISMA flow. Data were obtained from the Sinta-indexed Google Scholar database for national journals and, for international journals, there were no restrictions; all journals were accessed through the Publish Or Perish (PoP) application. Data analysis used bibliometrics related to keyword accuracy and was visualized using VOS Viewer software. A total of 500 articles were obtained, of which 18 articles were used as primary data and as material for analysis in the discussion.

Main Findings: The results showed that there were four indicators relevant to Guilford's theory regarding creative thinking skills in STEAM learning. Factors contributing to low creative thinking skills included lack of motivation, monotonous methods, models, and tasks, as well as the implementation of learning activities. Additionally, challenges in improving creative thinking skills in STEAM learning included long duration and the difficulty of improving fluency indicators.

Novelty/Originality of this study: This study is novel because it structuredly examines the supporting factors and various implementation challenges in developing creative thinking skills through STEAM-based science learning. This research combines pedagogical, contextual, and professional perspectives from teachers, resulting in empirical findings that enrich STEAM studies and strengthen the application of creative thinking development strategies in science education.

Corresponding Author:
Dini Fatrisia Hasniati,
Departement Of Mathematics and Natural Science, Universitas Negeri Surabaya,
Lidah Wetan, Kec. Lakarsantri, Surabaya, Jawa Timur, 60213, Indonesia
Email: dinifatrisia11@gmail.com

1. INTRODUCTION

Technological developments and globalization have created complex and dynamic challenges for 21st-century education, requiring student to master essential skills such as collaboration, critical thinking, communication, and creativity [1]. This competency plays an important role in enhancing students' creativity, which leads to innovative ideas and effective problem-solving skills. Creative thinking is an individual's ability to generate original ideas that are relevant to the main problem and contextual conditions, thereby producing new methods or products [2]. In the context of education, creative thinking skills enable students to realize their ideas, improve the quality of learning, and develop higher-order thinking skills.

Creative thinking skills are generally measured through four main indicators, namely fluency, flexibility, originality, and elaboration. These indicators support students in producing original work. In addition, meaningful learning is achieved because it involves students in the learning process, making learning seem enjoyable. Previous research shows that creative thinking skills can significantly affect student learning outcomes [3] and are influenced by learning interests and learning styles [4]. The results show that enhancing creativity requires a learning environment that can integrate various disciplines and encourage exploration beyond a single subject approach.

One approach that is in line with this concept is STEAM (science, technology, engineering, arts, and mathematics). STEAM emphasizes interdisciplinary learning aimed at developing scientific, logical, and creative problem-solving skills to increase student motivation through active engagement [5]. The "arts" element in STEAM is very important because it supports creativity, while other disciplines provide a conceptual and analytical foundation for decision making. Field evidence shows that STEAM-based learning can influence creative thinking skills and increase student engagement [6], as well as improve learning outcomes in certain subjects, such as mathematics [7].

Based on the previous explanation, it should be noted that the application of STEAM in learning has significant challenges. Among the studies show that teachers lack adequate training, resources, and pedagogical understanding of STEAM, which leads to misunderstandings and poor integration of components [8]. As a result of these problems, STEAM learning tends to focus on activities rather than meaningful problem-solving processes based on scientific and mathematical reasoning. This condition can weaken the role of STEAM in fostering creativity. According to Barkah et al [9], STEAM requires well-designed technical and design-based methods to support knowledge construction and creative problem solving.

Research has extensively examined the effectiveness of STEAM-based learning, but most studies tend to focus on learning outcomes rather than analyzing the factors and challenges that influence the development of creative thinking skills, especially in science learning. Comprehensive research identifies supporting factors, obstacles, and practical challenges in learning to train creative thinking through the STEAM approach, which is still limited. Therefore, there is a need for in-depth investigation that integrates pedagogical and contextual perspectives related to teachers and students in learning.

Understanding the factors and challenges in implementing STEAM-based science learning is urgent. This is because ineffective implementation hinders the development of students' creative thinking. This study aims to provide knowledge about strategies and practical considerations for guiding educators in designing effective STEAM learning. It is hoped that these findings will support teachers and policymakers in overcoming implementation problems and maximizing STEAM as a tool for fostering creativity.

2. RESEARCH METHOD

This study uses the systematic literature review (SLR) method with a bibliometric approach. The purpose of using this method is to identify, analyze, and synthesize findings from previous studies related to creative thinking aspects and factors and challenges in implementing STEAM-based science learning. The type of research used is secondary qualitative research based on systematic literature review. This research does not involve primary data from respondents, but uses secondary data from literature sources, including relevant national and international scientific journal articles. Journal articles were obtained through the Google Scholar database using the Publish or Perish (PoP) application. The sampling technique used was purposive sampling in the form of selecting articles based on predetermined inclusion and exclusion criteria. The inclusion criteria included: (1) articles discussing creative thinking in STEAM-based learning, (2) articles in the field of science (natural sciences, physics, chemistry, biology, and mathematics), (3) junior high school and high school research subjects, (4) articles published between 2020 and 2025, (5) articles that are fully accessible (open access). Exclusion criteria included: (1) articles that were not relevant to science learning, (2) proceedings, non-empirical articles, and non-systematic review articles, (3) articles that did not mention learning models or approaches. Based on this selection process, 18 articles were obtained and used as research samples.

This study did not use research instruments in the form of tests or questionnaires but used document analysis sheets in the form of articles reviewed based on the research focus, so that validity and reliability tests (Cronbach Alpha) were not required. The analysis sheets used in this study refer to several aspects, including: (1) indicators of creative thinking (fluency, flexibility, originality, elaboration), (2) the STEAM learning framework, (3) the focus of analysis on supporting factors and implementation challenges. The instruments used were developed based on Torrance's creative thinking framework and the STEAM concept, without adopting any specific quantitative measurement instruments.

Data collection was conducted using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. The steps involved were: (1) Identification, which was searching for articles using the keywords “Creative Thinking” AND “STEAM Education”; (2) Screening, which was filtering based on titles and abstracts; (3) Eligibility, which was assessing the suitability of the article content to the research questions; (4) Inclusion, which was determining which articles to analyze in depth.

Data analysis was conducted in the form of qualitative descriptive analysis through several stages, including grouping findings based on aspects of creative thinking, identifying factors supporting and challenging the implementation of STEAM, and synthesizing research results to answer research questions. The results of the analysis were presented in the form of narratives and summary tables of findings to strengthen the interpretation of the results.

