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A Systematic Review of The Implementation of STEM Based Learning to Enhance Students' Creative Thinking Skills

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Abstract. Creative thinking skills are a crucial competency required in 21st century education, where innovation and problem solving abilities are increasingly emphasized. STEM based learning (Science, Technology, Engineering, and Mathematics) is considered a potential approach to develop these cognitive capacities; however, a comprehensive synthesis of empirical evidence is needed to validate its effectiveness in secondary school contexts. Therefore, this study aims to analyze the implementation of STEM based learning in enhancing students' creative thinking skills. This study employs a systematic review approach by analyzing and synthesizing data from various quasi experimental studies that examine STEM learning interventions. The findings indicate that STEM based learning consistently leads to significant improvements in creative thinking skills, particularly in fluency and originality. Project based, inquiry based, and Ethno STEM models are identified as the most effective approaches compared to conventional learning. However, improvements in flexibility and elaboration tend to be more limited, influenced by factors such as implementation duration, teacher readiness, and insufficient scaffolding. Overall, the findings confirm that STEM based learning is an effective approach for fostering students' creative thinking skills and provides practical implications for educators in designing more optimal instructional strategies to support comprehensive creativity development.

Keywords: Systematic review, STEM, creative thinking skills, project based learning

1. Introduction

The 21st century presents a profound transformation in the way knowledge, skills, and innovation are valued in education. In a world increasingly driven by technological advancement and complex global challenges, creativity has emerged as a central competency for student success and societal advancement. Creative thinking, defined as the capacity to generate original, flexible, and elaborative ideas, has been widely recognized as one of the fundamental skills for the 21st century [1]. Creative thinking is commonly defined as the ability to produce ideas that are both novel and useful [2]. Moreover, creativity is a complex construct that involves not only the generation of novel ideas but also the ability to apply them effectively in problem-solving contexts. In STEM education, creativity is considered a multidimensional skill that can be developed and measured through structured learning processes [3].

To address this need, Science, Technology, Engineering, and Mathematics (STEM) education has gained prominence as an integrated pedagogical framework that promotes creativity through inquiry, design, and problem-solving activities. STEM-based learning has been widely reported to improve students' creative thinking skills through interdisciplinary integration and real-world problem solving [4,5]. Furthermore, STEM learning environments support the development of higher-order thinking skills, including creativity, critical thinking, and innovation, which are essential for 21st-century competencies [6]. STEM education is widely recognized as an integrated approach that connects multiple disciplines to solve real-world problems [7]. STEM-based learning encourages students to explore concepts across disciplines and apply them to real-world contexts, a process that naturally stimulates innovation, divergent thinking, and higher-order reasoning [8]. It also encourages students to apply knowledge in authentic contexts, thereby strengthening higher-order reasoning and innovation.

The integration of arts into STEM education, commonly referred to as STEAM, has been increasingly emphasized to foster students' creativity and interdisciplinary thinking. Students' beliefs also indicate that creativity plays a significant role in STEM learning environments, particularly in project-based contexts where artistic and innovative elements are integrated [9]. Previous systematic reviews have highlighted the increasing importance of STEM education research globally [10]. Recent meta-analytic evidence has confirmed that innovative approaches such as design thinking and STEM project-based learning significantly enhance students' creativity compared to traditional learning environments [11,12]. The effectiveness of these approaches is influenced by multiple factors, including teaching strategies, assessment methods, and duration of implementation.

Recent studies have further emphasized the importance of integrating design-based and design thinking approaches within STEM education. Design-based STEM learning enables students to develop creative products through iterative processes and real-world problem solving [13]. Similarly, integrating design thinking into STEM instruction has been shown to improve students' creativity, critical thinking, and problem-solving abilities through iterative and experiential learning processes [14].

Despite the growing number of studies, there is still a lack of consensus regarding effective instructional practices in integrated STEM learning [15]. Previous empirical studies have demonstrated that STEM-based instruction significantly enhances students' creative thinking across various educational levels; however, variations in implementation models and learning contexts still result in inconsistent outcomes [16,17].

