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The Urgency of STEM Learning Approach in Improving Students' Creative Thinking and Collaboration Skills

Ichwan Zarkasi Brillyano Gunawan[1], Rina Sugiarti Dwi Gita[2*], Kustiyowati[2]

[1] Student, Universitas PGRI Argopuro Jember, Jember, Indonesia
[2] Study Programs in Learning Technology, Universitas PGRI Argopuro Jember, Jember, Indonesia

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Corresponding Author:
Rina Sugiarti Dwi Gita
gitarina16@gmail.com

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Abstract: This study analyzes the urgency of the STEM (Science, Technology, Engineering, and Mathematics) learning approach in improving students' creative thinking and collaboration skills. Using the Systematic Literature Review (SLR) method with PRISMA protocol for transparency, this study conducted a bibliometric analysis of 52 relevant international journal publications from Scopus. Data visualization, including network analysis using VOSviewer, showed that STEM is a highly concentrated central concept, indicating significant relevance and research interest. The creativity and 21st century skills nodes were consistently closely connected to STEM, with a trend of rapidly increasing attention through 2023. The high density of the words "student" and "education" also confirms the research focus on the subject and context of learning. Collaboration, as an integral part of 21st century skills, reinforces the relevance of this discussion in the STEM context. This study validates the urgency of the STEM approach as an essential strategy to optimize students' creative thinking and collaboration skills, preparing them for the complexities and global challenges of the 21st century.

Keywords: Collaboration; Creative Thinking; STEM Approach

Introduction

The 21st century is marked by the rapid development of the industrial revolution, bringing various challenges, especially those related to technological progress, globalization, and changes in socio-economic dynamics (Pare & Sihotang, 2023). In line with the development of the 21st century educational paradigm, education in Indonesia is faced with the challenge of producing human resources with superior competencies who are able to compete globally in the future (Susiloningsih et al., 2025). One effort to overcome the above problems is to develop learning modules that are used to increase students' scientific creativity (Diana et al., 2021; Suyidno et al., 2024) Currently, existing learning modules do not fully train the 4C skills (Creative thinking, Critical thinking, Communication, and Collaboration), even though these skills are very much needed to face the challenges of the 21st century (Samala et al., 2023). Therefore, STEM (Science, Technology, Engineering, and Mathematics)-based education is believed to be able to create a young generation of successors to the nation who are more competitive on a global scale (Mukaromah et al., 2022).

The complexity of multidisciplinary global problems demands critical thinking and creativity that integrates various STEM concepts (Eurika & Prihatin, 2023). It is important for students to have creative thinking skills in order to solve problems (Utami et al., 2020).In addition, collaboration skills are also highly sought after and have received increasing attention in national and international assessments (Thornhill-Miller et al., 2023)Teacher collaboration has been raised as an institutional issue, and teacher collaboration programs have served as a means to create change and develop and enhance collective creativity (Hontvedt et al., 2019).

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In fact, from the disruption to all educational programs and the chaos of regulatory agency responses, collaboration emerged as a key driver of positive change (Khamis et al., 2021).

Collaboration skills are influenced by the approach used, which must address three domains: attitudes, knowledge, and skills. The STEM approach, an acronym for the disciplines of science, technology, engineering, and mathematics, encompasses all three domains (Cholis & Yulianti, 2020). Low student creativity is often caused by a lack of learning targets and difficulties in the material, especially in science lessons (Ariyani et al., 2025). According to (Ratnasari et al., 2023). In addition to generic science skills, in the learning process students also need to have and develop creative thinking skills, because through creative thinking, students are able to develop and find ideas related to views and concepts and emphasize aspects of rational thinking.

Based on research findings, the learning approaches implemented by teachers are still relatively unengaging. Teaching and learning activities are still teacher-centered, resulting in students being less motivated to learn (Ulandari et al., 2019). Students also have difficulty implementing science and technology in the real world (Dianti et al., 2023). This is because students are in a period of adjustment from something concrete to something abstract (Widodo & Wahyudin, 2018). Several other influencing factors are the curriculum and teaching methods which are dominated by traditional approaches (Ani et al., 2021).