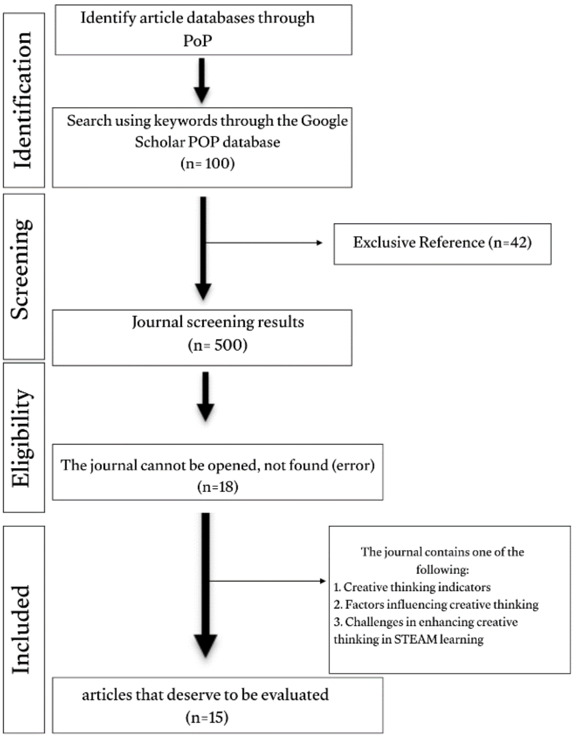

Figure 1. PRISMA flow chart

3. RESULTS AND DISCUSSION

Analysis of STEAM Word Networks and Creative Thinking

The results of the research through the literature review method were obtained based on predetermined inclusion criteria. The initial search used the keywords creative thinking and STEAM education, which yielded 500 articles. In the next stage, the titles, abstracts, duplicates, and topic relevance were screened, resulting in 18 articles that were selected based on relevance criteria and could be analyzed further. The articles obtained were sourced from reputable national and international journals with a publication range of 2020-2025. Some of the studies were conducted at the secondary and higher education levels, which are relevant to science, mathematics, and chemistry learning [10]-[23]. The research results show that the application of STEAM still tends to be in the exact sciences and is not yet evenly distributed across all levels. The article data can be seen in Table 1.

Table 1. Articles relevant to the research

Author	Judul	Jurnal	Artikel
[10] L. Rahmayanti, F.S.A. Nugraheni, N. Lestari	Penerapan Pembelajaran IPA Berbasis Science, Technology, Engineering, Art, Mathematics (STEAM) Untuk Meningkatkan Kterampilan Proses Kreatif [Implementation of Science, Technology, Engineering, Art, Mathematics (STEAM)-Based Science Learning to Improve Creative Process Skills]	Jurnal Pendidikan dan Pembelajaran IPA Indonesia	2024
[11] Josina Filipe, Monica	Integrated STEAM Education	*Education Science*	2024

Author	Judul	Jurnal	Artikel
Baptista, Teresa Conceicao	For Students' Creativity Development		
[12] Irdalisa, Zulherman, Mega Elvinasti, Sri Adi Widodo, Erlia Hanum	Effectiviness of Project Based Learning on STEAM Based Students Worksheet Anlysis With Ecoprint Technique	*International Journal of Education Methodology*	2024
[13] Elinawati, Bambang Subali, Bayu Ramadhani Putra, Siti Wahyuni, Pratiwi, Dwijananti, Mohammad Aryono Adhi, Mohammad Mubarrak Mohd Yusof.	Critical Thinking and Creativity in STEAM Based Collaborative Learning on Renewable Energy Issues	*Journal of Education and Learning*	2025
[14] Epifani Putri Mariana, Yosep Dwi Kristanto	Integrating STEAM Education and Computational Thinking: Analysis of Students' Critical and Creative Thinking Skills in an Innovative Teaching and Learning.	*Southeast Asia Mathematics Education Journal*	2023
[15] Khoirin Nida Fitria, Dwijanto, Nuriana Rachmani Dewi.	Kemampuan Berpikir Kreatif Matematis Ditinjau dari Self-Esteem pada Model PBL dengan Pendekatan STEAM [Mathematical Creative Thinking Ability Reviewed from Self-Esteem in the PBL Model with the STEAM Approach]	Jambura Journal of Mathematics Education	2023
[16] Heryanti Fatmah	Kreativitas Peserta Didik Dalam Pembelajaran Bioteknologi Dengan PjBL Berbasis STEAM [Student Creativity in Biotechnology Learning with STEAM-Based PjBL]	Pedagonal Jurnal Ilmiah Pendidikan	2021
[17] Siti Nufadilah & Joko Siswanto	Analisis Kemampuan Berpikir Kreatif Pada Polimer Dengan Pendekatan STEAM Bermuatan ESD Siswa SMA Negeri 1 Bantarbolang [Analysis of Creative Thinking Ability on Polymers Using the ESD-Containing STEAM Approach of Students of SMA Negeri 1 Bantarbolang]	Media Penelitian Pendidikan Jurnal Penelitian dalam Bidang Pendidikan dan Pengajaran	2020
[7] Fitri Ayuningsih, Siti Malika, Muh Rifki Nugroho, Winarti, Budi Murtiyasa, & Sumardi.	Pembelajaran Matematika Polinomial Berbasis STEAM PjBL Menumbuhkan Kreativitas Peserta Didik [STEAM-Based Polynomial Mathematics Learning PjBL Fosters Student Creativity]	Jurnal Basicedu	2022
[18] Siti Suryaningsih, Manda Rahmawanti, & Tri Suciati	STEAM PBL Pada Materi Hidrolisis Garam Untuk Membangun Keterampilan Berpikir Kreatif Siswa [STEAM PBL on Salt Hydrolysis Material to Build Students' Creative Thinking Skills]	Dalton: Jurnal Pendidikan Kimia dan Ilmu Kimia	2023
[19] Rizkia Putri Hasibuan, Sari Wahyuni Rozi Nasution	Pengaruh Penggunaan LKPD Model Project Based Learning	Jurnal PhyEdy Pendidikan FISIKA	2024

Author	Judul	Jurnal	Artikel
	Terintegrasi STEAM Terhadap Kemampuan Berpikir Kreatif Siswa [The Effect of Using STEAM-Integrated Project Based Learning Model Student Worksheets on Students' Creative Thinking Skills]	IPTS	
[20] Sariana Safriana, Fajrul Wahdi Ginting, Khairina Khairina	Pengaruh Model Project Based Learning Berbasis STEAM Terhadap Kemampuan Berpikir Kreatif Siswa Pada Materi Alat-Alat Optik di SMA Negeri 1 Dewantara. [The Influence of the STEAM-Based Project Based Learning Model on Students' Creative Thinking Skills on Optical Instruments Material at SMA Negeri 1 Dewantara.]	Jurnal Dedikasi Pendidikan	2022
[21] Agnesi Sekarsari Putri, Zuhdan Kun Prasetyo, Lusila Andriani Purwastuti, Anto Kolonal Prodjosantoso, Himawan Putranta	Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills	*International Journal of Evaluation and Research in Education (IJERE)*	2023
[22] Ngoc-Huy Tran, Chin Fei Huang, Jeng Fung Hung	Exploring the Effectiveness of STEAM Based Courses On Junior High School Students	*Frontiers in Education*	2021
[14] Epifani Putri Mariana, Yosep Dwi Kristanto,	Integrating STEAM Education and Computational Thinking: Analysis of Students' Critical and Creative Thinking Skills in an Innovative Teaching and Learning	*Southeast Asia Mathematics Education Journal*	2023
[23] Achmad Ridwan, Chinthia Fatimah, Tritiyatma Hadinugrahaningsih, Yuli Rahmawati, Alin Mardiah	Development of 21st Century Skills in Acid-Base Learning Through STEAM Projects	JTK: Jurnal Tadris Kimiya	2022

Bibliometric analysis using Vosviewer shows that the most frequently appearing keywords are STEAM, critical thinking, project problem solving, and creativity. The word critical thinking appears more often than creative thinking, indicating that STEAM research emphasizes analytical thinking skills rather than the ability to generate innovative ideas. In addition, the words project and problem solving are related to STEAM learning, which is generally implemented through project-based activities oriented towards contextual problem solving. On the other hand, none of the project tasks implemented were explicitly designed to build creative thinking in accordance with the indicators.

