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Can Students' Scientific Literacy and Critical Thinking Skills be Improved through the Development of Science Teaching Materials with a STEM-integrated Project Based Learning (PjBL) Model? (A Systematic Review)

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Abstract: In an era where innovation and problem-solving are central to scientific and technological advancement, education must equip students with the necessary skills to navigate complex challenges. Science literacy and critical thinking have become pivotal competencies in the 21st century. Integrating STEM (Science, Technology, Engineering, and Mathematics) into Project-Based Learning (PjBL) has emerged as a promising pedagogical strategy to nurture these skills. This research aims to identify and analyze research trends of STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. This research method is descriptive and analytical. The data used in this research was obtained from documents indexed by Google Scholar from 2016-2025 using Publish or Perish and Dimension.ai. Research procedures use PRISMA guidelines. The data identified and analyzed are the type of publication, publication source, and the title of research abaout the topic that is widely cited. The data analysis method uses bibliometric analysis assisted by VOS viewer software. The results of the analysis show that research trend on STEM-integrated PjBL model to improve students' science literacy and critical thinking skills indexed by Google Scholar from 2016 to 2025 has experienced a fluctuating increase. There are many documents in the form of articles, proceedings, chapters and preprints that discuss research into the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. Key words that are often used in research about it are systematic literature review, implementation, development, meta analysis, etc.

Keywords: Critical thinking; Project based learning; Review; Science literacy; STEM

Introduction

21st-century education demands that the younger generation possess scientific literacy and critical thinking skills to face increasingly complex global challenges (González-Pérez & Ramírez-Montoya, 2022; Hu & Bi, 2025; Ke et al., 2021; Valladares, 2021). Scientific literacy includes the ability to understand basic scientific concepts, apply them in everyday life, and make informed decisions based on available information (Ke et al., 2021; OECD, 2023; Roberts & Bybee, 2014). Critical thinking skills involve the ability to analyze, evaluate,

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and synthesize information to solve problems effectively (Facione, 2011; Halpern, 1998, 2013; Sharma et al., 2022).

However, in reality, Indonesian students' scientific literacy and critical thinking skills remain at concerning levels. Several studies reveal that students' critical thinking skills are still low. Senior high school students' critical thinking skills fall under the low category, with an achievement rate of only 31.38%. Similarly, junior high school students' skills in evaluation, analysis, and self-regulation are the least developed sub-skills (Ariani, 2020; Basri & As'ari, 2019).

This condition is also reflected in classroom practices, including at the junior high school level. Observations show that students' scientific literacy and critical thinking have not shown significant improvement. Although various strategies such as digital media, experiments, group discussions, and independent assignments have been implemented, the outcomes remain suboptimal. This is due to the lack of holistic approaches, insufficiently applicable teaching materials, and assessments that do not deeply measure students' scientific literacy and critical thinking.

The development of science teaching materials based on project-based learning (PjBL) integrated with STEM (Science, Technology, Engineering, and Mathematics) is one solution to address these issues. PjBL provides students with opportunities to learn through real-world experiences, solve problems, and develop projects relevant to their lives (Guo et al., 2020; Purwaningsih et al., 2020; Asfihana et al., 2022). Integrating STEM makes learning more meaningful by connecting science with technology, engineering, and mathematics. This approach helps students understand theoretical concepts and apply them in practical contexts (Davidi et al., 2021; Kelley & Knowles, 2016; Le et al., 2023; McDonald, 2016).

Science teaching materials using the PjBL-STEM model are designed to meet 21st-century learning needs by emphasizing mastery of concepts and applicable skills. This approach offers active and collaborative learning experiences in which students identify real-world problems, design solutions, and evaluate outcomes. In this context, teaching materials serve as the main guide for students and teachers to implement project-based learning integrated with STEM (Wieselmann et al., 2022; Lou et al., 2017; Meichtry, 1993). Innovative and relevant teaching materials encourage students to be more active, increase motivation, and deepen their understanding of scientific concepts (Fitria et al., 2023; Kurniahtunnisa et al., 2023). This aligns with research indicating that the PjBL-STEM model positively impacts student learning outcomes.