The application of the STEM approach in PjBL (Project-based Learning) has proven effective in increasing students' creativity, communication skills, and collaboration (Davidi et al., 2021). Especially in science learning, the application of the STEM approach provides a gap to train students in improving creative thinking skills as part of 21st-century skills through the contexts offered in the STEM approach (Muttaqiin, 2023). The ethnoscience-based STEM approach is also one solution to developing students' potential (Rahman et al., 2023).

However, many students still do not receive an integrated STEM education that focuses on developing 21st-century skills (Dhany & Yulianti, 2025). Therefore, an appropriate strategy is needed to optimize the use of STEM-based learning models to enhance student creativity and collaboration. Pre-research studies indicate that mastery of these skills among student teachers is still low, especially in critical thinking and written communication, while creativity and collaboration are only classified as sufficient (Atmojo et al., 2025). The implementation of the STEM approach can be done through various learning strategies such as STEM-based projects, integrated learning, problem-based learning, and the use of digital technology (Dianti et al., 2023).

The integrated PjBL learning model with a STEM approach is a learning innovation that can train the ability to find solutions in a diverse, flexible, new, unique way, but can be accepted as true (Anindayati & Wahyudi, 2020). In addition to PjBL, there is also the POPBL model, each stage of the POPBL (Problem-Oriented Project-Based Learning) model can help students think creatively by exploring, collecting, designing, and implementing ideas to create products that can solve problems (Usman et al., 2024). The integration of PBL in STEM makes it possible to actualize environmental literacy and student creativity (Anita et al., 2020). Then, several research results also show that the creative thinking abilities of pre-service science teachers need attention (Nurita et al., 2024). So, it can be concluded that 21st century skills combine the 4Cs, specifically correspondence (communication), cooperation (collaboration), decisive reasoning (critical thinking), and imagination (creativity) (Fajrina, 2020).

Based on the statement above and the results of previous research, PjBL-STEM learning can encourage students to be active in learning because in integrating this model, students can communicate and collaborate together when in groups, as well as think critically and creatively (Megawati et al., 2023). Several studies have reported that after participating in flipped learning, students generally show positive attitudes toward collaboration and communication with their peers, and are more willing to participate in class discussions (Yen- et al., 2021). The research results show that STEAM (Science, Technology, Engineering, Arts, and Mathematics)-based learning using loose parts media effectively improves the 4C abilities of children aged 4-5 years (Prameswari & Anik Lestariningrum, 2020).

STEM has been proven to enhance students' development of problem solving, communication skills, creativity, knowledge analysis, and collaboration (Elizabeth Patras et al., 2024). However, the results of the context analysis concluded that the application of the STEM concept in physics learning in several schools in Padang City is still limited (Nazifah, 2022). Based on several previous research results, researchers want to strengthen the statement that STEM-based learning models can increase student creativity and collaboration.

This study aims to analyze the urgency of the STEM approach in improving students' creative thinking and collaboration skills. Through this analysis, the learning process is expected to be able to prepare students for creative thinking and collaboration, while also producing a generation that is resilient in responding to the challenges of the 21st century. STEM learning in 21st-century skills: 4C (Critical Thinking, Creative Thinking,

Communication, and Collaboration) by providing a description through a literature review approach or library research in national and international journals.

Method

This study adopted the Systematic Literature Review (SLR) method with the PRISMA protocol, combined with bibliometric analysis to map the metadata of Scopus-indexed journals. The SLR serves to systematically identify, analyze, and synthesize previous studies, while the bibliometric analysis (Hakim, 2020). Measuring research progress using statistical methods. Applications such as Publish or Perish, Zotero, Mendeley, VOSviewer, and Microsoft Excel are used to select and analyze articles. The search process follows the Identification, Screening, Eligibility, and Inclusion process. A total of 51 Scopus-indexed journals were identified through the Publish or Perish application, plus one journal taken directly from the Scopus website.