The creative thinking indicators in this study that most frequently refer to Guilford's theory include fluency, flexibility, originality, and elaboration [24], while Torrance and Utami Munandar are less frequently referred to than Guilford. The difference between these three theories is that Guilford's indicators tend to be more comprehensive than those of Torrance and Utami Munandar. Torrance's indicators are adopted from Guilford [25], while Utami Munandar's indicators are a combination and development [26]. Of the 18 articles analyzed, there were 6 articles that measured all four indicators completely. The indicators of fluency and flexibility appeared frequently, while originality and elaboration tended to appear less frequently. These results are based on findings from studies [15]-[18]. These findings show that creative thinking skills in STEAM learning are partial and not yet standardized, which can have an impact on learning due to the suboptimal mapping of students' creative abilities comprehensively.

Based on the analysis results, it is known that Project Based Learning (PjBL) is the most dominant learning model used in STEAM learning, which aims to train and develop creative thinking skills. In theory, the application of PjBL is student-centered with a constructivist approach, so that students are more focused on the design, development, and completion of real projects [30]. The results of the study show that other learning models are applied in science education, including Problem-Based Learning (PBL), Discovery Learning, and Lesson Study, but with a lower frequency. PjBL is the learning model that tends to be applied most often in this study and is directed at activities that produce products or works.

difference between Discovery Learning and the two models is that it focuses on learning oriented towards the discovery of knowledge proposed by students through exploration [31]. Lesson study, compared to the two models, has different characteristics, namely a group of teachers working collaboratively in designing, testing, analyzing, and improving based on direct observation [32]. The results of the study from [33] on the application of Discovery Learning when compared to the application of PjBL show that there is a correlation between science skills and student learning outcomes using PjBl in acid-base material. Meanwhile, research on the application of Lesson Study from [34] shows that almost all students participated actively and had a positive impact on learning outcomes.

The main causes of low creative thinking in literature synthesis indicate limited learning time, low collaboration among students, the dominance of analytical activities over idea synthesis, and a lack of understanding among teachers in integrating STEAM holistically. Time constraints and teacher readiness are the main obstacles in implementing this model to achieve optimal results. This was obtained from studies [14]- [20]. Therefore, these factors have an impact on the lack of opportunities for students to explore ideas freely and deeply.

Aspects of Creative Thinking Skills

STEAM learning to build creative thinking skills requires a learning design to be implemented. One such design is in the form of creative thinking indicators and learning models that are applied. Creative thinking indicators have several perspectives from experts, including Guilford, Torrance, Munandar, and De Bono.

According to Guilford, there are four indicators used in creative thinking skills. This expert is the most influential figure in the field of creativity, so the indicators he proposed are widely applied in learning. The indicators according to Guilford consist of fluency, flexibility, originality, and elaboration [24]. Torrance, an expert in creativity, developed the TTCT (Torrance Test of Creative Thinking), which was adopted from Guilford's ideas, resulting in indicators consisting of the aspects of resistance to premature closure and abstractness of titles [25].

The results of the indicators from these two experts were then developed by Utami Munandar, or Munandar, with the indicators consisting of fluency, flexibility, originality, elaboration, and the ability to make combinations [26]. Based on the three experts in determining the indicators of creative thinking, they differ from the experts according to De Bono. De Bono formulated indicators of creative thinking based on unconventional abilities by providing unconventional solutions so that the indicator formulation is qualitative, consisting of being able to see various possibilities, connecting unusual ideas, and being able to solve problems from new approaches [27]. The results of this study show that there are 6 articles that have been selected using 4 indicators consisting of fluency, flexibility, originality, and elaboration.

Table 2. Indicators of Creative Thinking Skills in STEAM Learning

Author	Fluency	Flexibility	Originality	Elaboration
L. Rahmayanti, F.S.A. Nugraheni, N. Lestari	Providing many ideas quickly	Analyzing problems from various perspectives	Creating unique innovations and novelty	Detailed product design and incorporates artistic elements into his work.
Khoirin Nida Fitria, Dwijanto, Nuriana Rachmani Dewi.	Answering correctly in solving problems	Responding with multiple methods to solve problems	Solving problems in one's own way	Solve problems in a structured and detailed manner.
Heryanti Fatmah	Provide many ideas to resolve the question	Providing diverse ideas, answers, and questions	Providing unusual ideas in the form of explanations of definitions and terms.	Resolving questions with practical methods
Siti Nufadilah & Joko Siswanto	Generating diverse ideas, answers, and suggestions	Providing solutions from various perspectives to solve problems	Providing a unique and new way of combining various elements	Developing ideas in detail and in an interesting way

Author	Fluency	Flexibility	Originality	Elaboration
Fitri Ayuningsih, Siti Malika, Muh Rifki Nugroho, Winarti, Budi Murtiyasa, & Sumardi.	Generating diverse ideas or questions.	Responding to problems through different ideas	providing unique and innovative research output	Responding to all questions with high motivation and innovation
Siti Suryaningsih, Mnada Rahmawanti, & Tri Suciati	Answering many questions	Illustrating an issue from various perspectives based on concepts	Solving problems in ways that others would not think of and in his own unique way.	Addressing a detailed issue and developing it with many ideas.

Based on these four indicators, fluency is defined as a person's ability to solve problems through various ideas that are generated. The number of ideas generated in this indicator shows that a person has a high level of fluency in thinking. Flexibility is a person's ability to generate many methods to solve problems based on many points of view, resulting in diverse solutions. Originality is a person's ability to generate unusual and new ideas. This unusual way of thinking indicates a creative and innovative thinking ability because it is not bound by the standards of others but is able to go beyond the usual limits. Elaboration is the ability to develop ideas in detail. These results prove that STEAM learning to train thinking skills makes extensive use of Guilford's views.

In addition to indicators, the learning aspect also involves learning models as a form of guidance for a systematic learning process in accordance with the type of learning model determined. The search results found four types of learning models that use the STEAM approach to build skills, consisting of PjBL (Project Based Learning), PBL (Problem Based Learning), Discovery learning, and Lesson study. The results of the search show that many apply project-based learning models in STEAM learning to build creative thinking skills. This proves that PjBL is effective in building creative thinking skills. These results can be seen in Figure 2.