Previous studies support the effectiveness of this approach. For example, PjBL-STEM has been found effective in fostering high school students' creative, collaborative, and communicative thinking skills (Al-Ali, 2024). Moreover, the integration of STEM in project-based learning helps students develop analytical abilities, creativity, and problem-solving skills (Hebebci & Usta, 2022; Sucilestari et al., 2023). Both PjBL and STEM learning are active learning models that have proven effective in improving various student competencies (Aldi et al., 2022).

These findings demonstrate that PjBL-STEM teaching materials hold great potential in enhancing the scientific literacy and critical thinking skills of Indonesian students. These materials are not only designed to improve student outcomes but also support the learning objectives of the Merdeka Curriculum, which emphasizes flexible, contextual, and student-centered learning. As such, they can be adapted for use in various learning environments (Fahlevi, 2022; Zaeni et al., 2023).

Therefore, this research wants to know the research trend of the use of science teaching materials with a STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. It is hoped that this research can become a reference in developing further research related to the topic.

Method

This research method is descriptive and analytical, which aims to understand and describe research trends in the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. The data used in this study was obtained from information sources indexed by Google Scholar using analytical tools such as Publish or Perish and Dimension.ai. Article searches were conducted using the keywords PjBL AND STEM OR 'science learning' OR science literacy OR critical thinking. In this research, an analysis was carried out on 1,000 documents that had been indexed by Google Scholar between 2016 and 2025. The Google Scholar database was chosen as a place to search for documents because Google Scholar applies consistent standards in selecting documents to be included in its index, and Google Scholar displays more documents than the top databases. Others, especially research in the field of education (Hallinger et al., 2019, 2020; Zawacki-Richter et al., 2019). To filter data that has been collected via Publish or Perish, researchers used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.

Result and Discussion

This research aims to describe research trends on STEM-integrated PjBL model to improve students'

science literacy and critical thinking skills conducted from 2016 to 2025. Research documents on research trends about the topic are taken from documents from 2015 to 2024. Figure 1 is presented below regarding research trends on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills.

Figure 1 shows that the trend in research on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills from 2016 to 2025 has increased. Where the research trend is with an increase in the number of publications every year, namely from 2016 to 2024. However, in 2025 the research trend on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills experienced a decline because the analysis was conducted in the middle of the year, so the research trend is likely to increase until the end of 2025. The increasing trend in the research caused by 21st century education has focused on improving various kinds of competencies, like science literacy and critical thinking skills.

In 2016 there were 4 publications related to the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills, then this will continue to increase to 357 publications in 2024. This increasing research trend provides a deeper understanding the problem which is low of science literacy and critical thinking skills in science learning and ways to solve that problem. Based on thr research, the ways to improve of science literacy and critical thinking through various methods, one of them is project based learning model combined with STEM. Below are also table 1 presented research of STEM-integrated PjBL model to improve students' science literacy and critical thinking skills based on the type of publication.

