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Visualizing Research Trends on the Impact of STEM-Integrated Project-Based Learning Model on 21st-Century Skills Using VOSviewer and Harzing's Publish or Perish: A Systematic Literature Review

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Abstract

The 21st-century skills are essential component of curriculum frequently implemented in schools and universities to equip students for competition in the labor market. Integrating STEM (Science, Technology, Engineering, and Mathematics) into Project-Based Learning (PjBL) promotes active student engagement and interdisciplinary problem-solving to tackle complex issues. This article aims to provide research recommendations on how the STEM-integrated PjBL model affects students' 21st-century skills and to provide information on rarely-researched trends in this field. A Systematic Literature Review was conducted following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, utilizing Harzing's Publish or Perish software, VOSviewer, and Google Scholar databases, focusing on thirty references published between 2019 and 2023. The findings indicated that the STEM-based PjBL approach significantly enhances students' 21st-century skills, including critical thinking, creativity, collaboration, communication, conceptual understanding, and problem-solving abilities, thereby preparing them to navigate complex global challenges. Effective implementation requires interdisciplinary teacher collaboration, technology integration, and supportive learning environments. However, the analysis highlights that the integration of STEM and PjBL has not been extensively associated with collaboration and communication skills, presenting a valuable opportunity for future research in this area.

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INTRODUCTION

The development of 21st-century skills is a fundamental requirement in modern curricula, emphasizing their cultivation among students at both school and university levels to enhance their competitiveness in the workforce (Muttaqiin, 2023). In this era, teachers are tasked with equipping students with these essential skills. Consequently, the teaching methods employed must align with the principles of 21st-century learning (Yanuar, 2018). According to Yanuar (2018), 21st-century learning emphasizes a student-centered approach, promotes collaboration among learners, connects educational content to real-world problems, and prepares students to become responsible global citizens. To realize these objectives, students are encouraged to develop critical thinking, creativity, problem-solving, and decision-making abilities (Dewi et al., 2023).

In 2022, Indonesia ranked 59th out of 81 countries in literacy with a score of 359, 67th in numeracy with 366, and 65th in science with a score of 3832. Although these rankings show improvement compared to 2018, the scores remain far from satisfactory (Solihin et al., 2024). Observations of biology learning at the high school level revealed that the applied teaching models do not fully train critical thinking skills, resulting in low critical thinking skills (Allanta & Puspita, 2021). Many students report feeling bored and unproductive, struggling to solve problems from different perspectives. This is exacerbated by teachers conducting classes in a monotonous manner, with limited opportunities for students to explore creative solutions to presented problems (Karmila & Putra, 2022). These facts highlight that the majority of the education system has yet to adequately develop students' critical and creative thinking abilities—both of which are crucial for 21st-century learning (Mirfaka & Kumala, 2023). Critical thinking involves a cognitive process encompassing the ability to analyze, evaluate, draw conclusions, and solve problems (Pramasdyahsari et al., 2023). Students with well-developed critical thinking skills are typically more effective in articulating ideas, participating actively in discussions, and engaging in dynamic learning environments (Pelle et al., 2024). Research by Husna (2020) revealed that many students remain passive during lessons, requiring frequent encouragement from teachers to express their ideas. Conversely, students with strong communication skills are more confident in presenting their arguments, thereby fostering a more interactive and engaging classroom atmosphere.

Dialogue and discussion activities play a vital role in developing critical thinking by enabling students to share ideas, question information, and consider different perspectives. Intersubjective communication—open exchanges of ideas between teachers and students—has been shown to enhance students' analytical abilities and problem-solving skills (Sastradiharja et al., 2023). By posing open-ended questions and challenging issues, teachers can stimulate curiosity, encouraging students to independently seek solutions. This approach not only strengthens analytical skills but also boosts confidence in expressing opinions (Pelle et al., 2024). Active participation in communication or group activities further aids students in better understanding the materials (Miranty et al., 2020). Based on observations made by Fani & Rukmana (2022) during the pre-cycle phase reveal that many students are not actively involved in group learning. Often, one or two students dominate group tasks, while others remain disengaged. High-performing students frequently complete assignments independently, without meaningful collaboration with their peers. This lack of teamwork underscores a deficiency in collaboration skills, which, in turn, diminishes students' motivation to engage in the learning process. Prayogi et al. (2024) found that students who do not participate actively in group discussions tend to have a superficial understanding of the subject matter, negatively impacting their academic performance. A study by Wulandari et al. (2021) noted that students unable to collaborate effectively often score below the Minimum Completion Criteria (MCC), reflecting their failure to meet expected learning standards. Collaboration skills are not only critical for academic success but also essential for professional environments where teamwork and effective communication are highly valued. Students who lack training in collaboration may face challenges in the workplace, struggling to adapt to team-oriented roles and meet the demands of a competitive labor market (Nasution et al., 2024).

The PjBL (Project-Based Learning) model encourages students to be more independent in solving problems. However, it has certain limitations that can impede the classroom learning process. This approach requires significant time and financial resources for facilities, such as equipment for project creation (Kemendikbud, 2014). To address these challenges, incorporating modern technology is essential for facilitating more creative projects. The effectiveness of project-based learning can be enhanced by integrating it with contemporary technology. One effective strategy is combining the STEM (Science, Technology, Engineering, and Mathematics) approach with the PjBL model. STEM integrates four key components: science, technology, engineering, and mathematics, enabling students to develop skills in design, creativity, and innovation (Narut & Nardi, 2019). The STEM approach focuses on solving problems experienced in daily activities. The STEM approach can stimulate students to explore their curiosity in understanding the material, and students must be responsible for learning activities to make students carry out a critical thinking process (Novitasari et al., 2022). Applying the STEM approach to learning, students have a beneficial learning experience by systematically integrating knowledge, concepts, and skills.

Critical, creative, communicative, and collaborative thinking skills can be effectively developed through learning approaches that integrate science, technology, engineering, and mathematics (STEM). STEM education equips students with higher-order thinking skills while fostering their interest in learning, an essential requirement for adapting to the competitive demands of the modern era (Wahono in Putri, 2023). In science education, the STEM approach encourages students to think critically and creatively, while also promoting collaboration and effective communication. This positions STEM-based learning as a robust foundation for achieving 21st-century skills.

The PjBL-STEM model provides a practical solution for nurturing these essential skills. As a project-based learning approach, PjBL is highly recommended for 21st-century education (Firmantara & Handayani, 2023). In this model, each STEM component is synergistically applied within project-based learning activities. For instance, the science component is engaged when students explore renewable energy concepts, such as solar or wind power, to support energy management in a smart city model. The technology component is integrated through tools like automated sensors that detect vehicle presence in smart transportation systems or manage energy-efficient lighting. The engineering component comes into play as students design and build physical or digital models of smart cities, focusing on efficiency and environmental sustainability. Meanwhile, the mathematics component is utilized in calculations, such as estimating costs, areas, and the efficiency of transport or energy systems. By combining these four components, students gain both theoretical understanding and practical experience in applying STEM concepts to solve real-world problems (Wulanningtyas et al., 2023). This holistic integration not only enhances their technical skills but also prepares them to face complex challenges in a rapidly evolving world.

This article intends to provide research recommendations on how the STEM-integrated PjBL model affects students' 21st-century skills and to provide information on rarely-researched trends related to STEM-integrated PjBL.