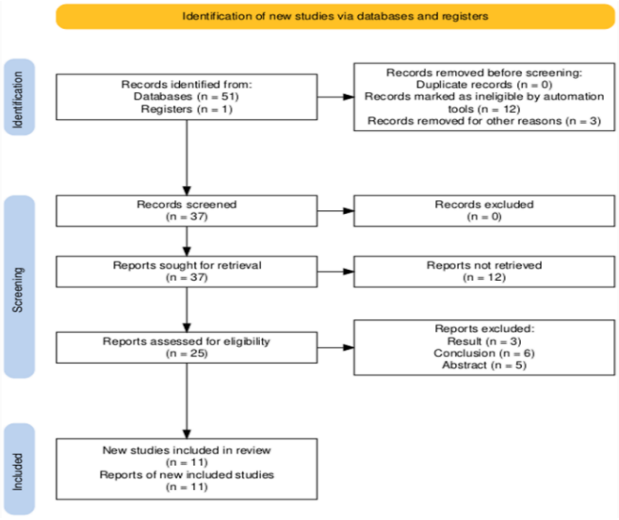

Figure1. Prisma Flow Diagram

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is an essential guide to ensuring transparency and accuracy in Systematic Reviews of Literature (SLRs), guiding researchers through four main phases. The Identification phase begins with collecting records from databases and registers. In this study, 52 articles were identified from databases (51) and registers (1). Of these, 15 were eliminated early (12 by automated tools, 3 for other reasons), leaving 37 articles for further processing. The Screening phase involved reviewing the titles and abstracts of the remaining articles to assess their relevance. These 37 articles were screened, and uniquely, none were excluded at this stage. However, of the 37 reports searched for full text, 12 were not successfully accessed. Next, the Eligibility phase evaluated the full texts of the 25 successfully accessed reports based on stringent inclusion and exclusion criteria. At this stage, 14 reports were excluded due to issues with results (3), conclusions (6), and abstract relevance (5). Finally, the Inclusion phase confirmed studies that met all criteria for further analysis. This rigorous process resulted in 11 studies being successfully included in the systematic review, demonstrating a systematic and transparent selection process from the initial 52 identified studies to 11 relevant studies.

Results and Discussion

This section presents the results of a systematic analysis of Scopus journal publications, as summarized in Table 1, and supported by data visualizations from Figures 2, 3, and 4. These findings comprehensively outline the urgency of the STEM approach in enhancing students' creative thinking and collaboration skills.

The importance of a STEM approach in enhancing students' creative thinking and collaboration skills is a consistent central theme in the scientific literature. The STEM approach effectively fosters critical thinking, creativity, collaboration, and communication. Integrating the Moving Skills Assessment (MSA) and Analytical Thinking Skills Assessment (ATSA) into STEM learning has significant potential to measure and enhance students' essential competencies. In STEM education, innovative instructional learning plans for both MSA and ATSA are effective (Phuseengoen & Singhchainara, 2022). Phuseengoen and Singhchainara (2022) emphasized the importance of a STEM approach in enhancing students' analytical thinking skills and learning satisfaction. However, to substantiate claims of improved creative thinking and collaboration, future research needs to include direct measurements of both competencies.

Based on the research analysis (Guerra 2024), this reflection suggests that to maximize the potential of STEM in enhancing creative thinking and collaboration, there needs to be a greater focus on integrating philosophical critical thinking to navigate the complexities of scientific knowledge beyond the academy, as well as adapting to the changes in collaborative interactions brought about by Generative Artificial Intelligence (GAI) tools. This suggests that the urgency of STEM is not only about content, but also about broader methodologies and frameworks of thinking.