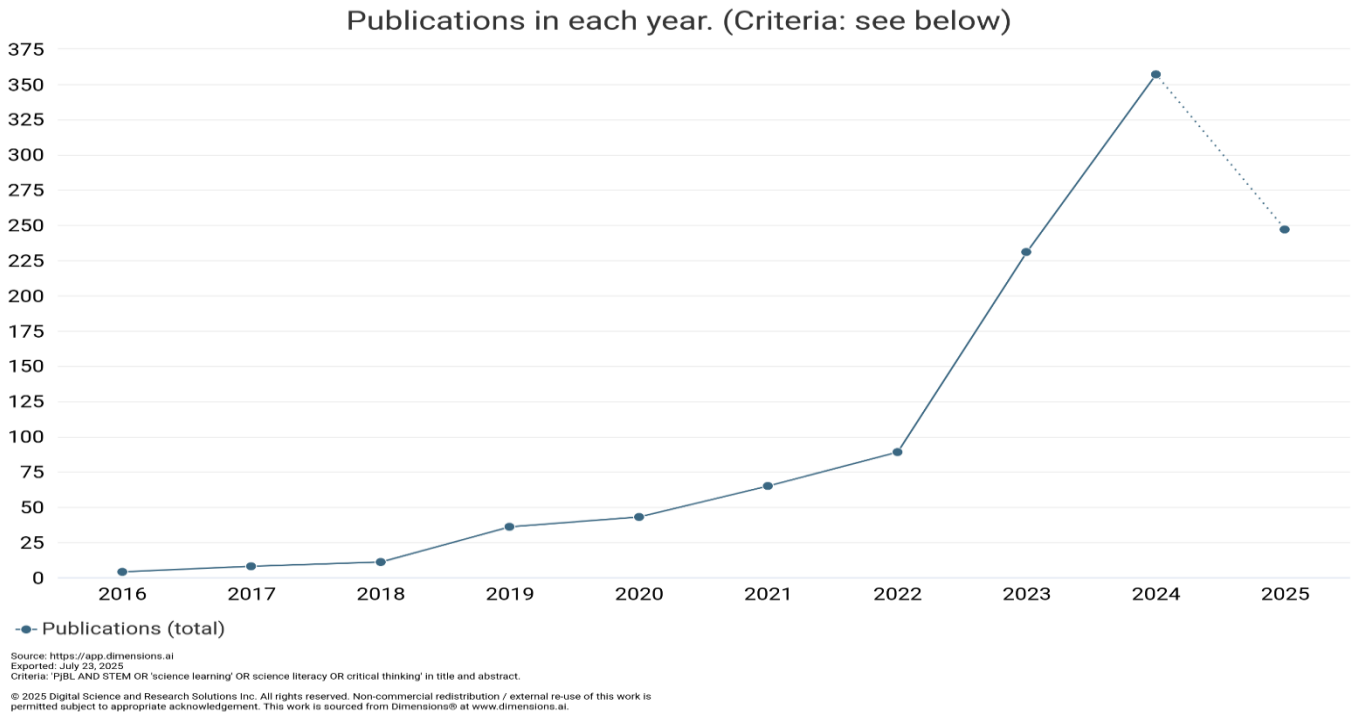

Figure 1. Research trends in STEM-integrated PjBL model to improve students' science literacy and critical thinking skills

Table 1. Trends in STEM-integrated PjBL Model to Improve Students' Science Literacy and Critical Thinking Skills Research Based on Publication Types

Publication Type	Publications
Article	1,036
Proceeding	33
Chapter	23
Preprint	3

Based on Table 1, it is known that research on STEM-integrated PjBL model to improve students' science literacy and critical thinking skills from 2016 to 2025 contained in 4 types of publications. In the form of articles there were 1,036 documents, chapters as many as 23 documents, proceedings as many as 23 documents, and preprints only 3 documents. Research trends STEM-integrated PjBL model to improve students' science literacy and critical thinking skills in article form is the type of publication that contains the most research compared to other types of publications. Meanwhile, the type of publication contains the least amount of the topic is a preprint. Research conducted by Oltarzhevskyi

(2019) states that an article is a complete factual essay of a certain length created for publication in online or print media (via newspapers, magazines or bulletins) and aims to convey ideas and facts that can convince and educate. These articles are usually published in scientific journals both in print and online (Suseno et al., 2020).

Below are also table 2 presented top ten (10) sources title trends in research on STEM-integrated PjBL model to improve students' science literacy and critical thinking skills which are often cited by other researchers related to this matter. Table 2 shows that the most widely published source of research trends on the project based learning model to improve science process skills in science learning is the Jurnal Penelitian Pendidikan IPA, namely 71 publications with 287 citations and an average citation of 4.04. Jurnal Penelitian Pendidikan IPA contains scientific articles form of research results that include science, technology, and teaching in the field of science. The first edition were published in 2015. All edition in this journal are open access, i.e. the articles published in them are immediately and permanently free to read, download, copy & distribute. Below are also table 3 presented top ten (10) article title trends in research on STEM-integrated PjBL model to improve students' science literacy and critical thinking skills which are often cited by other researchers related to this matter.