As the boundaries between scientific and technological disciplines blur, educational models have shifted from traditional content transmission toward inquiry-based and project-oriented approaches. This transition reflects a global educational movement emphasizing active learning, collaboration, and creativity. [18] noted that "integrating creative projects within STEM instruction enhances student motivation and performance by merging inquiry-based and project-based learning into authentic, collaborative experiences." Similarly, [19] observed that project-based STEM models encourage students to design, test, and refine their own solutions, thereby developing originality and fluency as core dimensions of creative thinking.

Empirical research consistently affirms the relationship between STEM education and creative thinking. In Indonesia, STEM integration has been implemented through various instructional approaches, such as Project-Based Learning (PjBL), Inquiry-Based Learning (IBL), Design-Based Learning (DBL), and Ethno-STEM frameworks [20]. These models situate creativity not as an isolated trait but as an outcome of structured learning processes that engage students in constructing knowledge through experimentation and reflection. For example, the incorporation of engineering design processes into science learning allows students to iterate ideas and assess solutions critically, a method that strengthens both innovation and conceptual understanding [8,21]

A quasi-experimental study conducted in Indonesia examined the impact of the STEM–PjBL model on middle school students' creative thinking skills. The findings indicated that the implementation of STEM-PjBL significantly improved students' creative thinking across multiple dimensions, including fluency, flexibility, originality, and elaboration [22]. Similar results were also reported in studies showing that STEM-PjBL enhances students' creative dispositions and learning motivation in junior high school settings [23]. Furthermore, recent empirical findings confirm that STEM-integrated project-based learning significantly improves students' creative thinking skills, particularly in science learning contexts [24]

STEM education's influence extends beyond science and engineering; it cultivates creativity through interdisciplinary inquiry. The integration of arts and design thinking within STEM—often referred to as STEAM—has been shown to significantly enhance students' originality and flexibility [25]. Ethno-STEM models have also gained increasing attention for their ability to connect scientific inquiry with indigenous knowledge systems. Research indicates that Ethno-STEM project-based learning not only improves critical thinking but also strengthens students' creative thinking skills [26]. In addition, significant post-test gains in creative thinking have been observed in STEM instruction that incorporates cultural and contextual elements [27].

The growing body of research underscores that creativity in STEM learning is developed through process-oriented pedagogy rather than product-focused outcomes. STEM literacy is understood as the integration of science, technology, engineering, and mathematics skills to solve real-life problems [28]. This integration enables students to become active problem solvers and innovators who can navigate technological and scientific challenges. In line with this perspective, global educational frameworks such as the United Nations' Sustainable Development Goals (SDG 4) emphasize quality education as a key driver of innovation and sustainable development, reinforcing the relevance of creativity-oriented STEM education in achieving these global aims [29].

Despite its promise, STEM based learning still faces implementation challenges. Studies highlight persistent issues such as limited instructional time, inadequate teacher training, and insufficient resources [8]. Effective STEM implementation requires educators to design inquiry driven activities that scaffold creative exploration, a task demanding pedagogical and technological expertise [20]. Moreover, assessment practices often fail to capture the multifaceted nature of creativity, as they tend to prioritize content mastery and standardized test performance. Fostering creativity requires learning environments that provide opportunities for exploration and sustained practice, conditions that are often difficult to achieve within rigid curricular structures [18]

Nevertheless, evidence continues to affirm the transformative potential of STEM education. The integration of STEM with problem-based learning has been shown to enhance students' ability to generate innovative ideas and construct meaningful explanations, thereby linking creativity with deeper conceptual understanding [30]. Similarly, STEM learning environments that emphasize open inquiry and iterative experimentation have been found to foster both creative dispositions and creative thinking skills [31]. These findings indicate that STEM learning supports both the cognitive and affective dimensions of creativity, including curiosity, resilience, and risk-taking.