Table1. Systematic Analysis of Scopus Journal Publications

Author	Title	Result
(Lhakard, 2024)	A Analysis of STEM Design Comparative Curriculum Policy for Country Development: A Case Study of Taiwan and Thailand.	indicates that both Taiwan and Thailand recognize the importance of STEM education for driving innovation and economic growth. However, Taiwan demonstrates a more comprehensive STEM policy framework and a stronger commitment to developing a skilled workforce. Taiwan's curriculum framework emphasizes hands-on, project-based learning, interdisciplinary integration, and the incorporation of modern technologies, fostering critical thinking, problem-solving, and collaborative skills among students. In contrast, Thailand is in the early stages of establishing STEM regulations and aligning curricula with industry needs. Thailand's evolving curriculum framework shows promise in promoting creativity, critical thinking, and practical problem-solving abilities. Regarding teacher professional development, Taiwan has a well-established system of ongoing training and industry-school collaboration, while Thailand is in the process of creating a STEM teacher competency program.
(Fernández-Morante et al., 2022)	ATS-STEM: Global Teaching Methodology to Improve Competences of Secondary Education Students.	The results showed an improvement in all the competences evaluated (although only the men showed an increase in collaboration). Nevertheless, there was a lower perception of competence in women than in men in discipline competences, problem solving and metacognitive skills. Therefore, the benefits of interdisciplinary ATS STEM learning experiences on the self-efficacy perceived by high school students were confirmed, although the results continue to show a gender gap.
(Wibowo et al., 2022)	Dissemination of Virtual Microscopic Simulation (VMS) to Sparking in STEM for Facilitating 21st-Century Skills (21-CS).	The results showed that the 21-CS skills questionnaire of teachers and students' perceptions of their understanding of 21st-century skills. These results can reveal that VMS with a STEM approach provides a positive relationship to practice 21st-century skills for teachers. Based on these results, the simple impact is when teachers have strong perceptions about problem-solving, critical thinking, collaboration, communication, and creativity, through STEM and VMS media
(Phuseengoen & Singhchainara, 2022)	Effects Of Stem-Integrated Movement Activities On Movement And Analytical Thinking Skills Of Lower Secondary Students.	The CLM lesson showed the E1/E2 as 79.67/78.00, and the STEMe showed as 88.10/86.50 which was higher than the standardized criterion at 80/80. Comparisons between pre- and post-test for the control and experimental groups of their MSA and ATSA are differences, significantly ($p<.01$) and the classified levels are neither satisfied nor dissatisfied and some levels for the pre-test and post-test. The STEMe was differentiated significantly ($p<.001$) and the classified levels indicated that were neither satisfied nor dissatisfied, and very satisfied levels for the pre- and post-test-MSA- ATSA, respectively. The ATSA and the MSA instruments were relatively significant, when using a simple correlation analysis (r) and standardized regression validity (β). The multiple correlations (R) and the efficient determination predictive efficiency (R2) value indicated that 41% and 66% of the variances in students' analytical thinking skills of the control and experimental groups were attributable to their post MSA learning assessment to their physical education environmental classes.
(Chiang et al., 2024)	Gender disparity in STEM education: a survey research on girl participants in the World Robot Olympiad.	The results showed that among the 5956 participants in the 2015–2019 WRO finals, girls accounted for only 17.3%. The Open Category that stimulated creativity attracted relatively more girl participants. As age group moved up, the number of girl participants decreased. The qualitative results showed that the focus of coaches, parents and students was not exactly the same. The all-girl team has the advantages in their communication, presentation and collaboration skills but less good at robot building. The results indicated the importance of promoting girls' participation in robot competitions and STEM fields. Coaches, mentors and parents need to provide girls with more support and encouragement in learning STEM subjects, especially at the junior high school level.