Table 2. Top 10 Sources Title Trend of STEM-integrated PjBL Model to Improve Students' Science Literacy and Critical Thinking Skills Research in 2016-2025

Name	Publications	Citations	Citations Mean
Jurnal Penelitian Pendidikan IPA	71	287	4.04
Journal of Physics Conference Series	31	286	9.23
AIP Conferences Proceedings	23	54	2.35
Advances in Social Science, Education and Humanities Research	16	31	1.94
KnE Social Science	11	10	0.91
Jurnal Pendidikan MIPA	10	0	-
Jurnal Pendidikan Sains Indonesia	9	3	0.33
JPBI (Jurnal Pendidikan Biologi Indonesia)	7	42	6.00
AL-ISHLAH Jurnal Pendidikan	7	19	2.71
Berkala Ilmiah Pendidikan Fisika	7	21	3.00

Table 3. Top 10 Citations on Trend of STEM-integrated PjBL model to improve students' science literacy and critical thinking skills Research in 2016-2025

Cites/year	Year	Author	Title
97.50	2023	Zulyusri Zulyusri, Ida Elfira, Lufri Lufri, Tomi Apra Santosa	Literature Study: Utilization of the PjBL Model in Science Education to Improve Creativity and Critical Thinking Skills
23.50	2023	A S Pramasdyahsari et al.	Fostering students' mathematical critical thinking skills on number patterns through digital book STEM PjBL
11.00	2021	V R Bulu, F Tanggur	The Effectiveness of STEM-Based PjBL on Student's Critical Thinking Skills and Collaborative Attitude
10.60	2020	H Lestari, I Rahmawati	Integrated STEM through Project Based Learning and Guided Inquiry on Scientific Literacy Abilities in Terms of Self-Efficacy Levels
10.25	2021	Yuli Rahmawati et al.	Developing the critical thinking skills of vocational school students in electrochemistry through STEM - project-based learning (STEM-PjBL)
9.00	2023	S D Indahwati, F Rachmadiarti, E Hariyono	Integration of PJBL, STEAM, and Learning Tool Development in Improving Students' Critical Thinking Skills
8.33	2022	Parno, D A Nur'aini, S Kusairi and M Ali	Impact of The STEM approach with formative assessment in PjBL on students' critical thinking skills
8.00	2023	Korry Nilyani, Asrizal, Usmeldi	The Effect of STEM Integrated Science Learning on Scientific Literacy and Critical Thinking Skills of Students: A Meta-Analysis
5.67	2022	R D Setyawati et al.	Improving Mathematical Critical Thinking Skill through STEM-PjBL: A Systematic Literature Review
3.80	2020	M Muhibbuddin, Nanda Yustina, S Safrida	Implementation Of Project-Based Learning (Pjbl) Model In Growth And Development Learning To Increase The Students' Science Literacy And Critical Thinking Skills

Table 3 shows that research on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills that is widely cited by other researchers is about "Literature Study: Utilization of the PjBL Model in Science Education to Improve Creativity and Critical Thinking Skills" which is 97.50 (Zulyusri et

al., 2023). Then the research entitled "Fostering students' mathematical critical thinking skills on number patterns through digital book STEM PjBL" was cited 23.50 times/year (Pramasdyahsari et al., 2023). Research by Bulu et al. (2021) entitled "The Effectiveness of STEM-Based PjBL on Student's Critical Thinking Skills and Collaborative Attitude" is also widely cited by other researchers, namely 11.00 per year. Lestari et al. (2021) in their research entitled "Integrated STEM through Project Based Learning and Guided Inquiry on Scientific Literacy Abilities in Terms of Self-Efficacy Levels" was cited 10.60 per year.

This research data is comparable to data on the increasing trend of research on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills from 2016 to 2025. This means that in that year, research related to it was continuously cited by other researchers. In the articles researched and written by these researchers, there are many terms/keywords related to STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. Below are presented ten (10) popular keywords related to the topic.

Table 4 shows that one of the keywords that often appear related to research on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills are systematic literature review, 4 occurences with a level of 3.77. This indicates that many researchers have conducted literature review analyses related to the topic of PjBL-STEM to improve students' abilities (Zulyusri et al., 2023; Setyawati et al., 2022). Table 4 also shows that "implementation" is also one of the keyword that appears frequently in research trends on the topic, namely 8 occurences with a relevance of 1.45. Many studies have been conducted by implementing the PjBL model to improve students' high-level skills such as science literacy and critical thinking (Muhibbuddin et al., 2020).