METHODS

This study adopted the Systematic Literature Review (SLR) method, guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework. The SLR approach was conducted systematically, following standardized protocols and clearly defined stages. Unlike conventional literature reviews, a systematic review involves a planned and structured process that emphasizes the evaluation, classification, analysis, and categorization of evidence-based information (Sastypratiwi & Nyoto, 2020). The typical procedures in a systematic review include: (1) Defining the background and purpose of the study; (2) Formulating research questions; (3) Conducting a comprehensive literature search; (4) Establishing clear selection criteria; (5) Applying practical screening methods; (6) Utilizing a quality checklist and procedural guidelines; (7) Developing a data extraction strategy; and (8) Formulating a

data synthesis strategy. By following these steps, the SLR method ensures a rigorous and objective evaluation of the literature, providing a robust foundation for evidence-based research.

Table 1. Review Protocol

Number	Process	Description
1	Data Retrieval	Data were retrieved from the Harzing Publish or Perish Google Scholar database using relevant keywords tailored to the research topic.
2	Data Screening	Relevant research journal articles were selected based on their alignment with the research title and core issues discussed.
3	Data Quality Assessment	Full-text data were evaluated against the inclusion and exclusion criteria outlined in Table 2.
4	Data Search Results	Data meeting all criteria were further analyzed to produce results aligned with the research objectives.

Table 2. Inclusion and Exclusion Criteria

Criteria	Inclusion	Exclusion
Population	PjBL	Variables that do not belong to PjBL
Intervention	STEM	Variables that do not belong to STEM
Comparator	-	-
Outcomes	21st Century Skills	21st Century Skills
Studi *Design and Publication Type*	-	-
Publication Years	2019-2023	Before 2019
Language	English, Indonesia	Not written in English or Indonesia

Table 3. Research procedure

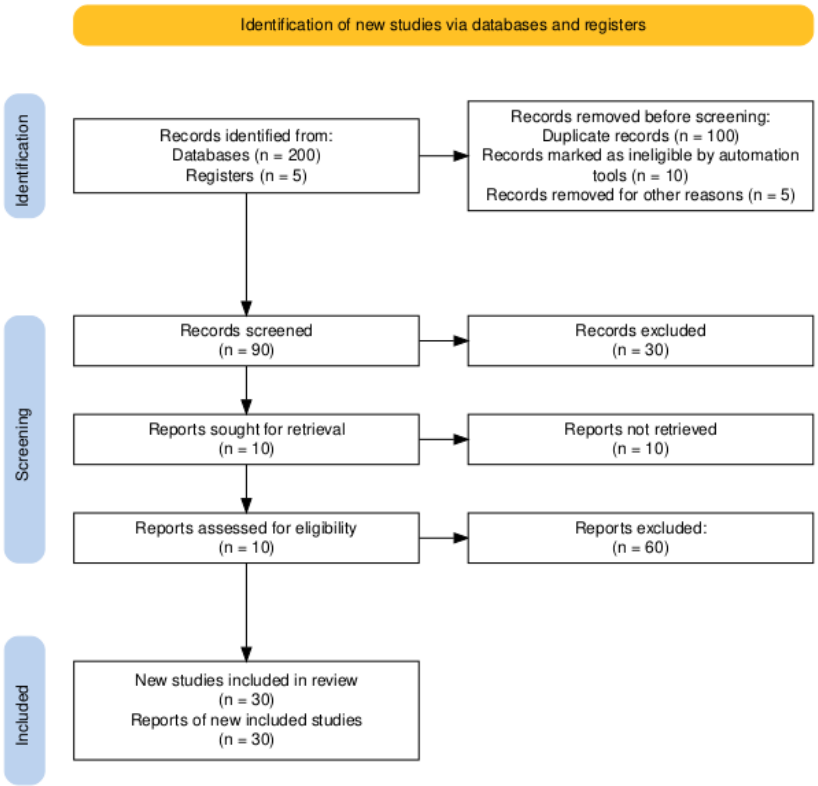

Figure 1. The steps of Systematic Literature Review (SLR) method

RESULTS AND DISCUSSION

Results

The literature review on the articles used must include criteria such as articles in English or Indonesian, titles and contents in accordance with the research objectives, and articles published in 2019-2023. The findings proved that the STEM-integrated PjBL model is influential in increasing 21st-century skills. The article review includes the article code, article title, and article review results. The review results are shown in Table 4.

Table 4. Results of Article Review

Code	Title of Article	Results
A1	Implementasi Model PjBL Berbasis STEM untuk Meningkatkan Penguasaan Konsep dan Kemampuan Berfikir Analitis Siswa (Tipani et al., 2019)	STEM-based PjBL improves students' concept mastery and analytical thinking skills.
A2	Implementasi Model PJBL-STEM terhadap Kreativitas Siswa pada Mata Pelajaran IPA di SMP Negeri 5 Batam (Storina, 2022)	The assessment results obtained an average student score of 79% with very creative criteria. This best practice concludes that implementing the Project-Based Learning (PjBL) model with a STEM approach can develop student creativity.
A3	Implementasi Model Pjbl-Stem untuk Meningkatkan Keterampilan Berpikir Tingkat Tinggi. (Fitriyani et al., 2020)	Significant effect of STEM-PjBL on higher-order thinking skills in biotechnology ($Ztabel$ STEM model). Zcount$= 2.89 = Ztable$
A4	Project Based Learning Berbasis STEM: Meningkatkan Kemampuan Berpikir Kritis dan Hasil Belajar Siswa. (Dewi et al., 2023)	STEM-PjBL influences critical thinking skills, science learning outcomes, and both simultaneously.
A5	Peningkatan Keterampilan Berpikir Kritis dengan Menggunakan Model Pembelajaran Project Based Learning (PjBL) berbasis STEM pada Materi Kalor dan Perpindahannya di Kelas V SD Negeri Ploso (Munawwaroh et al., 2023)	Critical thinking skills increased from 63.3% (fair) cycle I to 76.7% (good) cycle II.
A6	STEM-PjBL Learning: The Impacts on Students' Critical Thinking, Creative Thinking, Communication, and Collaboration Skills (Kurniahtunnisa et al., 2023)	Critical thinking skills increased. Paired t-test showed a significant difference (p=0.001) before and after STEM-PjBL learning.
A7	Pengaruh Model Pembelajaran STEM-PJBL terhadap Kemampuan Berpikir Kreatif Siswa SMP Negeri 1 Slogohimo Wonogiri di Era Pandemi pada Materi Hidrosfer (Karlina et al., 2023)	STEM-PjBL improves creative thinking skills during the pandemic era, especially on hydrosphere materials.
A8	Pengaruh project based learning terintegrasi stem pada pembelajaran hidrolisis garam terhadap keaktifan siswa (Nurfaijah et al., 2021)	STEM-integrated PjBL significantly impacts student activeness according to r count.
A9	Pengaruh PjBL STEM terhadap Literasi Sains dan Problem Solving Siswa SMP. (Afriana, 2022)	Significant improvement in problem-solving scores of experimental vs. control classes.