Author	Title	Result
		Organizers of related competitions should give girls more exposure and opportunities by adjusting the mechanism.
(Yusuf et al., 2023)	Integration of STEM Project-Based Learning into 21st Century Learning and Innovation Skills (4Cs) in Vocational Education Using SEM Model Analysis.	The study's findings indicated that while there was a correlation between STEM Project Based Learning and 4Cs competencies, communication skills were less effective in STEM Project Based Learning learning due to a variety of influencing factors. To improve students' communication skills, the author recommends that the school provide increased motivation to ensure that communication skills are acquired properly.
(Huang et al., 2022)	Promoting Secondary Students' Twenty-First Century Skills and STEM Career Interests Through a Crossover Program of STEM and Community Service Education.	The quantitative results showed that the participants' creative thinking, collaboration, and perseverance improved alongside their STEM career interests. These findings were further supported by the data gathered through focus-group interviews. This study provides theoretical and practical insights into the integration of STEM education with community service learning.
(Guerra, 2024)	The contribution of critical thinking to STEM disciplines at the time of generative intelligence.	The result of this reflection, which does not yet seem to be outlined in the literature, but which hopefully will be more extensively addressed in the future, indicates that critical thinking, guided by philosophy, can play a crucial role in STEM, especially concerning the Post-Normal Science model, in which the construction of scientific knowledge leaves the academy. Moreover, GAI tools significantly modify the interactions between the different knowledge actors.
(Jalaludin, 2024)	The Impact of Virtual Collaboration Tools on 21st-Century Skills, Scientific Process Skills and Scientific Creativity in STEM.	The results showed significant improvements in all three skill areas post-intervention: 21st-century skills, scientific process skills, and scientific creativity. Gender differences were significant for 21st-century skills, while regional differences significantly affected scientific process skills. The EYE program can enhance students' STEM-related skills using virtual collaboration tools like Zoom. However, regional and gender differences highlight the importance of adapting programs to address specific challenges and ensure equitable opportunities for all students.
(Baran et al., 2021)	The Influence of Project-Based STEM (PjbL-STEM) Applications on the Development of 21st-Century Skills.	The results of the analyzes applied in the study demonstrated that in the process of developing the STEM projects, the students did brainstorm to solve the current problems, conducted research, and obtained the necessary materials. This is because the students worked together, focused on real-life issues, and tried to put forward the possible solution. In addition to that, it was seen that only a few students did experiments and observations. Another finding was that most of the students used the Internet to get information. As can be understood from its definition, STEM is a science-based method of education which deals with real-life problems by covering a number of disciplines.
(Okwara & Pretorius, 2023)	The STEAM vs STEM Educational Approach: The Significance of the Application of the Arts in Science Teaching for Learners' Attitudes Change.	The results of this research show, the framework for STEM does not fully support an understanding that creativity can exist in science and that science can be taught in multiple ways, including the application of the arts. STEAM, on the other hand, is grounded in a transdisciplinary approach to science teaching and learning. It explores the application of the arts in science teaching and learning. This is aimed at improving the confidence, attitudes, and interests of learners in science through new approaches to problem-solving which might strengthen positive attitudes towards science. This approach incorporates the common processes of science and arts, which include discovery, observation, experimentation, description, interpretation, analysis, evaluation, wondering, visualizing, exploring, and communication.

Evaluation of STEM approaches is crucial to ensure optimal educational investment. Focusing on comprehensive indicators of success, from cognitive outcomes to overcoming challenges, is one application of STEM evaluation using the Assessment of Transversal Skills (ATS). The application of a global approach and learning methodology based on ATS-STEM model projects improves self-perception and the acquisition of

core competencies for STEM learning (Fernández-Morante et al., 2022). This research (Fernández-Morante et al., 2022) underscores the urgency of an interdisciplinary STEM approach in enhancing creative thinking (through discipline, problem-solving, and metacognition) and student collaboration. Although collaboration only increased among boys, STEM's effectiveness in enhancing self-efficacy was confirmed. However, the gender gap in perceived competence demands in-depth analysis and the development of more inclusive STEM teaching strategies to equitably benefit all students in developing these crucial skills.

In contrast to research conducted by Chiang et al. (2024), based on the analysis of the researchers conducting this study, it confirms the urgency of the STEM approach in improving creative thinking skills (especially through an emphasis on creativity in the program) and student collaboration (where female teams demonstrated excellence). However, these findings also revealed gaps in participation and technical skills based on gender, highlighting that the urgency of STEM also includes systematic efforts to promote female inclusion and provide relevant support from an early age, as well as adapting competition mechanisms, so that all students can fully benefit from STEM education.