Table 4. Keywords on Trend STEM-integrated PjBL Model to Improve Students' Science Literacy and Critical Thinking Skills Research in 2016-2025

Terms	Occurrences	Relevance
Systematic literature review	4	3.77
Teacher	7	1.81
Development	11	1.49
Implementation	8	1.45
Creative thinking	8	1.16
Meta analysis	5	0.91
Communication	6	0.85
STEM education	8	0.75
Science	13	0.60
Effectiveness	14	0.52

Below are the visualization is accomplished by generating a landscape map, which offers a visual representation of subjects related to scientific studies. The outcomes of bibliometric mapping for the co-word network in articles related to the topic STEM-integrated PjBL model to improve students' science literacy and critical thinking skills are illustrated in Figure 2.

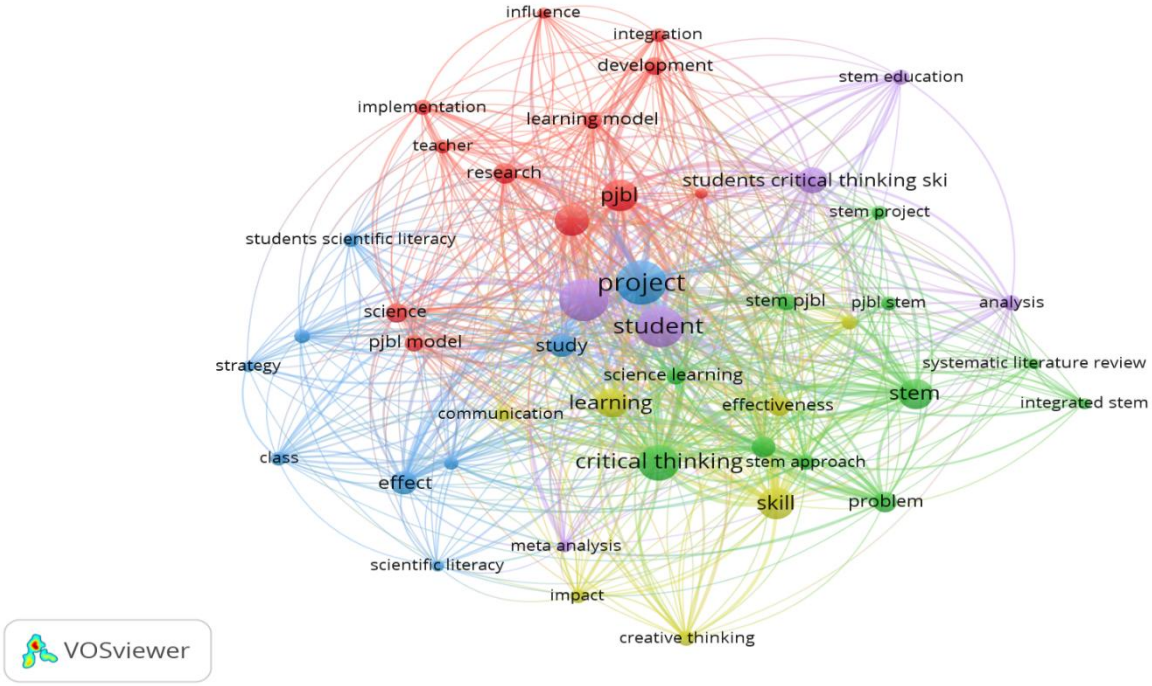

Figure 2. Network visualization on trend STEM-integrated PjBL model to improve students' science literacy and critical thinking skills research

Figure 2 shows the results of bibliometric keyword mapping on research trends on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. In Figure 2 there are 45 keyword items that are often used in research on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills from 2016 to 2025. Figure 2 also contains 5 clusters, where the first cluster is colored red and consists of 12 keyword items, namely development, implementation, learning model, teacher, etc. The second cluster in green consists of 11 keyword items, namely science learning, STEM project, systematic literature review, etc. The third cluster in blue consists of 9 keyword items, namely creativity, project, strategy, etc. The fourth yellow cluster consists of 7 keyword items, namely communication, effectiveness, impact, etc. The fifth purple cluster consists of 6 keyword items, namely analysis, meta analysis, student, etc.