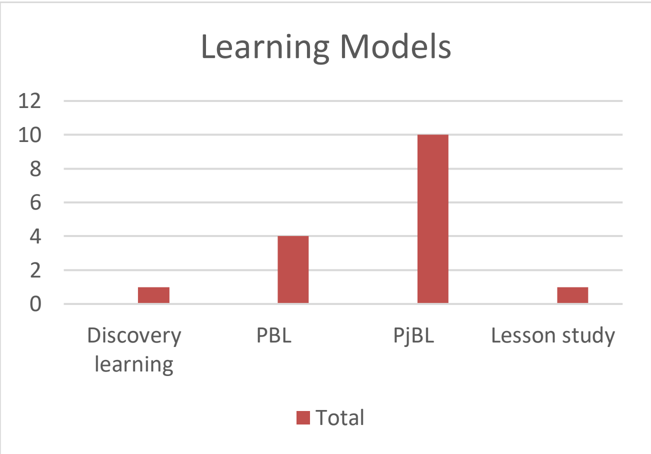

Figure 2. Graph showing the distribution of STEAM learning models in creative thinking skills

Based on the previous explanation, the first factor is that this learning model encourages students to innovate by providing solutions in the form of works. The results of these innovations are assessed based on logic, originality, and sustainable impact. STEAM as an interdisciplinary approach helps students explore knowledge from many disciplines such as science, technology, engineering, art, and mathematics.

The reasons why PBL and lesson study are rarely applied in STEAM learning for creative thinking skills are because PBL has limitations in its application. Among these limitations, the first is that PBL only focuses students on problem solving without requiring them to produce a product. The second limitation is that without pressuring students to produce a product, learning has the potential to be uninteresting because it is not oriented towards real results. In addition, solving problems requires a long time and the context of the problems tends to be specific, making it likely that the results will be more abstract.

The limitations of lesson study include a tendency to emphasize the professional development of teachers in teaching rather than emphasizing students in the process of improving learning outcomes. Lesson study does not direct students to work but rather to collaborate according to a syntax consisting of designing, observing, and reflecting on learning guided by the teacher. Based on these three types of learning models, they have similarities, namely that the learning process is student-centered through collaborative learning activities so that students are active. Collaboration is the main point in designing, implementing, and reflecting on the learning process in accordance with the syntax of the learning model used. Developing creative thinking skills using the STEAM approach is relevant to be applied in these three types of learning models because they are in line with 21st-century skills, namely critical thinking, creativity, communication, and collaboration.

Factors and Challenges of STEAM Learning to Improve Creative Thinking Skills

There are several factors that cause STEAM learning to have little effect on improving creative thinking, as well as challenges that must be faced when implementing it in learning. Factors and challenges are two different things. Factors are aspects that influence the success of a goal to be achieved. Factors are divided into two categories: negative and positive. Negative factors tend to cause regression, decline, or deficiency in something that has been done, while positive factors tend to have a good impact, resulting in improvement and progress in something that has been done. This study focuses on negative factors. The aim is to identify the causes of low creative thinking skills in STEAM-based science learning so that problems in learning can be minimized and overcome through various innovative methods and strategies. The results of this study can be seen in Table 3.

Table 3. Factors causing low creative thinking skills

Factor	Author
Learning activity implementer	Siti Nurfadilah & Joko Siswanto
Students are accustomed to working individually in each discipline.	Josina Filipe, Monica Baptista, Teresa Conceicao
Students are accustomed to working individually in each discipline.	Rizkia Putri Hasibuan, Sari Wahyuni Rozi Nasution
Students prefer analyzing to synthesizing new things.	Siti Suryaningsih, Manda Rahmawanti, & Tris Suciati
Students are unsure of their answers, do not yet fully understand the concepts, and are unable to work systematically.	Khoirin Nida Fitria, Dwijanto, Nuriana Rachmani Dewi.
Low category indicator due to lack of cooperation and collaboration among members	Heryanti Fatmah
Focus was disrupted because I was answering questions from other students while conducting observations.	Fitri Ayuningsih, Siti Malika, Muh Rifki Nugroho, Winarti, Budi Murtiyasa, & Sumardi.
Emphasizing learning to complete projects within specified time constraints.	Sariana, Fajrul Wahdi Ginting, Khairina
Failing to provide solutions to problems and lacking self-awareness when making mistakes.	Epifani Putri Mariana, Yosep Dwi Kristanto.

Table 3 shows that the implementation of learning activities is the main factor that determines and causes low creative thinking skills. This is because learning requires learning tools such as lesson plans (RPP). Lesson plans contain procedures, time, and learning outcomes that are used as guidelines. This factor is in line with the challenge of time, because STEAM learning requires a relatively long time [17]. Students are tasked with solving problems from various disciplines, while they need time to explore knowledge to complete the task [8]. The impact of this condition is that students are not interested in STEAM learning because the products they design are not completed and are ineffective in learning, making it difficult to bring out students' creativity. In addition, students prefer analysis to synthesizing new things [23].

The reason for this is the frequent use of problem-based learning, which encourages students to analyze a problem without providing a solution, so that students tend to understand the concept but find it difficult to come up with new ideas. This is in line with [28], who found that in learning, some students often plagiarize the work of others obtained from the internet. This may be due to the infrequent application and training of STEAM in the learning process. Therefore, to address this issue, teachers can develop learning strategies that encourage efficient creativity in accordance with educational standards.

The negative factors described above indicate that they can have an impact on low creative thinking skills in STEAM-based science learning. Therefore, to overcome the known causes, there are challenges in its application. Challenges are everything that will and must be faced to test one's abilities and perseverance, accompanied by courage. The results of this study show several challenges in training creative thinking skills. This can be seen in Table 4

Table 4. Challenges in developing creative thinking skills in STEAM learning

Challenge	Author
A series of different curriculum designs and extending the time or considering postponing the posttest	Ngoc-Huy Tran, Chin Fei Huang, Jeng Fung Hung
There is little research using STEAM, resulting in a lack of relevant research to support STEAM research in the real world.	Agnita Siska Pramasdyahsari, Maya Rini Rubowo, Velma Nindita, Binod Prasad Celana, Niroj Dahal, Bal Chandra Luitel
Combining knowledge from various disciplines	Kulchaya Piboon, Jintavee Khlaisang, dan Prakob Koraneekij
The worksheets created must be tailored to the characteristics of the students' needs.	Irdalisa, Zulherman, Mega Elvinasti, Sri Adi Widodo, Erlia Hanum
There may be boundaries between different disciplines.	Josina Filipe, Monica Baptista, Teresa Conceicao
The fluency indicator had the lowest percentage.	Kreativitas Peserta Didik Dalam Pembelajaran Bioteknologi Dengan PjBL Berbasis STEAM
The group will be fixated on certain assumptions, causing the information obtained to be inaccurate.	Elinawati, Bambang Subali, Bayu Ramadhani Putra, Siti Wahyuni, Pratiwi, Dwijananti, Mohammad Aryono Adhi, Mohammad Mubarrak Mohd Yusof.
It takes quite a long time due to the lack of teacher readiness.	Sariana, Fajrul Wahdi Ginting, Khairina
Short and vague answers because they are used to memorizing concepts, making it difficult for them to come up with new ideas.	Agnesi Sekarsari Putri, Zuhdan Kun Prasetyo, Lusila Andriani Purwastuti, Anto Kolonal Prodjosantoso, Himawan Putranta
It takes longer than conventional learning	Achmad Ridwan, Chinthia Fatimah, Tritiyatma Hadinugrahaningsih, Yuli Rahmawati, Alin Mardiah