Furthermore, the development of creativity in STEM learning aligns with constructivist theory, which posits that knowledge is actively constructed through interaction and reflection. Inquiry-based and project-based STEM classrooms provide opportunities for students to engage in divergent and convergent thinking, integrate interdisciplinary knowledge, and test ideas through experimentation [16]. These processes strengthen creative cognition while fostering collaborative learning environments.

The increasing emphasis on creativity-oriented STEM instruction reflects a broader paradigm shift in educational research. Global research trends indicate a growing recognition of creativity as a measurable and teachable competency within STEM education [8]. This shift reframes STEM learning from a purely cognitive domain into a more holistic framework that integrates imagination, emotion, and cultural context.

Despite the growing body of research, several gaps remain in the literature. Existing studies tend to be context-specific and are often limited to short-term interventions or single-subject applications. While previous research has provided valuable insights, it has not sufficiently compared different pedagogical models or examined variations across dimensions of creativity [20,22]. In addition, international studies frequently focus on either STEM content mastery or creativity assessment, rather than integrating both aspects within a single framework [32]. Therefore, this study aims to provide a comprehensive and integrative analysis of STEM-based learning as a multidimensional approach to enhancing students' creative thinking skills.

The novelty of this study lies in its holistic examination of *STEM based learning as a multidimensional catalyst for creativity*. By synthesizing findings from diverse pedagogical approaches project based, inquiry based, challenge based, and ethno STEM this research provides a unified framework linking instructional design, creative cognition, and educational outcomes. It advances existing scholarship by moving beyond individual case studies toward a comparative, evidence based understanding of STEM implementation. In doing so, it contributes to theoretical and practical discussions on how education systems can systematically cultivate creative thinkers prepared to navigate and shape an innovation driven world. However, this study is limited by its reliance on previously published research with varying methodologies and contexts, which may affect the generalizability of the finding.

2. Method

This section outlines the methodology employed in this systematic review and synthesis study. The research adopted a structured approach to identify, screen, and extract data from relevant scholarly literature regarding the implementation of STEM learning and its impact on creative thinking skills. The procedure was divided into three core phases: Paper Search, Screening, and Data Extraction, designed to ensure comprehensive coverage and reliability of the findings. This methodological approach aligns with systematic review procedures that emphasize structured identification, screening, and synthesis of empirical studies [33,34].

To facilitate a clearer understanding of the research procedure, the stages of this study are illustrated in Figure 1.

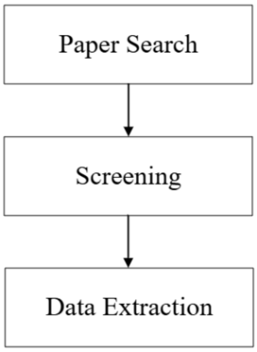

Figure 1. Research procedure flowchart.

3.1. *Paper Search*

A semantic literature search was conducted using Elicit AI, a research platform that integrates over 138 million academic papers from Semantic Scholar and OpenAlex databases. The search query applied was *"The implementation of STEM based learning to enhance students' creative thinking skills."* This semantic approach allowed for the retrieval of studies conceptually aligned with the research topic rather than relying solely on keyword matching. Elicit's advanced algorithm ranked the results by conceptual relevance, from which the fifty most pertinent papers were selected for review. Metadata, including titles, abstracts, and bibliographic information, were retrieved for each paper to facilitate subsequent screening. The use of Elicit ensured comprehensive coverage of relevant literature and minimized human bias in initial paper selection. This systematic and AI assisted search process provided a robust foundation for the subsequent stages of data screening and extraction.