Figure 2 above also shows that network visualization shows the network between the terms being visualized. Keywords classified into five clusters are arranged in a color chart showing the divisions/clusters that are connected to each other. The results of this analysis can be used to determine keyword research trends in the last year. This analysis shows several keywords that are often used in research on the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. The more keywords that appear, the wider the visualization displayed. Below are also presented keywords regarding to the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills based on overlay visualization.

Figure 3 shows the trend of keywords related to research on STEM-integrated PjBL model to improve students' science literacy and critical thinking skills in Google Scholar indexed journals from 2016 to 2025. Trends in the themes of writing articles related to the topic from the oldest to the newest year are marked with purple, blue themes, turquoise, dark green, light green and yellow. In the picture below you can see that keywords like creativity, STEM project, literacy were widely used by researchers in 2020 and 2021. In 2022, the keywords that frequently appeared were systematic literature review, meta analysis, learning model, PjBL STEM, etc.

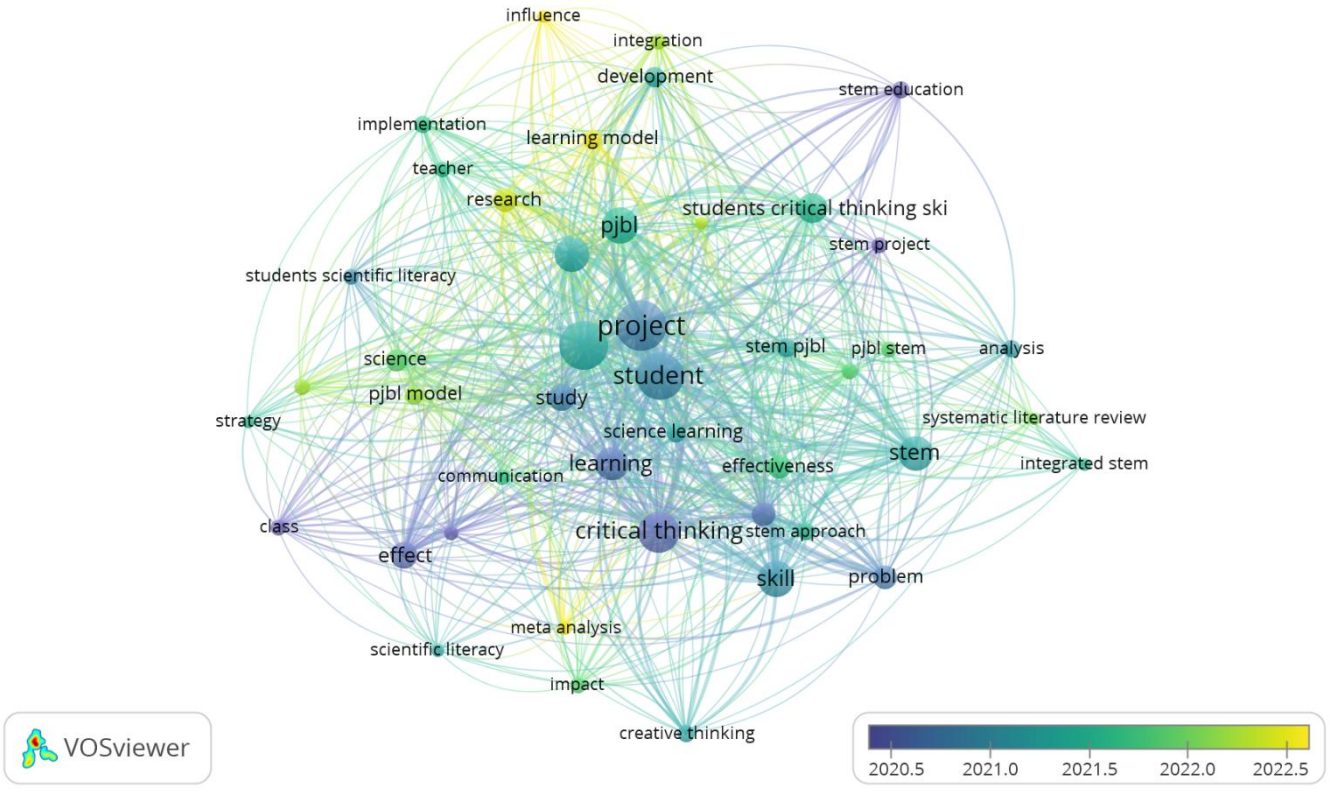

Figure 3. Overlay visualization on trend STEM-integrated PjBL model to improve students' science literacy and critical thinking skills research