Code	Title of Article	Results
A10	Peningkatan Kemampuan Berpikir Kritis dan Sikap Kreatif Siswa Kelas V Melalui Model Pembelajaran PJBL-STEM Berbantuan Media Aplikasi Belajar Siklus Air (ABSA) pada Mata Pelajaran IPA di Sekolah Dasar (Mirfaka & Kumala, 2023)	The average creative attitudes score increased in cycle 1, from 65.4 at meeting 1 to 74.3 at meeting 2. This increase was also seen in cycle 2, from 78.5 at meeting 1, and 83.1 at meeting 2 (Very Good category).
A11	Pendekatan STEM (Science, Technology, Engineering, Mathematics) pada Pembelajaran IPA Untuk Melatih Keterampilan Abad 21. (Muttaqiin, 2023)	STEM approach positively impacts 21st-century skills.
A12	Literature Review: Pengaruh Model Pembelajaran PjBL (Project Based Learning) Terhadap Keterampilan Berpikir Kritis Peserta Didik (Jeniver et al., 2023)	PjBL improves critical thinking skills in biology learning.
A13	Studi Literatur: STEM untuk Menumbuhkan Keterampilan Abad 21 di Sekolah Dasar (Rusminati & Juniarso, 2023)	STEM learning design is a favorable alternative for teachers to cultivate 21st-century skills, including critical thinking and problem-solving, creative thinking, communication, and collaboration.
A14	Pengaruh STEM-PjBL terhadap Keterampilan Berpikir Kreatif Siswa MTS. (Firmantara & Handayani, 2023)	STEM-PjBL improves creative thinking, confirmed by the N-Gain test in experimental and control classes.
A15	Analisis keterampilan berpikir kritis dan self efficacy peserta didik: Dampak PjBL - STEM pada materi ekosistem (Allanta & Puspita, 2021)	STEM-PjBL enhances critical thinking, creativity, and self-confidence in addition to developing their thinking skills and character.
A16	Efektivitas Pembelajaran STEM dengan Model PjBL Terhadap Kreativitas dan Pemahaman Konsep IPA Siswa Sekolah Dasar (Yulaikah et al., 2022)	Significant effectiveness of STEM-PjBL in enhancing creativity and science concept mastery compared to conventional models.
A17	Penerapan Stem From Home dengan Model PjBL guna Meningkatkan Penguasaan Konsep dan Keterampilan Berpikir Kreatif Siswa SMP (Ningrum et al., 2021)	Achieved 43% N-gain (high) in concept mastery and 63% (medium) in creative thinking skills. The model is effective for enhancing conceptual mastery and creativity.
A18	Pengembangan Perangkat Pembelajaran PjBL berbasis STEM dalam Meningkatkan Kreativitas Fisika Peserta Didik (Ridha et al., 2022)	PJBL-STEM learning model scored 4.00 (very good) and 3.17 (good) on practicality. The implementation scores on teacher and student activities were 3.92 (very good) and 3.00 (good), respectively.
A19	Efektivitas Pembelajaran IPA Berbasis Etno-STEM dalam Melatihkan Keterampilan Berpikir Analisis (Sartika et al., 2022)	Ethno-STEM-based science learning was effective, as indicated by 1) the implementation of learning averages at 3.7 (very good), 2) student activities relevant to learning averages at 3.6 (very good), 3) there was an increase in the value of analytical

Code	Title of Article	Results
		thinking skills by 0.6 (moderate), and 4) positive student responses to learning by 90%.
A20	Pengaruh Model Pembelajaran Project Based Learning (PjBL) Terintegrasi STEM Pada Mata Pelajaran Fisika Untuk Meningkatkan Kemampuan Berfikir Kreatif Peserta Didik SMA TGH Umar Kelayu Tahun Ajaran 2021/2022 (Qadafi et al., 2022)	Experimental class outperformed control in critical thinking (75.33 vs. 65.29), showing STEM-PjBL improves creative thinking.
A21	Fostering students' mathematical critical thinking skills on number patterns (Pramasdyahsari et al., 2023)	STEM PjBL digital book was valid and significant in fostering students' critical thinking skills and other 21st century learning skills. The students were satisfied and interested in learning through active teaching and learning methods.
A22	Critical Thinking Skills Reviewed from Communication Skills of the Primary School Students in STEM-Based Project-Based Learning Model (Oktavia & Ridlo, 2020)	STEM-PjBL enhances verbal communication and problem-solving skills.
A23	Implementation of STEM Integrated Project-Based Learning (PjBL) to Improve Problem-Solving Skills (M. Putri & Dwikoranto, 2022)	PjBL-STEM model is sufficient to improve problem-solving skills in dynamic fluid materials. This student-centered model significantly affects problem-solving skills but requires better facilities and teaching strategies.
A24	The Growth of Vocational High School Students' 4C Skills on the Use of PjBL STEM-Based Physics Digital Module (Lestari et al., 2023)	The results showed that the 4C skills of vocational school students have increased significantly.
A25	The Effectiveness of STEM-Based Learning in Teaching 21st Century Skills in Generation Z Student in Science Learning A Meta-Analysis (Ichsan et al., 2023)	STEM-based learning effectively trained Generation Z students' 21st-century science skills, with an effect size (ES) value of 1.47 and an N-gain of 0.86 in the high category.
A26	Development of ST EM - Project-Based Learning Devices to Train 4C Skills of Students (Kurniahtunnisa & Wowor, 2023)	1) Learning tools are very valid based on expert validation and construct validity, especially for critical thinking skills tests; 2) STEM-PjBL learning tools were well implemented. 3) STEM-PjBL learning tools effectively improve students' critical thinking skills, with >75% of students meeting the minimum completeness criteria. Based on the N-gain test, there is an increase in critical thinking skills with moderate criteria. The STEM-PjBL Learning Tool effectively trains creative, communicative, and collaborative thinking skills with high criteria.
A27	The Effectivity Study Implementation of the Physics e-Module with PjBL-STEM Model to Describe Students' Creative	PjBL-STEM Model Physics e-Module is efficacious in improving students' creative thinking skills by 85% and student learning motivation by 68% in the good category. The profile of student creative thinking

Code	Title of Article	Results
	Thinking Skills and Learning Motivation Profile (Millen & Supahar, 2023)	skills is 54.16%, while student learning motivation is 60.41%. Both have average and above-average scores.
A28	Integrated PjBL-STEM in Scientific Literacy and Environment Attitude for Elementary School (Winarni et al., 2022)	PjBL and STEM significantly influenced science literacy and environmental attitude in three indicators. In addition, the diorama project enabled students to investigate environmental conservation efforts, accommodating science and technology. Environmental literacy and STEM instruments to integrate with cognitive, motivation, behavior, and values.
A29	Impact of The STEM approach with formative assessment in PjBL on students' critical thinking skills (Parno et al., 2022)	CTS in the experimental class, with a mean of 65.19 and an increase of 0.52 (medium), was significantly higher than the control class, with 52.36 and 0.35 (medium). The effect size value of 1.13 (very large) indicated that PjBL-STEM-AF learning needs to be done more often. In the experimental class, students gave more positive responses to learning than in the control class. It is suggested that future research adds the "Art" aspect to the STEM approach to develop students' CTS further.
A30	Effectiveness of Project-Based Learning Low Carbon STEM and Discovery Learning to Improve Creative Thinking Skills (Rahmania, 2021)	Some basic science competencies at the junior high school level can be integrated with the STEM approach through classroom activities. PjBL and STEM approaches can shape students into human resources who can think critically and creatively, systematically and logically to meet the standards of 21st-century human resources and face increasingly complex global challenges.