3.2. *Screening*

The screening process was conducted to ensure that only studies meeting specific inclusion criteria were considered. Each of the fifty retrieved papers was examined based on its relevance to STEM based learning and creative thinking outcomes. To be included, studies had to involve a STEM oriented educational intervention, measure creative thinking as a primary or secondary outcome, and include student participants in either formal or informal learning settings. Eligible studies employed empirical research designs such as randomized controlled trials, quasi experimental, or pre post studies and reported quantitative or qualitative data on creativity related outcomes. Papers focusing solely on academic achievement or theoretical discussions without empirical evidence were excluded. The review team evaluated all criteria holistically to determine inclusion, emphasizing studies that examined creativity within a STEM context. This structured yet interpretive screening ensured that the final dataset represented rigorous, evidence based investigations into the relationship between STEM learning and creative thinking.

3.3. *Data Extraction*

Following the screening phase, data were extracted from the eligible studies using a large language model integrated into Elicit AI. The model followed detailed extraction instructions to ensure consistency and reliability across the dataset. Information was gathered on several key dimensions, including the nature of STEM implementation (pedagogical model, integration type, duration, and subject area) and the creative thinking assessment methods used (instruments, constructs measured, and assessment timing). Additionally, data on effectiveness results—such as pre and post test outcomes, effect sizes, statistical significance, and moderating factors—were recorded. Further extraction covered study design characteristics, educational context, and participant demographics. This systematic data extraction process ensured that both methodological rigor and contextual diversity were captured, enabling a comprehensive synthesis of how STEM based interventions influence students' creative thinking skills across different educational environments.

4. Result and Discussion

The results obtained from the systematic review and synthesis of selected studies provide a comprehensive overview of how STEM based learning interventions contribute to the development of students' creative thinking skills. This section presents an integrated discussion of findings, beginning with the general patterns of STEM based learning implementation and creative thinking outcomes, followed by a comparative analysis of the effectiveness of different pedagogical models.

The findings reveal that STEM-based learning consistently promotes the development of students' creative thinking skills across various educational contexts. This is primarily due to its interdisciplinary nature, which integrates science, technology, engineering, and mathematics into meaningful learning experiences. Through this integration, students are encouraged to engage in problem-solving, design-based activities, and real-world applications, which stimulate higher-order thinking processes. These results are consistent with previous systematic reviews indicating that STEM-based learning effectively enhances students' creative thinking through interdisciplinary and problem-solving oriented instruction [35]. furthermore, research trends indicate that creative thinking remains a crucial yet still underdeveloped competency in science education, emphasizing the need for innovative instructional approaches such as STEM [36]

4.1. *Patterns of STEM Based Learning Implementation and Creative Thinking Outcomes*

Table 1 Present a comprehensive overview of the diverse research designs and contexts applied to examine the implementation of STEM based learning and its relationship with students' creative thinking skills.

Table 1. Summary of reviewed studies on stem based learning and creative thinking.

Study	Study Design	Sample Size/ Educational Level	STEM Implementation Model	Creative Thinking Measurement Approach
Muhibbuddin et al., 2019	Quasi experimental, pretest–posttest control group	67, Senior High (Indonesia)	Worksheet based, interdisciplinary STEM	Torrance Test of Creative Thinking (elaboration, originality, fluency), performance based, pre test/post test, validated instrument [37]