The urgency of a STEM approach to improving students' creative thinking and collaboration skills needs to be reconsidered. Research (Okwara and Henrik Pretorius 2023) actually indicates that a STEAM approach is more urgent and relevant. STEAM overcomes the limitations of STEM in embracing creativity, explicitly integrating the arts to enrich problem-solving and positive attitudes toward science. Through its transdisciplinary nature, STEAM also implicitly facilitates collaboration, making it a more comprehensive framework for achieving the goal of improving students' creative thinking and collaboration skills.

Meanwhile, research conducted by (Nur Atiqah Jalaludin et al. 2024) directly confirms the urgency of the STEM approach in enhancing creative thinking (through scientific creativity and 21st-century skills) and student collaboration, supported by the use of virtual tools. However, the existence of gender and regional disparities underscores the need for inclusive adaptation of STEM programs for equitable distribution of benefits. Another study conducted in two countries, Taiwan and Thailand, the results of the study by Lhakard (2024) confirm the universal urgency of the STEM approach in enhancing creative thinking and collaboration skills. Taiwan is a more advanced example with a robust policy framework and proven implementation in promoting both skills through a student-centered curriculum and strong teacher professional development. Meanwhile, Thailand shows a promising direction, although still in its early stages. This difference highlights that the urgency of STEM lies in a strategic commitment and comprehensive policy implementation to truly realize the potential for increasing creative thinking and student collaboration.

Similar to research by Baran et al. (2021), the results of this study strongly confirm the importance of a STEM approach in developing creative thinking skills through real-life problem-solving and student collaboration through teamwork on projects. However, there are opportunities to further optimize STEM implementation by encouraging greater participation in experiments and direct observation, and balancing the use of digital information sources with practical experiences to maximize the development of students' creative and scientific skills.

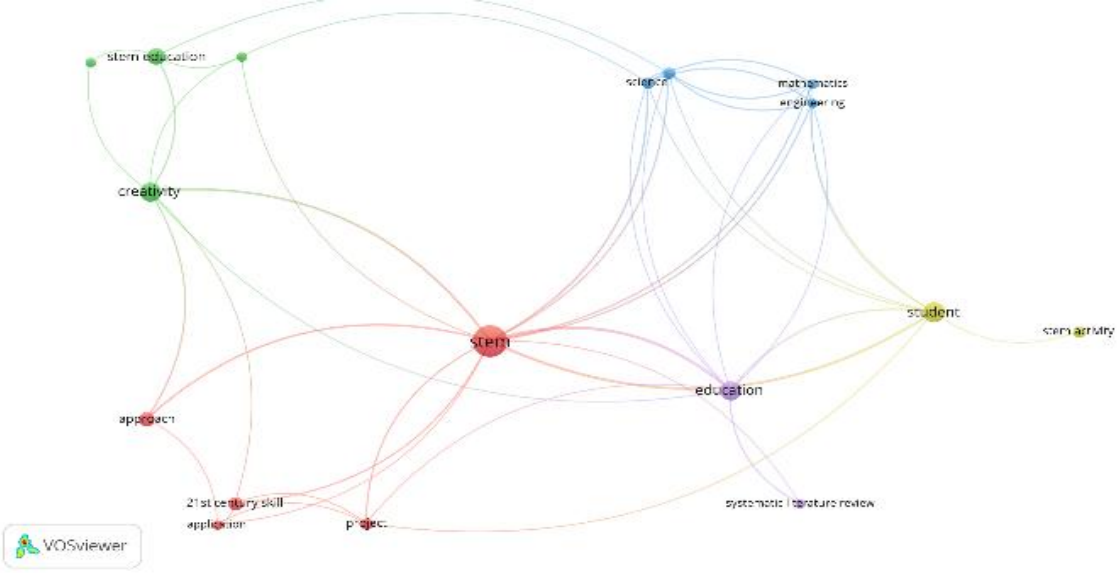

Figure1. Network Map Visualization of STEM-Related Keywords, Creativity, and Collaboration in Scientific Publications