Research on STEM-integrated PjBL model to improve students' science literacy and critical thinking skills is one area of research that has developed rapidly in recent years. The following also presents keywords for STEM-integrated PjBL model to improve students'

science literacy and critical thinking skills research based on density visualization.

Figure 4 shows density visualization. The density of research themes is shown in bright yellow. The brighter the colors of a theme, the more research is done. The fainter the color means the theme is rarely researched (Kaur et al., 2022; Liao et al., 2018). Faintly colored themes such as creative thinking, STEM project and learning model are dimly colored keywords. This shows that these keywords can be used as a reference for further research. Doyan et al. (2023) and Bahtiar et al. (2023) stated that yellow indicates keywords that are currently and frequently used in research, like critical thinking, PjBL model, STEM, etc.

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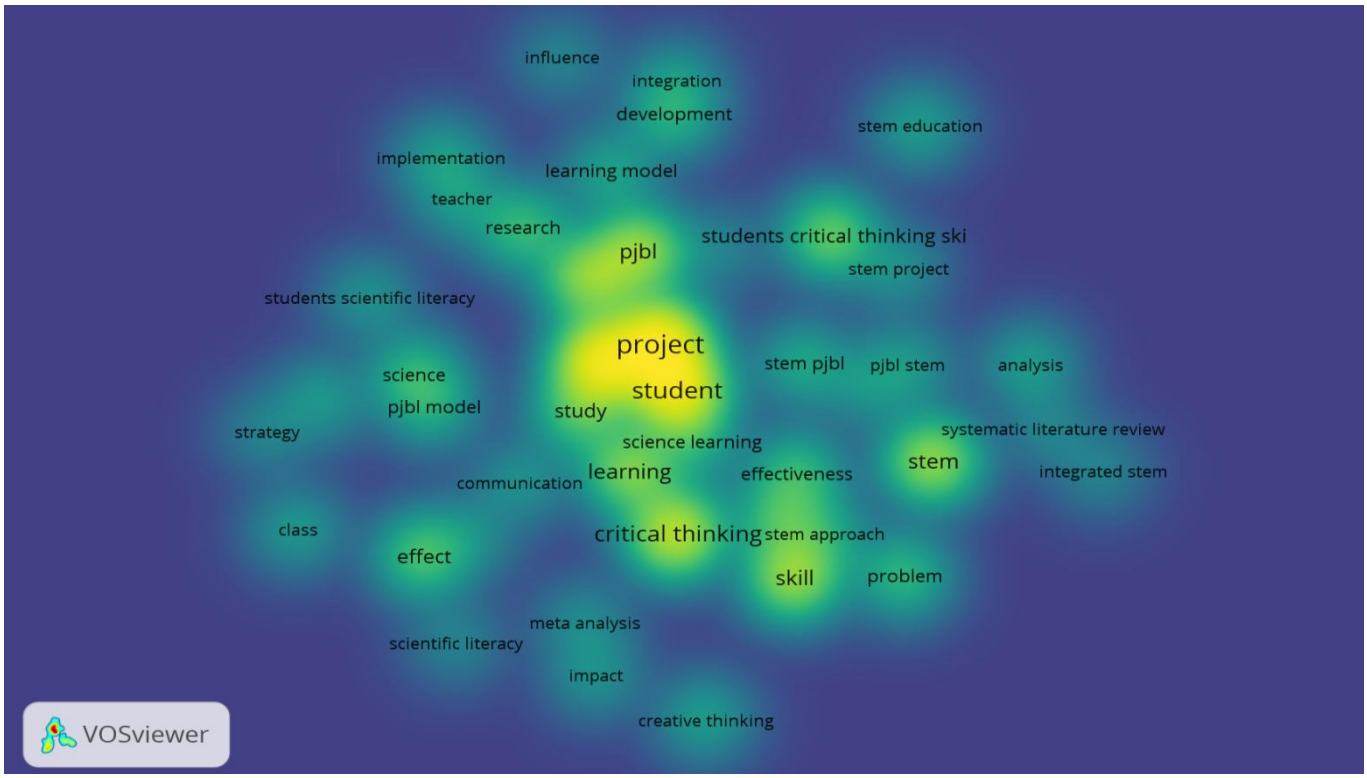