Study	Study Design	Sample Size/ Educational Level	STEM Implementation Model	Creative Thinking Measurement Approach
Astri et al., 2022	Quasi experimental, two group pretest–posttest	64, Grade 11 (Indonesia)	Project based learning, interdisciplinary STEM	Custom essay test (fluency, flexibility, originality, elaboration), pre test/post test [38]
Khalil et al., 2023	Quasi experimental, stratified random sampling	94, High School (UAE)	Inquiry based/project based/problem based, interdisciplinary STEM	Torrance Test of Creative Thinking (fluency, elaboration, flexibility, originality), performance based, reliability reported [39]
Babalola & Keku, 2024	Quasi experimental, purposive sampling	84, Secondary (Nigeria)	Ethno STEM integrated project based learning, interdisciplinary	Custom essay test (fluency, flexibility, originality), pre test/post test, validated instrument [27]
Iskandar et al., 2020	Quasi experimental, three groups	90, Senior High (Indonesia)	STEM based, interdisciplinary	Custom essay (no mention of dimensions), pre test/post test, validated instrument[16]
Aldilla et al., 2023	Meta analysis	Not mentioned, all levels	Project based learning, problem based learning, inquiry based STEM [40]	No mention found
Rahmawati et al., 2022	Systematic literature review	Not mentioned, all levels	Project based/problem based STEM, focus on mathematics [20]	No mention found
Putri et al., 2020	Quasi experimental, two groups	23, Vocational (Indonesia)	Challenge based learning in STEM	Custom essay test (fluency, flexibility, originality, elaboration), pre test/post test [41]
Zahara et al., 2020	Quasi experimental, nonequivalent control	Not mentioned	Inquiry based STEM	Test instrument (no details found), pre test/post test, reliability reported [42]
Sumarni & Kadarwati, "Ethno STEM Project Based Learning"	Pre experimental, one group pretest–posttest	230, High School (Indonesia)	Ethno STEM project based learning, interdisciplinary	Open ended questions (fluency, flexibility, originality, elaboration), pre test/post test, reliability reported [26]

Most of the reviewed studies employed quasi experimental designs with pretest–posttest structures, emphasizing the measurement of learning gains before and after STEM interventions. This methodological consistency highlights a strong focus on causality and measurable outcomes rather than theoretical speculation. The predominance of studies conducted in secondary and vocational schools demonstrates the increasing interest in integrating STEM principles into formal education, particularly in developing educational systems seeking to enhance 21st century competencies. Although the sample sizes vary widely—from small classroom based experiments to larger institutional implementations—all studies share a commitment to evaluating how STEM based pedagogies can improve creativity. The inclusion of systematic reviews and meta analyses in the dataset enriches the overall evidence base, offering a broader perspective on patterns across different studies and educational levels. These reviews support the notion that STEM based instruction consistently encourages creativity when combined with interactive, problem solving, and collaborative learning elements. Despite regional and methodological differences, the collective evidence suggests that STEM education provides a powerful platform for nurturing innovation, curiosity, and creative expression among students, particularly when teachers adopt student centered instructional models.

The studies reveal considerable diversity in the pedagogical models used for implementing STEM learning. The most frequently applied approaches include project based, inquiry based, and problem based learning, reflecting a clear trend toward active learning strategies that promote creativity through real world problem solving. Several studies employed interdisciplinary integration, combining science, technology, engineering, and mathematics concepts within a single learning framework. This interdisciplinary nature allows students to make meaningful connections between abstract knowledge and practical applications, leading to deeper understanding and more original thinking. Additionally, some implementations incorporated cultural or contextual adaptations, such as ethno STEM models, which connect local traditions and indigenous knowledge with scientific inquiry. Such culturally grounded STEM instruction promotes inclusivity and relevance, making creative learning more authentic and engaging. Another critical element observed across studies is the emphasis on experiential and collaborative learning activities—students engage in group projects, design challenges, and open ended investigations that foster divergent thinking. The duration of these interventions ranged from short term classroom experiments to multi week instructional programs, though even brief interventions yielded noticeable improvements in creative outcomes. The evidence thus demonstrates that STEM learning, when structured around hands on, contextualized experiences, effectively bridges disciplinary boundaries and cultivates an environment conducive to creativity and innovation.