Based on the results of the analysis in Table 3, it shows that there is one challenge in training creative thinking skills, namely a decline in the fluency indicator. These results show that students need time to come up with diverse answers. This is because each individual's fluency depends on the amount of experience they have. Through experience, students explore a lot of knowledge from various perspectives, making it easier to train creative thinking skills. This is in line with [17], who show that a person's creativity can develop and enable them to answer questions fluently due to the influence of experience and practice. Consistent practice is an alternative and a solution to facing many challenges. Therefore, the challenges in this indicator are also in line with the challenges according to [21] that the diversity of curriculum designs requires teachers to adapt in designing learning so that when implementing STEAM-based learning to train creative thinking skills, it takes a long time. Beside that, also explain that in order to maximize student creativity and achieve learning objectives, it is necessary to delay the posttest so that there is more time for learning. If this solution is applied in learning, it will have an impact on the quality of student learning outcomes, such as being able to improve creativity, such as being able to answer questions in detail, clearly, and thoroughly. This shows that this solution can address the challenges according [29] that the challenges in training creative thinking skills in STEAM-based science learning are that students answer questions briefly and not in detail because they are accustomed to memorizing concepts.

Explicitly, the STEAM approach has high-level thinking skills, including critical and creative thinking, but the achievement of learning objectives depends on the design of the education [35], [36]. Research from [37] shows that comprehensive STEAM integration can increase student creativity, which is applied through tasks and produces products in the form of soundtracks for animations. Through these tasks, students are engaged in problem solving and creative production. A meta-analysis by [38] also shows that, conceptually, STEAM has a high potential for fostering creativity, but the results depend on the quality of cross-disciplinary integration and not just the instrumental combination of subjects. Therefore, the literature synthesis in this study shows that STEAM does not automatically foster creativity; rather, the results are determined by pedagogical designs that can activate divergent processes in students, not just convergent or analytical ones.

Empirical evidence from various studies shows a tendency for critical thinking in STEAM practices, especially in problem-based or project-based learning. Research from [39] shows that in secondary education, consistent application of STEAM can improve critical thinking and problem solving in the fields of science and mathematics, including a significant increase in critical thinking scores. Another analysis, in study [40], shows that the application of STEAM-based learning accompanied by collaborative activities can improve students' critical thinking and creative thinking, but there are weaknesses in the areas of analysis, evaluation, and problem solving. On the other hand, a literature synthesis-based study [41] also shows that the integration of STEAM in the arts supports other disciplines rather than being a source of pure creative ideas. This condition means that various elements of STEAM still have issues, one of which is the arts, which are often positioned as a cognitive ability, but in reality are a driver of intrinsic creativity.

The educational view of critical thinking and creativity is often seen as two high-level cognitive levels, so simultaneous preparation is needed to prepare students to face the challenges of the 21st century. These two cognitive levels are alternatives at a high level because critical thinking tends to be given in the form of analytical tasks, such as tests, logic, and evaluation, making it easier to assess and measure students' initial focus, while creative thinking requires complex instruments for learning that allow students to come up with innovative and novel ideas, so that the assessment is not merely problem solving but innovation. Therefore, the application of STEAM in learning is still mostly analytical and problem-solving based rather than creative thinking, as it tends to focus on improving critical thinking.

The findings obtained from the synthesis of relevant literature with previous research show that Project Based Learning is effective in enhancing student creativity through learning that produces products. This study also expands on similar findings in the use of learning models, showing that PjBL has a level of effectiveness that is highly dependent on project design, learning duration, and teacher readiness. This study differs from previous studies that focused on learning outcomes, as it highlights the process and obstacles in implementing STEAM-based learning. According to [42], PjBL is implemented in the form of project assignments aimed at encouraging students to think divergently and critically so that they can build creativity. Students' creativity emerges when they face real challenges and produce solutions that did not exist before as a form of authentic problem solving. Therefore, in the application of STEAM, the focus is not only on project tasks, but also on creating a learning environment that can integrate cross-disciplinary knowledge, encouraging students to explore real problems in their surroundings, so that the results reflect creative ideas rather than just focusing on right and wrong.

Pjbl as a learning model does not automatically improve learning effectiveness, because the quality of results depends on the design of the project. Research from [43] states that the application of PjBl in improving learning quality can have an impact on creativity, which is influenced by several things, such as reflective thinking, openness to experimenting with ideas, and providing feedback during the process. This is an important condition in learning because if students are only given tasks to complete without being given the space to develop new solutions, then PjBl as a learning model only covers problem solving and critical thinking, but creativity does not increase optimally.

The involvement of PjBl as a learning model in improving student quality is also influenced by the duration of learning activities and teacher readiness. Research from [44] states that the success of PjBL depends on teacher readiness, including the ability of students to reflect on material in the form of innovative ideas, develop scaffolding strategies, and strengthen STEAM principles comprehensively in projects. Therefore, teachers who are not accustomed to implementing integrated learning across disciplines tend to unconsciously direct projects toward analytical aspects rather than building new ideas.

The conditions described above indicate that many previous studies have focused more on learning outcomes such as academic grades, problem-solving skills, and competency achievement. This literature synthesis highlights the learning process and barriers to STEAM implementation as scientific contributions. In line with [45], integrating STEAM requires attention to many things, including examining the learning process, understanding classroom dynamics, and identifying the causes of obstacles in the learning process, such as time constraints, tools, or the readiness of teachers in applying and designing their lessons. so that the knowledge studied and synthesized becomes insight and a reason for the importance of implementing PjBl, both for its objectives and the impact it provides.

The results of the analysis can be generalized that STEAM learning will be more effective in improving creative thinking skills. This condition can be optimized if supported by integrated learning design, adequate time, and an assessment system that is able to accommodate the subjective characteristics of creativity. This is supported by research from [46] that all elements of STEAM must provide ample opportunities to explore ideas, so that they are not narrowed down to problem elements from various perspectives and the results of creativity develop better than a shallow and irrelevant cross-disciplinary combination in learning. STEAM in the context of learning design is not about combining disciplinary content, but rather collaboration that is accessible to students, such as exploring original ideas, forming collaborations between friends in a team, producing real works, and reflecting on the process and results [29]. In the context of STEAM for beginners, it shows that both individual and group reflection processes can be developed through experience, so that in completing tasks, it can encourage critical reflection on the material being studied [47]. Research from [48] shows that students involved in STEAM learning can improve critical thinking through reflective activities in the form of social interaction and group work.