Based on the analysis of Figure 2, the STEM concept is the dominant central keyword, indicating the strong relevance of this approach in the analyzed literature. This confirms the central position of STEM in current discussions and research. STEM is closely linked to creativity and collaboration (both in Cluster 1). This link indicates that the literature consistently associates the STEM approach with the development of these two skills. The emergence of 21st-century skills linked to creativity, application, and projects further emphasizes the position of creative thinking and collaboration as integral parts of 21st-century competencies relevant to STEM learning. Cluster 1 specifically brings together STEM, creativity, collaboration, and 21st-century skills, highlighting the urgency of the STEM approach in developing these skills. The significant density of student and education underscores the research's central focus on the subject (student) and learning context. Clusters 2, 3, and 4 each enrich the understanding of the contributions, Core components, and implementation of student-centered STEM activities, providing strong visual validation of this research's empirical foundation in the scientific literature.

The STEM approach to improving 21st-century skills is not only proven through media, but also proven through learning models such as research conducted by (Yusuf et al., 2023), where this study found a correlation between STEM Project-Based Learning (PjBL) and 4C competencies, which include critical thinking, creativity, collaboration, and communication. This correlation directly confirms the urgency of the STEM approach (especially through PjBL) in developing these skills. The correlation shows that the application of STEM PjBL has the potential to improve students' creative thinking skills (creativity) and collaboration.

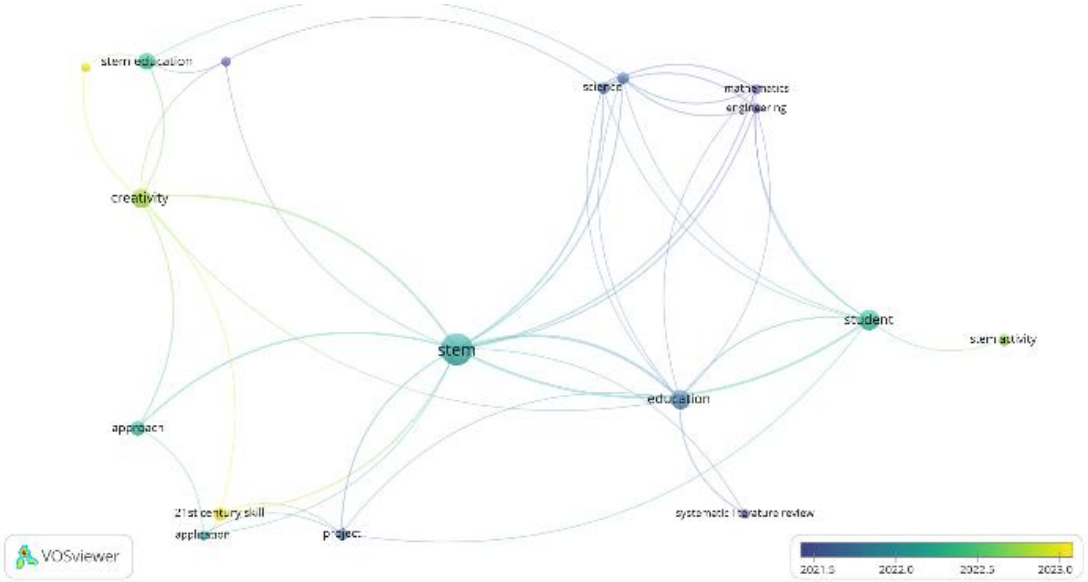

Figure2. Overlay Visualization of Recent Publication Trends Related to STEM, Creativity, and 21st Century Skills with VOSviewer

Figure 3 shows recent publication trends that support the urgency of this research: STEM remains a consistent research focus (2022-2023), while creativity and 21st-century skills show a rapid increase in attention (approaching 2023). Although collaboration is not prominent in the overlay, its association with STEM and creativity confirms that it is also part of a growing research trend. This temporal pattern empirically reinforces the urgency of a STEM approach to improving students' creative thinking and collaboration skills in line with contemporary educational needs.