The assessment of creative thinking within the reviewed studies reflects both methodological diversity and growing sophistication in evaluation tools. Several studies utilized standardized instruments such as the Torrance Test of Creative Thinking, which assesses fluency, flexibility, originality, and elaboration—dimensions widely recognized as central to creativity. Other studies employed custom designed essay or performance based tasks tailored to specific STEM subjects, such as physics or general science, allowing for context sensitive measurement. The format of these assessments ranged from written responses and open ended problem solving tasks to project evaluations and reflective essays. Pretest–posttest comparisons were consistently used to measure improvement, with most studies reporting significant gains in creative thinking following STEM based instruction. However, only a subset of studies reported details on reliability and validity, indicating a need for stronger methodological rigor in future research. Interestingly, the dimensions of fluency and originality were the most frequently improved aspects of creativity, suggesting that STEM activities effectively stimulate idea generation and novel solution development. Flexibility and elaboration also improved but tended to show smaller effect sizes, possibly due to shorter intervention durations. These findings imply that while STEM based learning successfully activates core creative processes, sustained engagement and iterative project cycles may be necessary to achieve balanced development across all creativity dimensions.

The findings from Table 1 collectively emphasize the transformative potential of STEM-based learning in fostering creativity. Across various contexts, STEM instruction consistently encourages divergent thinking, multiple problem-solving approaches, and deeper student engagement. The integration of STEM disciplines not only enhances content mastery but also supports the development of cognitive and metacognitive skills related to creativity. In addition, student-centered and collaborative learning shifts students from passive recipients to active knowledge creators, aligning with constructivist and experiential learning principles and promoting meaningful interdisciplinary learning [43]

The evidence also highlights the critical role of teacher readiness, as effective STEM implementation requires educators capable of facilitating inquiry and interdisciplinary learning. However, challenges such as limited pedagogical knowledge and insufficient support may affect implementation quality [44]. Overall, STEM-based learning provides a strong framework for developing creative thinking, particularly when implemented through inquiry-driven and contextualized approaches.

4.2. *Comparative Effectiveness of STEM Pedagogical Models*

Table 2 presents a comparative summary of various STEM based pedagogical models and their effectiveness in improving students' creative thinking skills. The data indicate that all STEM models examined—such as project based learning, inquiry based learning, problem based learning, challenge based learning, and ethno STEM—demonstrate positive effects on creative thinking outcomes when compared with traditional or control learning conditions.

Table 2. *Pedagogical model* comparisons *and effectiveness of STEM based learning interventions.*

Study	STEM Model	Pre test Scores	Post test Scores	Effect Size / Normalized Gain / Statistical Significance
Muhibbuddin et al., 2019	Worksheet based STEM	No significant difference between experimental and control groups	Experimental group higher than control group	Normalized gain: creative thinking 81.05, learning outcomes 78.61; significant differences
Astri et al., 2022	Project based learning STEM	Experimental: 27.97, Control: 30.16	Experimental: 82.81, Control: 36.72	Normalized gain: Experimental group fluency 80%, originality 70%; Control group elaboration 20%, originality 4%; significant ($p < 0.05$)
Khalil et al., 2023	STEM based curriculum	No mention found	No mention found	Eta squared = 0.119 (moderate); significant for fluency, flexibility, originality; not for elaboration
Babalola & Keku, 2024	Ethno STEM project based learning	Experimental: 5.220, Control: 5.434	Experimental: 6.675, Control: 5.759	ANOVA $F=70.796$, $p<0.001$; significant improvement in experimental group; Improvement: 0.663 (66.3%, medium category)
Iskandar et al., 2020	STEM based	No mention found	No mention found	No mention found
Aldilla et al., 2023	Meta analysis (project based, problem based,	No mention found	No mention found	Effective at all levels; no specific effect sizes

Study	STEM Model	Pre test Scores	Post test Scores	Effect Size / Normalized Gain / Statistical Significance
	inquiry based learning)			
Rahmawati et al., 2022	Systematic literature review (project based, problem based learning)	No mention found	No mention found	Positive effect overall; one study found no significant difference
Putri et al., 2020	Challenge based learning STEM	No mention found	No mention found	Normalized gain; significant at 0.05; flexibility, fluency, originality improved
Zahara et al., 2020	Inquiry based STEM	Experimental: 38.03, Control: 37.20	Experimental: 83.17, Control: 79.53	Normalized gain: Experimental group 0.72 (high), Control 0.66 (average); t test significant ($p<0.05$); 27.4% high, 47.4% medium, 25.2% low (creative thinking)
Sumarni & Kadarwati	Ethno STEM project based learning	No mention found	No mention found	Normalized gain: highest in fluency, lowest in elaboration; positive improvement overall