The main challenge in creating creative education is the ability to measure creativity itself, because creativity cannot always be assessed objectively, such as through concept tests or simple problem solving. It is necessary to include indicators of creative thinking as a dimension in determining creativity assessment, so that the assessment results are subjective and based on specific assessment instruments. Research from [49] shows that the development of valid and reliable creativity assessment instruments can be considered in measuring students' creative thinking, with instrument designs that include indicators of creative thinking, because conventional tests are difficult to measure and require special instruments that take into account the dimensions of creativity in students. This research is in line with [50], which states that a person's creativity has many dimensions, such as fluency, flexibility, originality, and elaboration, so it cannot be measured using simple methods.

The literature synthesis reviewed in this study has theoretical and practical implications. Theoretically, this study can contribute to the body of knowledge through its examination of creative thinking in the context of STEAM, which is mapped based on indicators, factors, and challenges. Practically, this study can serve as a reference for teachers and curriculum developers in designing more effective and creativity-oriented STEAM learning. The novelty of this study lies in its comprehensive approach, which integrates bibliometric analysis with a systematic study of indicators, factors, and challenges of creative thinking in STEAM-based science learning. This approach provides a comprehensive picture of the actual conditions of STEAM implementation. This study has limitations in terms of the number of articles and the tendency for research to focus on specific contexts and levels. In addition, most of the articles analyzed still use a simple quantitative approach, so that the research process carried out on creative thinking is not yet in-depth. Therefore, it is recommended that future research use an empirical design that includes experiments or mixed methods, develop creativity assessment instruments, and explore the application of STEAM at more diverse educational levels with different learning contexts.

4. CONCLUSION

Based on the results of this study, it can be concluded that the aspect most widely used as an indicator of creative thinking skills from the perspective of creativity experts is Guilford. The STEM word network appears more frequently than STEAM, indicating that many studies apply the STEM approach rather than STEAM. On the other hand, the learning model that is more frequently applied is PBL (Problem-Based Learning). This shows that the learning applied tends to analyze problems based on concepts and does not encourage students to provide solutions in the form of real work. Factors contributing to the decline in creative thinking skills include learning activity implementers and students being accustomed to working individually, thus requiring adaptation to group discussions and collaboration. This situation means there's not enough time for learning, so the results aren't as good as they could be. When the results aren't as good as they could be, students get less motivated. Another factor is that students don't really understand the concepts, so when they answer questions, they can't explain things in detail and in a logical way, and they don't realize when they've made mistakes. Because of this, there are a lot of challenges when putting this into practice. The results of the study show that the challenges in this learning process include the need for a long time because some students are not accustomed to combining knowledge from various disciplines, resulting in answers that are brief and inaccurate. The cause of this inaccurate information is that students are fixated on the information they have obtained. In addition, it is necessary to analyze the characteristics and initial needs of students.

ACKNOWLEDGEMENTS

The author would like to express gratitude to all parties involved who have supported the implementation of this research. Thus, this research can be completed with results that can be used to be beneficial.

AUTHOR CONTRIBUTIONS

DFH was responsible for the research design, data collection, data analysis, and manuscript preparation. R ES, and MS, contributed to conceptual development, research methodology guidance, and critical review of the manuscript. All authors have read and approved the final version of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

REFERENCES

[1] T. Tanti, W. Utami, D. Deliza, and M. Jahanifar, "Investigation in vocation high school for attitude and motivation students in learning physics subject," *Journal Evaluation in Education (JEE)*, vol. 6, no. 2, pp. 479-490, 2025, doi: 10.37251/jee.v6i2.1452.

[2] R. N. A. Komalasari, I. Ibrohim, and D. Listyorini, "Creativity in biology: The impact of Problem-Oriented Project Based Learning on high school students," *JPBI (Jurnal Pendidikan Biologi Indonesia)*, vol. 10, no. 2, pp. 555-562, 2024, doi: 10.22219/jpbi.v10i2.32497.

[3] I. A. M. S. Widiastuti, I. B. N. Mantra, I. L. P. Utami, N. L. Sukanadi, and I. N. A. Susrawan, "Implementing problem-based learning to develop students' critical and creative thinking skills," *JPI (Jurnal Pendidikan Indonesia)*, vol. 12, no. 4, pp. 658-667, 2023, doi: 10.23887/jpiundiksha.v12i4.63588.

[4] A. Suradika, H. I. Dewi, and M. I. Nasution, "Project-based learning and problem-based learning models in critical and creative students," *Jurnal Pendidikan IPA Indonesia*, vol. 12, no. 1, pp. 153-167, 2023, doi: 10.15294/jpii.v12i1.39713.

[5] D. Martin-Cudero, A. I. Cid-Cid, and R. Guede-Cid, "Analysis of mathematics education from a steam approach at secondary and pre-universitary educational levels: A systematic review," *Journal of Technology and Science Education*, vol. 14, no. 2, pp. 507–528, 2024, doi: 10.3926/jotse.2349.

[6] S. Safriana, F. W. Ginting, and K. Khairina, "Pengaruh model project based learning berbasis steam terhadap kemampuan berpikir kreatif siswa pada materi alat- alat optik di sma [The influence of the steam-based project-based learning model on students' creative thinking skills on optical instruments material in high school]." *Jurnal Dedikasi Pendidikan*, vol. 6, no. 1, pp. 127–136, 2022, doi: 10.30601/dedikasi.v6i1.2315

[7] F. Ayuningsih, S. Malikah, M. R. Nugroho, W. Winarti, B. Murtiyasa, and S. Sumardi, "Pembelajaran matematika polinomial berbasis steam pjbl menumbuhkan kreativitas peserta didik [Polynomial mathematics learning based on steam PJBL fosters students' creativity]," *Jurnal Basicedu*, *6*(5), 8175–8187, 2022, doi: 10.31004/basicedu.v6i5.3660

[8] K. L. Boice, M. Alemdar, J. R. Jackson, T. C. Kessler, J. Choi, S. Grossman, and M. Usselman, "Exploring teachers' understanding and implementation of STEAM: one size does not fit all," *Frontiers in Education*, vol. 9, 2024, doi: 10.3389/feduc.2024.1401191

[9] B. Dianita, and V. A. Tiarani, "Problem based learning model with experiential learning to increase creative thinking and critical thinking ability," *Jurnal Penelitian dan Pengembangan Pendidikan*, vol. 7, no. 2, pp. 328-335, 2023, doi: 10.23887/jppp.v7i2.62254.

[10] L. Rahmayanti. F. Nugraheni, and N, Lestari, "Penerapan pembelajaran ipa berbasis science, technology, engineering, art, mathematics (steam) untuk meningkatkan keterampilan proses kreatif [Implementation of science learning based on science, technology, engineering, art, mathematics (steam) to improve creative process skills]. *Jurnal Pendidikan IPA Indonesia*, vol. 14, no. 1, pp. 21-29, 2024, doi: 10.23887/jppii.v14i1.68873.