Discussion

Bibliometric Network Visualization of Research Trends of PjBL-STEM Models on 21st-Century Skills

The metadata of articles was examined using Publish or Perish software, with visualizations created through VOSviewer (van Eck & Waltman, 2010). The analysis resulted in network, overlay, and density visualizations, as depicted in Figure 2. A bibliometric network is composed of nodes and connections, where nodes symbolize keywords or topics, and connections illustrate the relationships between them. The strength of these relationships is indicated by the proximity of the nodes, with shorter distances representing stronger connections. The initial stage of metadata visualization identified 10 distinct clusters, each highlighted by a specific color: red, green, yellow, blue, light blue, purple, orange, brown, light purple, and pink.

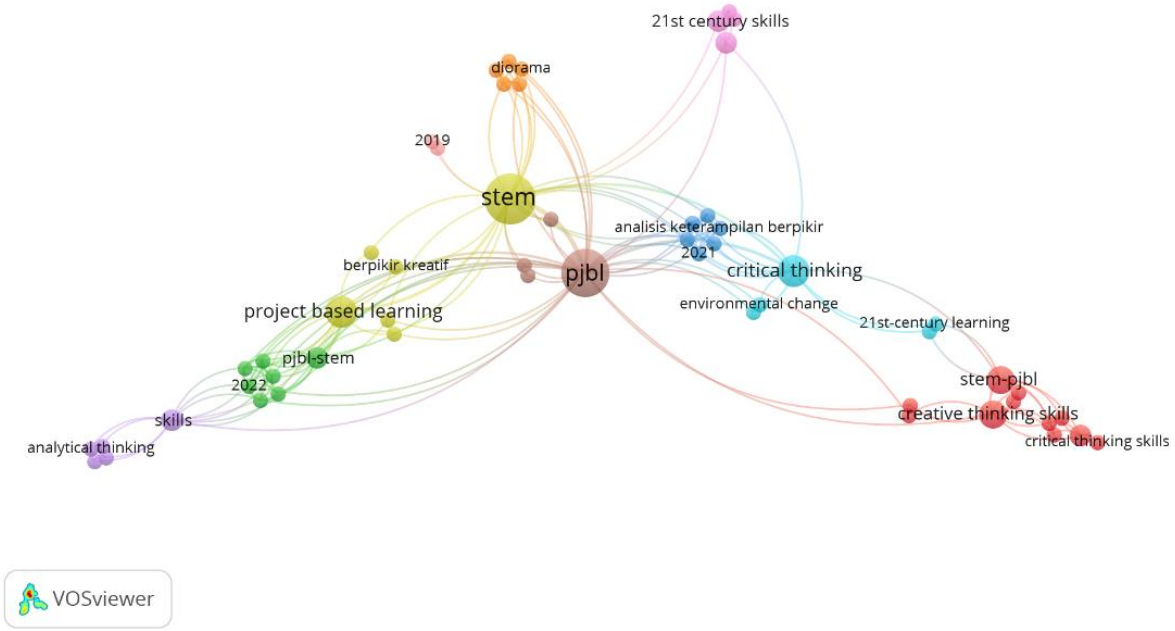

Figure 2. Network Visualization of Each Cluster

This mapping provides a comprehensive representation of the bibliometric network structure for research on the PjBL-STEM model in relation to 21st-century skills. The clustering distinctly highlights bibliometric groupings, with each color signifying a different cluster. The proximity between words illustrates the closeness of their relationship, while the text size indicates the frequency of their occurrence.

Each circle in Figure 2 represents keywords frequently identified in the metadata, with the circle's size corresponding to the number of publications associated with that keyword. Larger circles indicate a higher number of related publications. Keywords that are adjacent and frequently co-occur are positioned closer together. In VOSviewer, the relationships between keywords, depicted as connected circles, demonstrate the importance and relevance of a keyword within the research network. The size of the circles directly reflects the frequency of a keyword's appearance in the analyzed documents. For instance, if the keyword 'STEM-PjBL' appears more prominently than keywords like '21st Century Skills' or 'Creative Thinking Skills,' it suggests that 'STEM-PjBL' occurs more frequently in the dataset. This implies the topic's significant dominance or influence, as it represents a primary focus in numerous studies. Moreover, the circle size also indicates the extent to which a keyword connects with others in the network. Keywords with larger circles often serve as central nodes, linking various concepts and sub-topics within the field. For example, 'STEM-PjBL' may act as a focal point, bridging different aspects of research on STEM and project-based learning. Such keywords signify their importance both in terms of frequency and their role in shaping the research network. The visualization results of the 10 clusters, highlighting the interconnections and thematic groupings, are summarized in Table 5.

Table 5. Clusters Based on Frequently-Occurring Keywords

Cluster	Colors	Item	Frequently Occurring Keywords
1	Red	11	STEM-PjBL, 21st-century learning, n-gain, concept mastery, STEM from home, creative thinking skills, critical thinking skills
2	Green	7	PjBL-STEM, fisika, improve problem-solving, 21st-century learning, 2022, implementation of STEM integration, problem-solving skill.
3	Yellow	6	STEM, berpikir kreatif, *student activeness*, students, PjBL, critical thinking ability
4	Blue	6	Dampak PjBL-STEM, *self-effiacy*, *effiacy* peserta didik analisis keterampilan berfikir kritis, IPA, 2021
5	Light blue	5	*Critical thinking*, environmental change, project-based learning, digital book, 21st-century learning
6	Purple	5	etno-stem, analytical thinking, skills, natural science, effectiveness
7	Orange	5	Elementary school, diorama, environmental attitude, scientific literacy, student
8	Brown	4	PjBL, *high level thinking skills*, penguasaan konsep, kemampuan berpikir analitis
9	Light purple	4	STEM learning, generation z, 21st-century skills, science
10	Pink	2	Augmented reality, 2022

The following analysis visualizes the overlays shown in color. The colors depict research trends by year. Dark colors indicate older studies; the most recent research is in yellow (Figure 3). The following terms reflect current research trends: Project-Based Learning, 21st-century skills, STEM-PJBL, and creative thinking skills.