Across different studies, experimental groups consistently achieved higher post test scores than control groups, confirming the beneficial influence of STEM instruction on creative performance. The most substantial gains were found in models emphasizing inquiry and active experimentation, where students were encouraged to explore problems through open ended investigation and collaboration. These pedagogical designs provide learners with opportunities to engage in critical questioning, data collection, and iterative solution testing, all of which are central to the development of creativity. Moreover, the consistent improvement across multiple contexts—ranging from elementary to higher education—suggests that STEM pedagogy can be flexibly adapted to different learning environments without diminishing its creative impact. These findings collectively establish a robust foundation for understanding how diverse STEM approaches contribute to creativity enhancement, highlighting the versatility and universality of STEM based learning in promoting innovative thinking skills.

An examination of the comparative data in Table 2 reveals nuanced variations in the degree to which each STEM pedagogical model impacts different dimensions of creative thinking. Project based learning consistently demonstrated strong improvements in originality and elaboration, as students were required to produce tangible artifacts or projects that demanded innovative design and detailed execution. Inquiry based learning, on the other hand, showed particularly high gains in flexibility and fluency, as it encouraged students to approach problems from multiple perspectives and generate numerous possible solutions. Challenge based and problem based approaches also produced notable improvements, especially in divergent thinking and the ability to connect interdisciplinary concepts. Ethno STEM, which integrates cultural and contextual knowledge, displayed a unique strength in fostering relevance driven creativity, where students could relate abstract STEM concepts to real world and community based challenges. The effect sizes across models suggest that creativity is maximized when instructional designs balance freedom for exploration with structured guidance. The improvements in creative dimensions also appear to be cumulative, implying that extended exposure to integrated STEM learning enhances both the quantity and quality of students' creative output. Overall, these comparative findings underscore that creativity development through STEM is multidimensional, requiring the alignment of pedagogical strategy, content integration, and cultural context to achieve optimal outcomes.

From a methodological perspective, the studies summarized in Table 2 demonstrate rigor in design and consistency in outcome reporting. Most employed quantitative approaches, utilizing pre test and post test designs with control or comparison groups to measure the effects of STEM based interventions on creative thinking. Statistical analyses frequently reported significant differences between experimental and control conditions, often accompanied by measures such as normalized gain and Cohen's d to quantify effect size. These indicators consistently pointed toward moderate to high levels of effectiveness for STEM based models. In some cases, mixed method designs were employed to capture not only measurable changes but also qualitative insights from student reflections and classroom observations. This combination of data types enriched the interpretation of results, revealing how STEM environments stimulate curiosity, persistence, and risk taking—key behavioral markers of creativity. Importantly, several studies also identified moderating factors, such as the duration of intervention, student background knowledge, and teacher expertise, which influenced the degree of improvement. For instance, programs implemented over longer periods and facilitated by trained teachers tended to produce stronger gains in creative thinking. Such methodological findings affirm that the success of STEM based creativity enhancement depends on careful instructional design, consistency in implementation, and sustained engagement across the learning cycle.