[11] J. Fillipe, M. Baptista, and T. Conceicao. "Integrated STEAM education for students creativity development," *Education sciences*, vol. 14, no. 6, pp. 676, 2024, doi: 10.3390/educsci14060676.

[12] I. Irdalisa, Z. Zulherman, M. Elvianasti, S. A. Widodo, and E. Hanum, "Effectiveness of project-based learning on steam-based student's worksheet analysis with ecoprint technique," *International Journal of Educational Methodology*, vol. 10, no. 1, pp. 923-935, 2024, doi: 10.12973/ijem.10.1.92.

[13] E. Ellianawati, B. Subali, B. R. Putra, S. Wahyuni, P. Dwijananti, M. A. Adhi, and M. M. M. Yusof, "Critical thinking and creativity in STEAM-based collaborative learning on renewable energy issues," *Journal of Education and Learning*, vol. 19, no. 1, pp. 112–119, 2025, doi: 10.11591/edulearn.v19i1.21638

[14] E. P. Mariana, and Y. D. Kristanto, "Integrating STEAM education and computational thinking: Analysis of students' critical and creative thinking skills in an innovative teaching and learning," *Southeast Asian Mathematics Education Journal*, vol. 13, no. 1, pp. 1–18, 2023, doi: 10.46517/seamej.v13i1.241.

[15] N. K. Fitria, D. Dwijanto, and N. R. Dewi, "Kemampuan berpikir kreatif matematis ditinjau dari *self-esteem* pada model PBL dengan pendekatan STEAM [Mathematical creative thinking ability reviewed from self-esteem in the PBL model with the STEAM approach]," *Jambura Journal Of Mathematics* Education, vol. 4, no. 2, pp. 110-118, 2023, doi: 10.37905/jmathedu.v4i2.20395.

[16] S. Y. Chen, C. F. Lai, Y. H. Lai, and Y. S. Su, "Effect of project-based learning on development of students' creative thinking," *The International Journal of Electrical Engineering & Education*, vol. 59, no. 3, pp. 232-250, 2022, doi: 10.1177/0020720919846808.

[17] S. Nurfadilah, and J. Siswanto, "Analisis kemampuan berpikir kreatif pada konsep polimer dengan pendekatan STEAM Bermuatan ESD Siswa SMA Negeri 1 Bantarbolang [Analysis of creative thinking skills on polymer concepts using the ESD-Containing STEAM approach of students at SMA Negeri 1 Bantarbolang]," *Media Penelitian Pendidikan: Jurnal Penelitian dalam BIdang Pendidikan dan Pengajaran*, vol. 14, no. 1, pp. 45-51, 2024, doi: 10.26877/mpp.v14i1.5543.

[18] S. Suryaningsih, M. Rahmawanti, and T. Suciati, "Steam-Pbl pada materi hidrolisis garam untuk membangun keterampilan berpikir kreatif siswa [Steam-PBL on salt hydrolysis material to build students' creative thinking skills]," *Dalton : Jurnal Pendidikan Kimia Dan Ilmu Kimia*, *6*(3), 219, 2023, doi: 10.31602/dl.v6i3.12811

[19] R. P. Hasibuan, S. W. R. Nasution, and F. H. Nasution, "Pengaruh penggunaan LKPD model project based learning terintegrasi steam terhadap kemampuan berpikir kreatif siswa [The effect of using the LKPD model of integrated project based learning (STEAM) on students' creative thinking abilities]," *Jurnal PhysEdu Pendidikan FISIKA IPTS*, vol. 6, no. 2, pp. 1-9, 2024, doi: 10.37081/physedu.v6i2.5102

[20] S. Safriana, F. W. Ginting, and K. Khairina, "Pengaruh model project based learning berbasis steam terhadap kemampuan berpikir kreatif siswa pada materi alat-alat optik di sma negeri 1 dewantara [The influence of the steam-based project-based learning model on students' creative thinking skills on optical instruments material at SMA Negeri 1 Dewantara]," *Jurnal Dedikasi Pendidikan,* vol. 6, no. 1, pp. 127-136, 2022, doi: 10.30601/dedikasi.v6i1.2315.

[21] V. A. Putri, K. C. A. Sotyawardani, and R. A. Rafael, "Peran artificial intelligence dalam proses pembelajaran mahasiswa di Universitas Negeri Surabaya [The role of artificial intelligence in the student learning process at