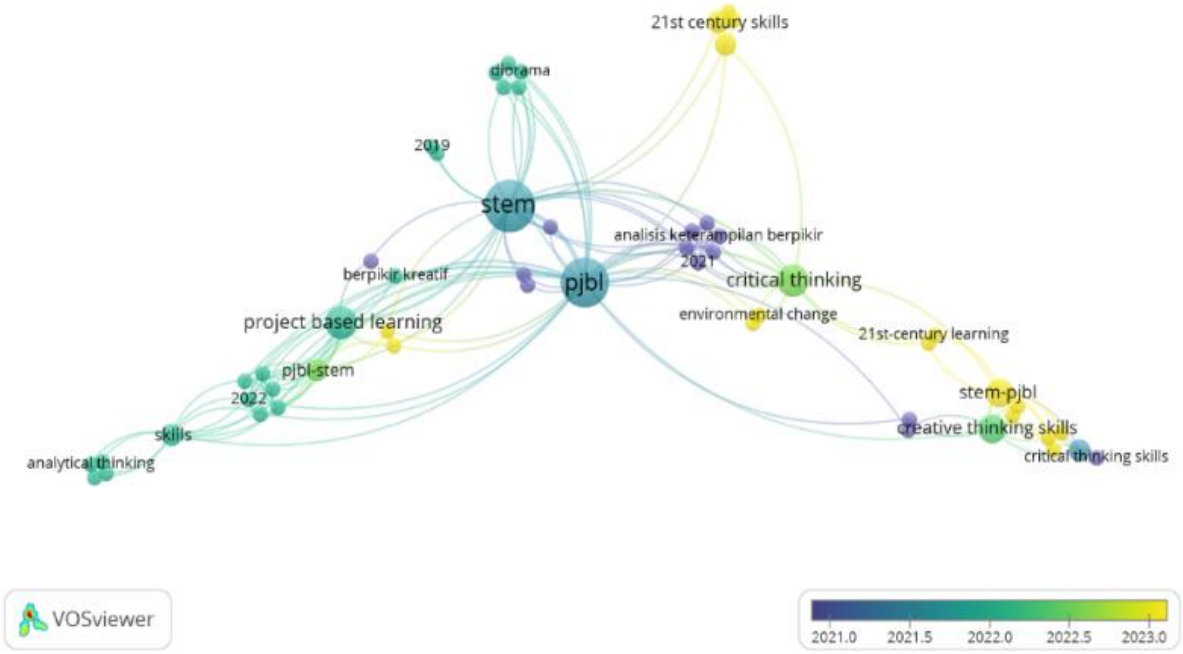

Figure 3. Overlay Visualization

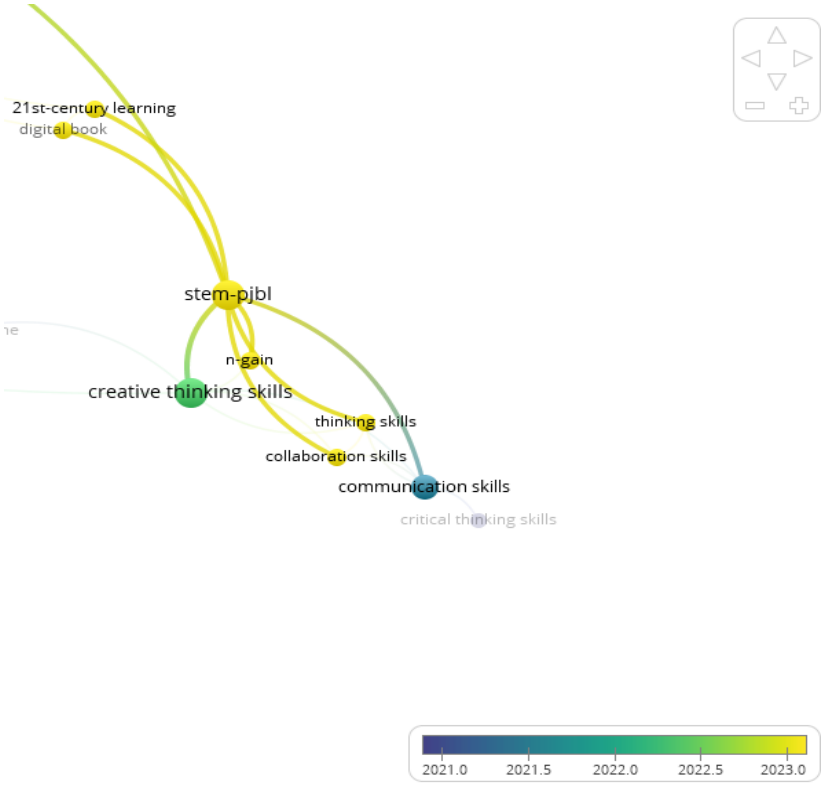

Figure 4. Overlay Visualization

As seen in Figure 4, current study trends are indicated in yellow and have not been extensively connected. This offers a chance to conduct experiments connecting PjBL-STEM to collaboration and communication abilities.

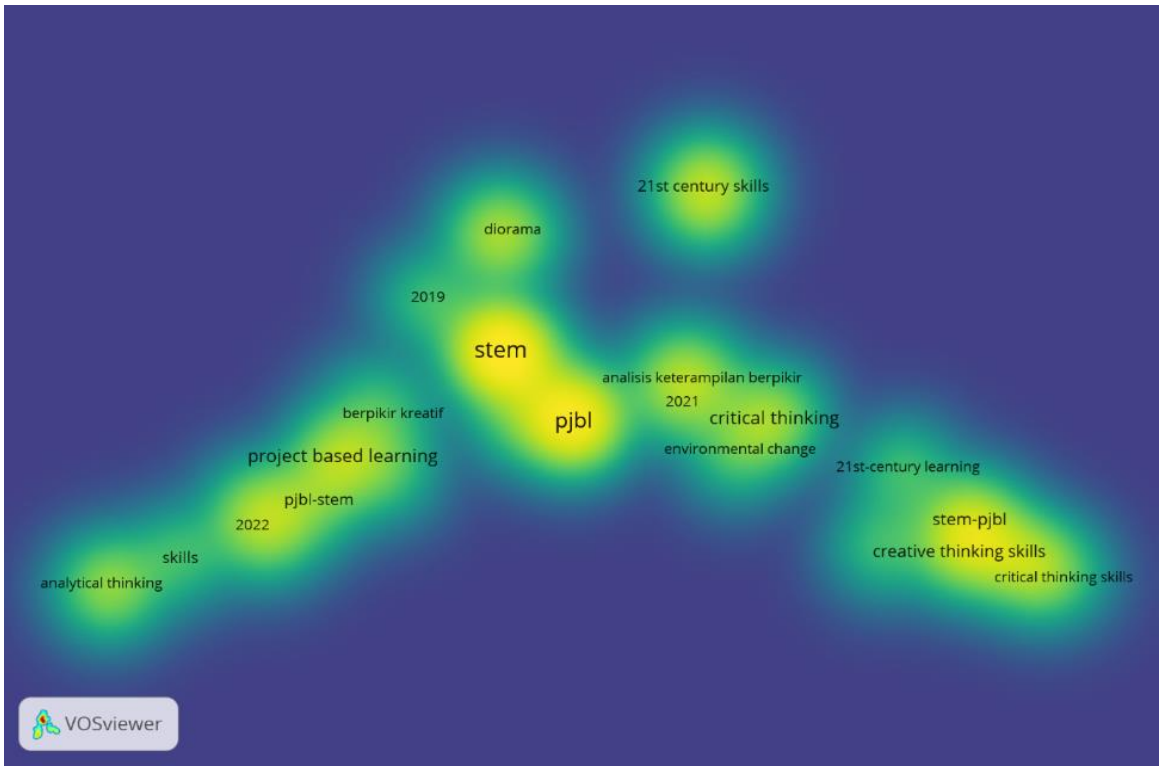

Figure 5. Density Visualization

Figure 5 shows that some topics, including keywords like "analytical thinking skills, 21st-century learning, and diorama," have not been widely researched.