Figure 4. Density visualization on trend STEM-integrated PjBL model to improve students' science literacy and critical thinking skills research

In an era where innovation and problem-solving are central to scientific and technological advancement, education must equip students with the necessary skills to navigate complex challenges. Science literacy and critical thinking have become pivotal competencies in the 21st century. Integrating STEM (Science, Technology, Engineering, and Mathematics) into Project-Based Learning (PjBL) has emerged as a promising pedagogical strategy to nurture these skills (Krajcik & Czerniak, 2018). Project-Based Learning is a student-centered pedagogy in which learners gain knowledge and skills by working over an extended period to investigate and respond to real-world, complex questions or problems (Thomas, 2000). STEM integration within PjBL situates learning in authentic contexts, encouraging interdisciplinary understanding and the application of knowledge across domains (Beers, 2011). This combination allows learners to develop both conceptual understanding and practical skills relevant to contemporary societal issues (Moore et al., 2014).

Science literacy refers to the ability to engage with science-related issues and with the ideas of science as a reflective citizen (OECD, 2019). A number of studies have shown that STEM-integrated PjBL enhances students' understanding of scientific concepts by providing authentic contexts that make science more relevant and meaningful (Hasni et al., 2016). Students exposed to such models are more likely to demonstrate improved reasoning, data analysis, and evidence-based argumentation—core components of science literacy (Kanter & Konstantopoulos, 2010).

For example, Erdogan et al. (2015) found that STEM PjBL environments led to statistically significant gains in middle school students' science achievement and literacy, particularly when projects were long-term and allowed for iterative problem-solving. Additionally, PjBL tasks that encourage exploration and experimentation help students build connections between scientific theories and real-world applications (Krajcik & Shin, 2014).

Critical thinking encompasses skills such as analysis, evaluation, and synthesis, which are essential for problem-solving in STEM fields. STEM-PjBL encourages students to engage in higher-order thinking as they define problems, explore alternative solutions, and justify their decisions with evidence (Hmelo-Silver, 2004). Through collaborative project work, students are prompted to critically assess information sources, question assumptions, and reflect on their learning processes (Bell, 2010). In a meta-analysis by Sahin (2013), PjBL strategies in STEM settings were associated with significant improvements in students' problem-solving and critical thinking abilities, particularly when students were given autonomy and the opportunity to revise and improve their work based on feedback.

Despite its benefits, implementing STEM-integrated PjBL poses challenges. These include the need for teacher training, interdisciplinary curriculum alignment, and sufficient time and resources (Margot & Kettler, 2019). Furthermore, the assessment of both science literacy and critical thinking remains complex, requiring formative tools that capture student growth beyond standardized tests. Overall, STEM-integrated Project-Based Learning has a profound impact on students' science literacy and critical thinking. By situating learning in meaningful, interdisciplinary, and inquiry-based contexts, it fosters skills necessary for informed citizenship and future STEM careers. Continued research and support for teacher professional development are essential to fully realize its potential in diverse educational settings.

Conclusion

Research on trends in the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills has urgency high because of its potential to provide various benefits to 21st century education. The research trend on STEM-integrated PjBL model to improve students' science literacy and critical thinking skills indexed by Google Scholar from 2016 to 2025 has experienced a fluctuating increase. There are many documents in the form of articles, proceedings, chapters and preprints that discuss research into the STEM-integrated PjBL model to improve students' science literacy and critical thinking skills. Key words that are often used in research about it are systematic literature review, implementation, development, meta analysis, etc.

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Conflicts of Interest
No conflict interest.

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