Surabaya State University],” *Prosiding Seminar Nasional Universitas Negeri Surabaya*, vol. 2, pp. 615–630, 2023.
[22] N. H. Tran, C. F. Huang, and J. F. Hung, “Exploring the effectiveness of STEAM-Based courses on junior high school students’ scientific creativity. *Frontiers in Education*, vol. 6, pp. 1–8, 2021, doi: 10.3389/feduc.2021.666792
[23] A, Ridwan, C. Fatimah, T. Hadinugrahaningsih, Y. Rahmawati, and A. Mardiah, “Development of 21st century skills in acid-base learning through STEAM projects,” *JTK (Jurnal Tadris Kimiya)*, vol. 7, no. 1, pp. 121–134, 2022, doi: 10.15575/jtk.v7i1.4913.
[24] A. M. Syifa’, and A. A. Rohman, “Analisis kemampuan berpikir kreatif guilford berdasarkan gaya berpikir siswa [Guilford's analysis of creative thinking abilities based on students’ thinking styles],” *Square : Journal of Mathematics and Mathematics Education*, vol. 5, no. 2, pp. 67–81, 2023, doi: 10.21580/square.2023.5.2.18387
[25] D. P. Wulandari, S. Susiswo, and I. M. Sulandra, “Proses kemampuan berpikir kreatif siswa matematika berdasarkan masalah open-ended pada materi bangun datar [The process of creative thinking ability of mathematics students based on open-ended problems on flat geometry material],” *Jurnal Cendekia : Jurnal Pendidikan Matematika*, vol. 5, no. 4, pp. 2198–2207, 2021, doi: 10.31004/cendekia.v5i3.847
[26] L. D. Simbolon, A. C. P. B. Ginting, and R. F. Sinaga, “Analisis hubungan antara kemampuan berpikir kreatif dan kritis siswa dalam menyelesaikan soal cerita bangun ruang kubus kelas vii SMP Negeri 1 Batang Kuis [Analysis of the relationship between students’ creative and critical thinking abilities in solving story problems on cubic geometry in class VII of SMP Negeri 1 Batang. Quiz],” *JagoMIPA: Jurnal Pendidikan Matematika Dan IPA*, vol. 4, no. 3, pp. 619–630, 2024, doi: 10.53299/jagomipa.v4i3.740
[27] B. Fatmawati, B. M. Jannah, and M, Sasmita, “Students’ creative thinking ability through creative problem solving based learning,” *Jurnal Penelitian Pendidikan IPA*, vol. 8, no. 4, pp. 2090-2094, 2022, doi: 10.29303/jppipa.v8i4.1846.
[28] L. Zailskaitė-Jakštė, R. Damaševičius, and R. Burbaitė, “Teachers professional development framework: challenges and achievements implementing e-learning course for STEAM,” In *Conference Proceedings. The Future of Education*, 2024.
[29] D. M. Anggraeni, B. K. Prahani, N. Suprapto, N. Shofiyah, and B. Jatmiko, “Systematic review of problem based learning research in fostering critical thinking skills,” *Thinking Skills and Creativity*, vol. 49, pp. 101334, 2023, doi: 10.1016/j.tsc.2023.101334.
[30] Z. Nurazizah. A. S. Mubarok, E. Herawan, and D. P. Putri, “Deep learning with project-based learning (pjbl) model for student creativity,” *Pedagogia: Jurnal Pendidikan*, vol. 14, no. 2, pp. 219-252, 2025, doi: 10.21070/pedagogia.v14i2.1957
[31] N. A. E. B. Sembiring and I. S. Jahro, “Diffrences in learning outcomes and science process skills of students learned with the model project based learning and discovery learning on acid-base material,” *Journal of Education Technology*, vol. 9, no. 2, pp. 314-326, 2024, doi: 10.33394/jtp.v9i2.11245.
[32] M. C. Muzaini, et al., “Effectiveness of STEAM-Integrated project-based learning to improve creative and collaborative thinking skills of elementary school students,” *Al-Adzka: Jurnal Ilmiah Pendidikan Guru Madrasah Ibtidaiyah*, vol. 14, no. 1, pp. 106-120, 2024, doi: 10.18592/aladzkapgmi.v14i1.13749.
[33] S. M. Hartati, I. Rahayu, and K. Kashardi, “Critical thinking ability using steam-based pbl learning at junior high school student,” *Cendekia: Media Jurnal Pendidikan*, vol. 14, no. 2, pp. 75-81, 2023, doi: 10.35335/cendikia.v14i2.4190.
[34] R. Rosmaiyadi, et al., “Pembelajaran berbasis lesson study dengan menggunakan model project based learning (pjbl) pada mata pelajaran bahasa indonesia untuk meningkatkan kemampuan literasi baca tulis siswa [Lesson study-based learning using the project-based learning (PJBL) model in Indonesian language subjects to improve students’ reading and writing literacy skills],” *Cakrawala Linguista*, vol. 7, no. 1, pp. 17-25, 2024, doi: 10.26737/cling.v7i1.4991.
[35] S. Sulastri and G. P. Cahyani, “Pengaruh project based learning dengan pendekatan steam terhadap kemampuan berpikir kritis pada pembelajaran online di SMK Negeri 12 Malang [The influence of project-based learning with a steam approach on critical thinking skills in online learning at SMK Negeri 12 Malang],” vol. 9, no. 3, pp. 373- 379, 2021, doi: 10.26740/jpak.v9n3.p372-379
[36] D. P. Sari, D. Hasanah, and I. Q. Barriyah, “Model pembelajaran berbasis steam projek untuk meningkatkan kemampuan berpikir kritis dan kreatif siswa,” *EDUKASI: Jurnal Penelitian & Artikel Pendidikan*, vol. 15, no. 2, pp. 165-180, 2023, doi: 10.31603/edukasi.v15i2.10489.
[37] A. Leavy, L. Dick, M. Meletiou-Mavrotheris, E. Paparistodemou, and E. Stylianou, “The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature,” *Journal of Computer Assisted Learning*, vol. 39, no. 4, pp. 1061-1082, 2023, doi: 10.1111/jcal.12806.
[38] D. Aguilera, and J. Ortiz-Revilla, “STEM vs. STEAM education and student creativity: A systematic literature review,” *Education sciences*, vol. 11, no. 7, pp. 331, 2021, doi: 10.3390/educsci11070331
[39] N. B. Haka, E. Wijaya, and A. S. Salsabila, “The effectiveness of the STEAM approach in elementary education: A systematic literature review,” *STEAM Journal for Elementary School Education*, vol. 1, no. 2, pp. 78-98, 2025, doi: 10.26740/sjese.1.02.2025.2.
[40] E. Elinawati, Et al, “Critical thinking and creativity in STEAM-based collaborative learning on renewable energy issues,” *Journal of Education and Learning (EduLearn)*, vol. 19, no. 1, pp. 112-119, 2025, doi: 10.11591/edulearn.v19i1.21638.
[41] R. S. Camarero, J. O. Revilla, and I. M. Greca, “The impact of integrated STEAM education on arts education: A systematic review,” *Education Science*, vol. 13, no. 11, pp. 2-14, 2023, doi: 10.3390/educsci13111139.
[42] F. Khafah, K. P. Suprapto, and E. Nuryadin, “The effect of project-based learning model on students’ critical and creative thinking skills in the ecosystem concept,” *Jurnal Pendidikan Biologi Indonesia*, vol. 9, no. 3, pp. 244-255, 2023, doi: 10.22219/jpbi.v9i3.27461.
[43] N. S. Sinusi, I. Ibrohim, and S. E. Rahayu, “Enhancing students’ reflective thinking skills through Problem-Oriented Project-Based Learning (POPBL) with PEKERTI worksheet,” *Jurnal Pendidikan Biologi Indonesia*, vol. 10, no. 3, pp.

1107-1117, 2024, doi: 10.22219/jpbi.v10i3.36082.
[44] D. N. Sari, H. F. Adira, and S. Sukiman, "Integrating of PjBL (project based learning) in the merdeka curriculum for development of 4c skills of elementary school students," *Action Research Journal Indonesia*, vol. 7, no. 4, pp. 3453-3467, 2025, doi: 10.61227/arji.v7i4.638.
[45] N. Spyropoulou, K. Mathiopulos, and A. Kameas, "We believe in STEAM education, but we need support": in-service teachers' voices on the realities of STEAM implementation," *Education Science*, vol. 15, no. 10, pp. 2-20, 2025, doi: 10.3390/educsci15101300.
[46] M. I. Ihsan, P. Pano, and P. Suwasono, "Research trends: STEAM approach in science learning," *Jurnal Penelitian Pendidikan IPA*, vol. 11, no. 8, pp. 1-11, 2025, doi: 10.29303/jppipa.v11i8.11658.
[47] M. Bassachs, et al. "Fostering critical reflection in primary education through STEAM approaches," *Education Science*, vol. 10, no. 12, , 2020, doi: 10.3390/educsci10120384.
[48] D. Herro, et al, "Co-Measure: Developing an assessment for student collaboration in STEAM activities," *International Journal of STEM Education*, vol. 4, no. 26, 2017, doi: 10.1186/s40594-017-0094-z.
[49] R. Setiani, W. Widiasih, and S. Suparti, "Analysis of student creativity assesment instruments: Supporting SDGs and MBKM in higher education," *IJORER: Interbational Journal of Recent Education Research*, vol. 6, no. 1, 2025,doi: 10.46245/ijorer.v6i1.746.
[50] W. Karunarathne, and A. Calma, "Asssesing creative thinking skills in higher education: deficit and improvements," *Taylor & Francis*, vol. 49, 2024, doi: 10.1080/03075079.2023.2225532.