The Impact of PJBL-STEM in Science Learning

Integrating STEM with problem-based learning aims to equip students with essential skills, including problem-solving, decision-making, forming hypotheses, conducting investigations, and evaluating results to address real-world challenges. This approach supports the development of critical thinking as an integral part of the learning process. The PjBL model emphasizes a student-centered methodology, where learners take an active role in their education, with teachers acting as facilitators (Nurbaiti et al., 2016). The PjBL-STEM model encourages students to engage in meaningful learning through project-based activities, enabling them to investigate and comprehend concepts. This method promotes active participation, fostering the development of critical, creative, and analytical thinking skills, as well as higher-order thinking abilities (Jeniver et al., 2023). For instance, an ice cream-making project demonstrates the practical application of this model. Students explore the scientific principles behind lowering the freezing point of a solution, design an optimal ice cream formula, and consider entrepreneurial aspects such as cost management and marketing strategies. This activity cultivates creativity by challenging students to innovate and fosters analytical thinking as they resolve manufacturing issues (Triastuti, 2020). Another example is constructing a miniature bridge using materials such as cardboard, straws, or ice cream sticks. In this project, students apply physics concepts like structure and balance, incorporate technology in their designs, and use mathematical calculations to ensure the bridge's strength and stability. Such activities not only enhance conceptual understanding but also strengthen collaboration and problem-solving skills. Research further suggests that implementing the PjBL-STEM model in science education boosts student creativity. By engaging in challenging projects, learners are encouraged to think innovatively, generate ideas, and apply them to real-world scenarios. This process enhances their critical and analytical thinking abilities, preparing them to tackle complex problems effectively (Storina, 2022).

The Effect of the PjBL-STEM Model on 21st-Century Skills

The PjBL-STEM model consistently enhances students' critical, analytical, and creative thinking abilities. This improvement is evidenced by the results of N-gain tests and paired sample t-tests, which demonstrate significant progress in these skills before and after implementing the model. The application of PjBL-STEM has proven effective in advancing students' scientific literacy, environmental awareness, and academic performance across various subjects, including science, biotechnology, and physics. This approach enables students to work both independently and collaboratively in groups, fostering deeper knowledge acquisition and encouraging teamwork. By integrating science, technology, engineering, and mathematics, the PjBL-STEM model equips students with the skills needed to address complex problems innovatively and systematically. It shapes learners into competent, critical, creative, and adaptable individuals prepared to meet the challenges of the 21st century. This teaching method supports the development of problem-solving abilities in a structured and interdisciplinary manner, ensuring students are better equipped for global demands (Tabun et al., 2019; Afriana, 2022; Karlina et al., 2023).

Implications and Limitations of the Research

This study has provided an in-depth mapping and categorization of STEM-integrated PjBL (Project-Based Learning) research themes, derived from 30 articles collected via the Publish or Perish software and the Google Scholar database. By utilizing VOSviewer for visualizing the metadata from Publish or Perish, key focus areas of STEM-integrated PjBL research have been identified. The network visualization revealed underexplored areas, such as the relationship between STEM-PjBL and communication skills, as well as STEM-PjBL and collaboration skills.

The findings suggest that the PjBL-STEM model holds significant potential for enhancing communication and collaboration skills, which are essential components of 21st-century competencies.

To maximize its impact, future research—both quantitative and qualitative—is needed to develop a professional development program for teachers under the framework of the Merdeka Curriculum. This would enhance educators' preparedness for implementing PjBL-STEM effectively.

Practical Applications in the Merdeka Curriculum

The insights from this research can be practically applied to the Merdeka Curriculum through several strategic initiatives: First, the mapping results can serve as a foundation for designing teacher training programs that focus on competencies in planning and implementing project-based learning using the STEM approach. These programs can include practical guidance and simulations that involve real-world projects, such as designing simple technological prototypes or addressing environmental challenges aligned with the Merdeka Curriculum. Second, the findings can guide the creation of flexible, project-based learning modules tailored to the Merdeka Curriculum's characteristics. These modules can include detailed project scenarios, step-by-step implementation instructions, and guidelines for cross-disciplinary integration using STEM principles. Teachers can leverage these resources to help students develop the Pancasila Learner profile, particularly in critical thinking and independence. Third, the research highlights the importance of allocating dedicated time for project-based learning in school schedules. This allows educators and students to focus on the design, development, and reflection phases of their projects, enhancing learning outcomes and fostering deeper engagement. First, the study advocates for the formulation of specific assessment criteria tailored to PjBL-STEM under the Merdeka Curriculum. These criteria could measure critical thinking, collaboration, and the application of STEM concepts in real-world contexts. Such holistic assessments ensure that the evaluation process aligns with the curriculum's objectives. While this research has identified significant opportunities for STEM-integrated PjBL, its reliance on metadata visualization and secondary sources limits the depth of direct empirical evidence. Future studies could address this limitation by conducting longitudinal and experimental research to validate the practical applications and implications highlighted in this study.

CONCLUSION

This article aims to offer research recommendations on the implementation of the STEM-integrated PjBL (Project-Based Learning) model, focusing on its impact on students' 21st-century skills. It also highlights underexplored research trends related to STEM-integrated PjBL by analyzing 30 research articles from Indonesian and English journals. The findings indicate that applying the STEM-based PjBL learning model significantly enhances students' 21st-century skills, including critical thinking, creativity, collaboration, communication, mastery of concepts, and problem-solving. These skills are essential for preparing students to tackle complex global challenges. However, the analysis also revealed that the integration of PjBL-STEM has not been extensively studied in relation to collaboration and communication skills, presenting a valuable opportunity for future research. To maximize the potential of PjBL-STEM, teachers from related disciplines—science, technology, engineering, and mathematics—can collaborate in designing and implementing projects. Such interdisciplinary efforts enable students to recognize the connections between fields while addressing real-world problems. Additionally, effective time management and the integration of technology, such as simulation software, digital design tools, and online collaboration platforms, are critical for the successful implementation of STEM-integrated PjBL. A supportive learning environment further enhances the model's effectiveness, fostering deeper engagement and better learning outcomes.

REFERENCES

Afriana, J. (2022). Pengaruh PjBL STEM terhadap Literasi Sains dan Problem Solving Siswa SMP. *Jurnal Didaktika Pendidikan Dasar*, *6*(2), 627–638. https://doi.org/10.26811/didaktika.v6i2.551

Allanta, T. R., & Puspita, L. (2021). Analisis keterampilan berpikir kritis dan self efficacy peserta didik: Dampak PjBL-STEM pada materi ekosistem. *Jurnal Inovasi Pendidikan IPA*, *7*(2), 158–170. https://doi.org/10.21831/jipi.v7i2.42441

Dewi, N. N. S. K., Arnyana, I. B. P., & Margunayasa, I. G. (2023). Project Based Learning Berbasis STEM: Meningkatkan Kemampuan Berpikir Kritis dan Hasil Belajar Siswa. *Jurnal Ilmiah Pendidikan Profesi Guru*, *6*(1), 133–143. https://doi.org/10.23887/jippg.v6i1.59857

Fani, Z. A., & Rukmana, E. N. (2022). Penelitian penerapan SLiMS dalam pengolahan perpustakaan pada database Google Scholar: sebuah narrative literature review. *Informatio: Journal of Library and Information Science*, *2*(1), 29. https://doi.org/10.24198/inf.v2i1.37428

Firmantara, M. R., & Handayani, D. (2023). Pengaruh STEM-PjBL terhadap Keterampilan Berpikir Kreatif Siswa MTS. *JIPM*, *12*(1), 179–193. https://doi.org/10.25273/jipm.v12i1.14604

Fitriyani, A., Toto, T., & Erlin, E. (2020). Implementasi Model PjBL-Stem Untuk Meningkatkan Keterampilan Berpikir Tingkat Tinggi. *Bioed : Jurnal Pendidikan Biologi*, *8*(2), 1. https://doi.org/10.25157/jpb.v8i2.4375