The comparative analysis of STEM pedagogical models presented in Table 2 carries important implications for educational practice and policy. The consistent improvement in creative thinking across all models suggests that STEM learning is not merely a content based reform but a transformative pedagogical shift toward innovation driven education. Inquiry based and project based models, in particular, demonstrate strong potential to serve as core frameworks for cultivating creativity across disciplines. Their effectiveness lies in the balance between structure and autonomy, where students are guided through problem solving processes yet encouraged to take intellectual risks and explore unconventional ideas. Challenge based and ethno STEM approaches further highlight the importance of contextual and cultural relevance, ensuring that creativity development aligns with real world problem contexts. These models collectively demonstrate that creative thinking flourishes when learning environments are dynamic, interdisciplinary, and socially meaningful. For educators, this underscores the need to design curricula that integrate experimentation, collaboration, and reflection as central components of STEM instruction. At the policy level, the findings advocate for teacher professional development programs focused on facilitating inquiry and creativity oriented learning. In sum, Table 2 reinforces that STEM pedagogy is most effective when implemented as a holistic, student centered approach that bridges conceptual understanding with the cultivation of imagination, innovation, and creative problem solving skills essential for thriving in the modern knowledge economy.

This section begins with an exploration of the general patterns of STEM based learning implementation and the outcomes associated with creative thinking, followed by a comparative analysis of the effectiveness of different pedagogical models. The discussion is then extended to include broader thematic insights, underlying theoretical perspectives, supporting and constraining factors, as well as implications and directions for future research.

The results indicate that STEM-based learning significantly enhances students' creative thinking skills across multiple dimensions, particularly fluency and originality. These findings are further supported by previous studies showing that STEM project-based learning provides meaningful learning experiences that significantly enhance students' creativity through active engagement and real-world problem solving [45]. Similar results have also been reported in experimental studies demonstrating that STEM education has a positive effect on students' creative thinking skills, although the level of improvement may vary depending on instructional design and implementation [46]. These findings are consistent with previous studies indicating that STEM-based project learning can significantly improve students' creative thinking skills [26]. Previous empirical studies have also demonstrated that STEM-based instruction significantly enhances students' creative thinking across various educational levels;

however, variations in implementation models and learning contexts still result in inconsistent outcomes [16,17].

These findings are further reinforced by recent empirical evidence. Students' scientific creativity has been found to remain relatively low, particularly in terms of originality and problem-finding abilities, indicating the need for STEM-based instructional approaches that actively foster creativity through meaningful engagement [47]. Similarly, the implementation of STEM Project-Based Learning has been shown to have a strong positive relationship with students' creativity and critical thinking, supported by both quantitative and qualitative findings [48]. In addition, students who participated in STEM-PjBL demonstrated significantly greater improvements in creative thinking compared to those in conventional learning environments, as evidenced by quasi-experimental studies [49].

The improvement in creative thinking skills is also influenced by the structured learning environment provided by STEM-based models, which integrate collaboration, experimentation, and interdisciplinary learning processes. These elements contribute to the development of students' creative dispositions and problem-solving abilities [6]. Overall, the results align with a growing body of research indicating that STEM-based learning provides an effective framework for enhancing students' creative thinking skills across diverse educational contexts [5,50]).

5. Conclusion

The overall analysis of the reviewed studies provides strong evidence that STEM based learning models effectively enhance students' creative thinking skills across different educational levels and contexts. The combination of findings from Tables 1 and 2 shows that approaches such as project based, inquiry based, ethno STEM, and challenge based learning consistently result in significant improvements in fluency, flexibility, originality, and elaboration. Experimental groups exposed to STEM integrated instruction demonstrated higher post test scores and greater normalized gains than control groups, indicating measurable growth in creative thinking performance. Among the various pedagogical models, inquiry based and project based STEM approaches were found to be the most effective in fostering creative engagement and innovation. The integration of cultural and contextual elements, as seen in ethno STEM models, also contributed to deeper learning experiences and stronger creative outcomes. Moreover, interdisciplinary and problem based approaches provided a holistic framework that supported both conceptual understanding and creative expression. In conclusion, the synthesis of results highlights that STEM based pedagogical practices, particularly those emphasizing inquiry, collaboration, and contextual relevance, significantly contribute to the development of students' creative thinking abilities. These findings reinforce the importance of implementing active, student centered, and interdisciplinary STEM learning strategies to prepare learners for complex problem solving and innovation in the modern world.

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