The development of 21st-century skills is crucial in modern education. This is in line with research findings from (Wibowo et al., 2022), which underscores the urgency of a STEM approach in enhancing students' creative thinking skills (through problem-solving, critical thinking, and creativity), as well as collaboration and communication. It has been shown that the implementation of STEM with a Virtual Multimedia System (VMS) positively strengthens teachers' perceptions of these 21st-century skills. This indicates that STEM plays a crucial role in developing these competencies in teachers, which ultimately has a direct impact on the development of similar skills in students.

From all the analyses based on the results of previous research conducted by researchers, it was found in the results of research conducted by Huang et al. (2022)This directly reinforces the importance of a STEM approach to enhancing students' creative thinking and collaboration. Significant improvements in both

skills, supported by quantitative and qualitative data, demonstrate the effectiveness of STEM in developing vital 21st-century skills. The integration of STEM with community service learning also provides practical insights into its contextual application.

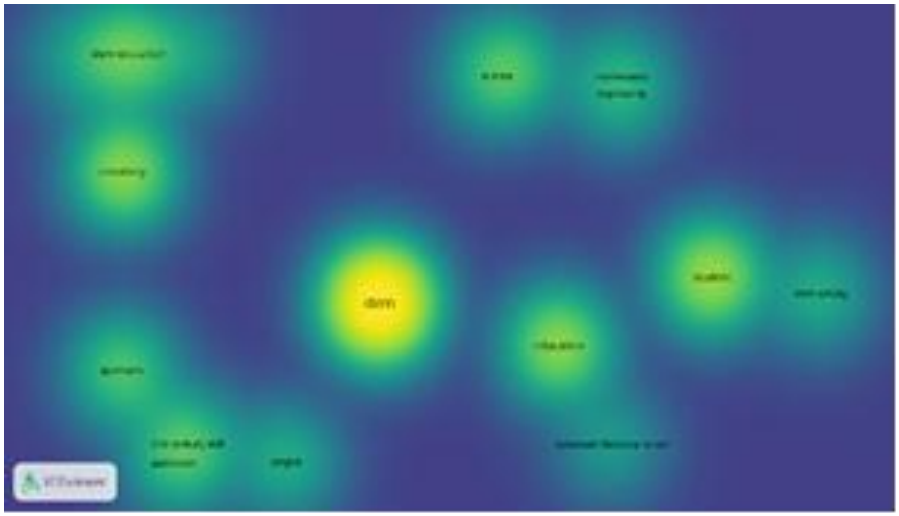

Figure 3. Visualization of Keyword Density in STEM Literature, Creativity, and Collaboration with VOSviewer

The visualization of Figure 4 shows that STEM is the highest concentration in the literature, fundamentally confirming the relevance of this approach. Surrounding STEM are other high-density areas, including creativity and 21st-century skills, which directly support this study's argument regarding enhancing students' creative thinking and collaboration skills as an integral part of 21st-century competencies. The significant density of students and education also underscores the central focus on the subject and learning context. Thus, this density map comprehensively indicates that this research title falls within a highly active and widely discussed research area, reinforcing its academic and practical urgency.

Conclusion

Based on the research objectives outlined, it can be concluded that this study comprehensively identifies and validates the urgency of the STEM learning approach as an essential strategy for optimizing students' creative thinking and collaboration skills. Through an in-depth analysis of the relevance of key concepts and scientific publication trends, this study confirms that STEM implementation is not only crucial for the development of students' cognitive and social skills but also fundamental in preparing them to face the complexities and global challenges of the 21st century. Thus, the implementation of the STEM approach is expected to produce a generation that is adaptive, innovative, and able to collaborate effectively in facing future dynamics.

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Author Contributions
Conceptualization, I.Z.B.G.; Methodology; R.S.D.G. and I.Z.B.G.; Validation; R.S.D.G.; formal analysis, R.S.D.G. and K.; resources,; K.; data curation, K.; writing—original draft preparation, I.Z.B.G. and R.S.D.G.; writing—review and editing, I.Z.B.G. and K.; visualization, R.S.D.G.

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Conflict of Interest
The author declares no conflict of interest.

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