Husna, A. R. (2020). Analisis Keterampilan Berbicara Siswa Kelas IV SDN 1 Sripendowo Ketapang Lampung Selatan Dalam Pembelajaran Tematik. *FITK UIN Syarif Hidayatullah Jakarta*. https://repository.uinjkt.ac.id/dspace/handle/123456789/54417

Ichsan, I., Suharyat, Y., Santosa, T. A., & Satria, E. (2023). Effectiveness of STEM-Based Learning in Teaching 21 st Century Skills in Generation Z Student in Science Learning: A Meta-Analysis. *Jurnal Penelitian Pendidikan IPA*, *9*(1), 150–166. https://doi.org/10.29303/jppipa.v9i1.2517

Jeniver, Muhyiatul, F., & Heffi, A. (2023). Literature Review: Pengaruh Model Pembelajaran PjBL (PROJECT-BASED LEARNING) Terhadap Keterampilan Berpikir Kritis Peserta Didik. *BIOCHEPHY*, *03*(1), 10–20.

Karlina, C. M., Susilowati, E., & Fakhrudin, I. A. (2023). Pengaruh Model Pembelajaran STEM-PJBL terhadap Kemampuan Berpikir Kreatif Siswa SMP Negeri 1 Slogohimo Wonogiri di Era Pandemi pada Materi Hidrosfer. *JagoMIPA: Jurnal Pendidikan Matematika Dan IPA*, *3*(1), 33–41. https://doi.org/10.53299/jagomipa.v3i1.270

Karmila, & Putra, P. P. (2022). Pengaruh Pembelajaran STEM (Science, Technology, Engineering, and Mathematics)Terhadap Keterampilan Berpikir Kreatif Siswa. *Jurnal Literasi Digital*, *2*(1), 11–20.

Kemendikbud, 2018. (2014). *The Regulation of the Minister of Education and Culture No. 59 in 2014 about 2013 Curriculum for Senior High Schools*.

Kurniahtunnisa, K., Anggraito, Y. U., Ridlo, S., & Harahap, F. (2023). STEM-PjBL Learning: The Impacts on Students' Critical Thinking, Creative Thinking, Communication, and Collaboration Skills. *Jurnal Penelitian Pendidikan IPA*, *9*(7), 5007–5015. https://doi.org/10.29303/jppipa.v9i7.2985

Lestari, M., Supriyadi, & Sulhadi. (2023). The Growth of Vocational High School Students ' 4C Skills on the Use of PjBL STEM-Based Physics Digital Module. *Physics Communication*, *7*(37), 63–70.

Millen, N. R., & Supahar. (2023). The Effectivity Study : Implementation of the Physics e-Module with PjBL-STEM Model to Describe Students ' Creative Thinking Skills and Learning Motivation Profile. *Journal of Science Education Research*, *7*(2), 8–10.

Miranty, A. A., Ahmad, H., & Jaelani, A. K. (2020). Pengaruh model pembelajaran kooperatif berbantuan scramble terhadap hasil belajar tema 1 alat gerak hewan dan manusia kelas v gugus 5 kecamatan selaparang tahun ajaran 2019/2020. *Progres Pendidikan*, *1*(1), 42–51. http://prospek.unram.ac.id/index.php/PROSPEK/article/view/7

Mirfaka, A., & Kumala, F. N. (2023). Peningkatan Kemampuan Berpikir Kritis dan Sikap Kreatif Siswa Kelas V Melalui Model Pembelajaran PJBL-STEM Berbantuan

Media Aplikasi Belajar Siklus Air (ABSA) pada Mata Pelajaran IPA di Sekolah Dasar. *Jurnal Pembelajaran, Bimbingan, Dan Pengelolaan Pendidikan*, *3*(7), 637–652. https://doi.org/10.17977/um065v3i72023p637-652

Moammar Qadafi, Andriyani Hastuti, & Jamaluddin. (2022). Pengaruh Model Pembelajaran Project Based Learning (PjBL) Terintegrasi STEM Pada Mata Pelajaran Fisika Untuk Meningkatkan Kemampuan Berfikir Kreatif Peserta Didik SMA TGH Umar Kelayu Tahun Ajaran 2021/2022. *Jurnal Pengabdian Magister Pendidikan IPA*, *5*(2), 223–228. https://doi.org/10.29303/jpmpi.v5i2.1604

Munawwaroh, L., Krisnamurti, C. N., Magdalena, M., & Wahyuni, S. (2023). Peningkatan Keterampilan Berpikir Kritis dengan Menggunakan Model Pembelajaran Project Based Learning (PjBL) berbasis STEM pada Materi Kalor dan Perpindahannya di Kelas V SD Negeri Ploso. *Jurnal Penelitian, Pendidikan Dan Pengajaran: JPPP*, *4*(2), 97–102. https://doi.org/10.30596/jppp.v4i2.15030

Muttaqiin, A. (2023). Pendekatan STEM (Science, Technology, Engineering, Mathematics) pada Pembelajaran IPA Untuk Melatih Keterampilan Abad 21. *Jurnal Pendidikan Mipa*, *13*(1), 34–45. https://doi.org/10.37630/jpm.v13i1.819

Narut, Y. F., & Nardi, M. (2019). Analisis Sikap Peduli Lingkungan Pada Siswa Kelas VI Sekolah Dasar di Kota Ruteng. *Scholaria: Jurnal Pendidikan Dan Kebudayaan*, *9*(3), 259–266. https://doi.org/10.24246/j.js.2019.v9.i3.p259-266

Nasution, F. U., Amanda, N., Galingging, P. I., & Arwita, W. (2024). Permasalahan Kolaborasi Siswa dengan Penerapan Model Project Based Learning (PjBL) di SMA Negeri 14 Medan. *Innovative: Journal Of Social Science Research*, *4*(3), 9800–9807.

Ningrum, R., Rahman, T., & Riandi, R. (2021). Penerapan STEM FROM HOME dengan Model PjBL untuk Meningkatkan Penguasaan Konsep dan Keterampilan Berpikir Kreatif Siswa SMP. *PENDIPA Journal of Science Education*, *6*(1), 299–307. https://doi.org/10.33369/pendipa.6.1.299-307

Novitasari, Febriyanti, R., & Wulandari, I. A. (2022). Students' Worksheet Effectivity Ethnomathematics-Based with STEM Approach to Critical Thinking Ability. *Vygotsky: Jurnal Pendidikan Matematika Dan Matematika*, *4*(1), 57–66.

Nurbaiti, S., Kartijono, N. E., & Herlina, L. (2016). Pengaruh Model Pembelajaran Project Based Learning Materi Sistem Eksresi Terhadap Hasil Belajar Siswa. *Unnes Journal of Biology Education*, *5*(2), 50229. http://journal.unnes.ac.id/sju/index.php/ujbe

Nurfaijah, S., Sumarni, W., Sumarti, S., Kurniawan, C., & Kunci, K. (2021). Pengaruh Project Based Learning Terintegrasi STEM Pada Pembelajaran Hidrolisis Garam Terhadap Keaktifan Siswa. *CiE (Chemistry in Education)*, *10*(2), 33–41. http://journal.unnes.ac.id/sju/index.php/chemined

Oktavia, Z., & Ridlo, S. (2020). Critical Thinking Skills Reviewed from Communication Skills of the Primary School Students in STEM-Based Project-Based Learning Model. *Journal of Primary Education*, *9*(3), 311–320. https://doi.org/10.15294/jpe.v9i3.27573

Parno, Nur'aini, D. A., Kusairi, S., & Ali, M. (2022). Impact of The STEM approach with formative assessment in PjBL on students' critical thinking skills. *Journal of Physics: Conference Series*, *2165*(1). https://doi.org/10.1088/1742-6596/2165/1/012044

Pelle, Y. Y., Ali, U., & Weny, N. A. (2024). Pengaruh Kemampuan Berpikir Kritis dan Keterampilan Komunikasi Bagi Siswa dalam Menjawab Soal Higher Order Thinking Skills (HOTS) di Sekolah Menengah Teologi Kristen Rote Timur. *Apostolos: Journal If Theology and Christian Education*, *4*(3), 101–108.

Pramasdyahsari, A. S., Setyawati, R. D., Aini, S. N., Nusuki, U., Arum, J. P., Astutik, L. D., Widodo, W., Zuliah, N., & Salmah, U. (2023). Fostering students' mathematical

critical thinking skills on number patterns through digital book STEM PjBL. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(7). https://doi.org/10.29333/ejmste/13342

Prayogi, S., Sukaisih, R., Muhali, M., & Asy'ari, M. (2024). Dampak Penerapan Pembelajaran Kooperatif Tipe STAD terhadap Keterampilan Kolaborasi dan Hasil Belajar Siswa dalam Mata Pelajaran Fisika. *Journal of Authentic Research*, *3*(2), 156–173. https://doi.org/10.36312/jar.v3i2.2126

Putri, F. N. (2023). Developing Microsoft Access Based- E-Siska Learning Media for Vocational High School Students Developing Microsoft Access Based- E-Siska Learning Media for …. *Jurnal Pendidikan Administrasi Perkantoran (JPAP)*, *11*(3), 147–159.

Putri, M., & Dwikoranto, D. (2022). Implementation of STEM Integrated Project Based Learning (PjBL) to Improve Problem Solving Skills. *Berkala Ilmiah Pendidikan Fisika*, *10*(1), 97. https://doi.org/10.20527/bipf.v10i1.12231

Putri, Y. A., & Zulyusri. (2022). Development of STEM - Project Based Learning Devices to Train 4c Skills of Students. *Bioeduca: Journal of Biology Education*, *4*(2), 1–11.

Rahmania, I. (2021). Project Based Learning (PjBL) Learning Model with STEM Approach in Natural Science Learning for the 21st century. *Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences*, *4*(1), 1161–1167. https://doi.org/10.33258/birci.v4i1.1727

Ridha, M. R., Zuhdi, M., & Ayub, S. (2022). Pengembangan Perangkat Pembelajaran PjBL berbasis STEM dalam Meningkatkan Kreativitas Fisika Peserta Didik. *Jurnal Ilmiah Profesi Pendidikan*, *7*(1), 223–228. https://doi.org/10.29303/jipp.v7i1.447

Rusminati, S. H., & Juniarso, T. (2023). Studi Literatur: STEM untuk Menumbuhkan Keterampilan Abad 21 di Sekolah Dasar. *Journal on Education*, *5*(3), 10722–10727. https://doi.org/10.31004/joe.v5i3.1974

Sartika, S. B., Efendi, N., & Wulandari, F. E. (2022). Efektivitas Pembelajaran IPA Berbasis Etno-STEM dalam Melatihkan Keterampilan Berpikir Analisis. *Jurnal Dimensi Pendidikan Dan Pembelajaran*, *10*(1), 1–9. https://doi.org/10.24269/dpp.v10i1.4758

Sastradiharja, E. . J., Nawawi, M. A., & Muhsinah, L. (2023). Komunikasi Intersubjektif untuk Peningkatan Kemampuan BerpikirKritis Siswa di SMP Islam Plus Az-Zahra Kota Depok. *Jurnal Pendidikan Tambusai*, *7*(1), 3941–3945.

Solihin, R. R., Susanto, T. T. D., Fauziyah, E. P., Yanti, N. V. I., & Ramadhania, A. P. (2024). The Efforts of Indonesian Government In Increasing Teacher Quality Based On PISA Result In 2022: A Literature Review. *Perspektif Ilmu Pendidikan*, *38*(1), 57–65. https://doi.org/10.21009/pip.381.6

Storina, R. (2022). Implementasi Model PJBL-STEM terhadap Kreativitas Siswa pada Mata Pelajaran IPA di SMP Negeri 5 Batam. *Biodidak*, *2*(2), 87–93. https://journal.unrika.ac.id

Tabun, Y. F., Sunarno, W., & Sukarmin. (2019). Problem Based Learning, Kemampuan Berpikir Kritis, Kerjasama dan Hasil Belajar Siswa Smp. *Proceeding of Biology Education*, *3*(1), 58–63. https://doi.org/10.21009/pbe.3-1.8

Tipani, A., Toto, & Yulisma, L. (2019). Implementasi Model PjBL Berbasis STEM Untuk Meningkatkan Penguasaan Konsep dan Kemampuan Berpikir Analitis Siswa. *Bio Educatio*, *4*(2), 70–76. http://www.jurnal.unma.ac.id/index.php/BE/article/view/1700

Triastuti, E. (2020). Model Pembelajaran STEM PJBL Pada Pembuatan Ice Cream Melatih Keterampilan Berfikir Kreatif dan Wirausaha. *Ideguru: Jurnal Karya Ilmiah Guru*, *5*(2). https://doi.org/10.51169/ideguru.v5i2.159

Winarni, E. W., KARPUDEWAN, M., KARYADI, B., & GUMONO, G. (2022). Integrated PjBL-STEM in Scientific Literacy and Environment Attitude for Elementary School. *Asian Journal of Education and Training*, *8*(2), 43–50. https://doi.org/10.20448/edu.v8i2.3873

Wulandari, C. yu, Rahmaniati, R., & Hikmah Kartini, N. (2021). Peningkatan Keterampilan Kolaborasi dan Hasil Belajar dengan Menggunakan Model Pembelajaran Teams Games Tournament. *Pedagogik: Jurnal Pendidikan*, *16*(1), 1–11. https://doi.org/10.33084/pedagogik.v16i1.2331

Wulanningtyas, M. E., Ester, C., Hutabarat, M., Panjaitan, H., Fisika, P. S., & Katolik, U. (2023). Smart City: Pembelajaran Berbasis Proyek Terintegrasi STEM. *Prosiding SENANTIAS: Seminar Nasional Hasil Penelitian Dan PkM*, *4*(1), 178–182.

Yanuar. (2018). Unit Pembelajaran STEM Mata Pelajaran IPA SMP Energi dan Daya Listrik. *SEAMEO Regional Center for QITEP in Science*.

Yulaikah, I., Rahayu, S., & Parlan, P. (2022). Efektivitas Pembelajaran STEM dengan Model PjBL Terhadap Kreativitas dan Pemahaman Konsep IPA Siswa Sekolah Dasar. *Jurnal Pendidikan: Teori, Penelitian, Dan Pengembangan*, *7*(6), 223. https://doi.org/10.17977/jptpp.v7i6.15275