

Building Bridges: How Integrated STEM with Problem-Based Learning Can Enhance Student Critical Thinking and Learning Outcomes in Chemistry

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Abstract. Low critical thinking skills and student learning outcomes are still widely found, especially in chemistry learning. This study aims to analyze the application of STEM integrated problem-based learning (PBL) on chemistry materials, and to analyze STEM-based learning integrated with PBL to improve students' critical thinking skills and learning outcomes on chemistry materials. The method used in this research is a systematic literature review based on articles traced through Google Scholar, Garuda, and ERIC databases. The data obtained was then analysed descriptively. The results showed that: (1) From a number of STEM-PBL implementations that have been carried out in various fields, the implementation of STEM-PBL in chemistry learning obtained a percentage of 32%; (2) STEM-PBL implementation can improve students' critical thinking skills and learning outcomes ranging from moderate to high categories. STEM-PBL learning is effectively used to improve critical thinking skills and learning outcomes, so it can be used as an alternative in chemistry learning.

Keywords: STEM approach, *problem based learning model*, critical thinking skills, learning outcomes.

Introduction

The development of science and technology (IPTEK) is growing rapidly with the presence of the Industrial Revolution 4.0 (Liao et al., 2018). The industrial revolution 4.0 changed the lives and ways of human work in various fields of life, including in the field of education (Afrianto, 2018). Education in the era of revolution 4.0 is characterised by 21st century learning that emphasises participants to be active in finding their own learning resources in order to have broad cognitive abilities (Wulandari & Inggit, 2018). The characteristics of 21st century learning lead to scientific, thematic, contextual, interactive, collaborative, holistic, and learner-centred learning (Muhali, 2019). Furthermore, 21st century learning requires learners to have various 21st century skills which include critical thinking skills, problem solving, communication, collaboration, and creativity (Ismail et al., 2023; Zubaidah, 2019).

The critical thinking skills of Indonesian students are in fact still in the low category. This is evidenced by the results of the PISA score in the field aspect, where Indonesia ranked 71 out of 79 participating countries in 2018 (OECD, 2019). In 2022, students' scores in science decreased compared to 2018, but Indonesia experienced an increase of 6 positions (Marwah & Pertiwi, 2024). In solving PISA questions, high-level thinking skills are needed, one of which is critical thinking skills. This can be interpreted that if the ability in the field of science of students is low, then the critical thinking skills of students are also low (Rahayuni, 2016). The low critical thinking skills of students will also have an impact on low learning outcomes (Ananda & Salamah, 2021). Whereas critical thinking skills are high-level thinking skills (Brookhart, 2020) and skills that are important in the field of education and in the world of work (Kivunja, 2015; Nold, 2017).

Low student learning outcomes, especially in the field of chemistry, are quite common (Erlina et al., 2019; Jamilah et al., 2021; Komang et al., 2014; Priliyanti et al., 2021). The low learning outcomes in several chemistry concepts are influenced by several factors, including: (1) chemical concepts that are abstract and a combination of concept understanding and application are difficult for students to understand, (2) students find it difficult to apply chemical theories, (3) students lack motivation to learn chemistry, and (4) most students consider chemistry a difficult subject (Suswati, 2021). Furthermore, Sudiana et al. (2019) explained that chemistry learning difficulties are a common phenomenon that occurs in various schools. In addition, learning methods that predominantly use conventional models also contribute to low student learning outcomes (Erlina et al., 2019; Jamilah et al., 2021).

Given the complexity of 21st century skills that must be possessed by students, and the low learning outcomes in chemistry, learning innovations are needed that can support mastery of these skills and learning success. According to (McFarlane, 2013) mastering 21st century skills requires complex interactions between scientific disciplines (integrated learning) related to life problems. One of the efforts that can be made is to apply learning models/methods or approaches that are oriented towards 21st century skills (Muhali, 2019). A potential approach to support 21st century skills is the Science, Technology, Engineering, and Mathematic (STEM) approach (Diana et al., 2021). Haatainen & Aksela (2021) explained that education reforms all over the world are now emphasizing similar pedagogical approaches that focus on 21st century skill, for example for STEM education. STEM was found to be effective for improving critical thinking skills (Akcanca, 2020). The STEM approach will encourage students to solve real-life problems not only in science aspects, but also through aspects of technology, engineering, and mathematics (Bybee, 2019). The integrative nature of STEM also allows its application to be combined with various types of learning models or methods (Davidi et al., 2021). Hallström & Schönborn (2019) also explained that global demands bring the Education curriculum to increase the application of STEM learning as 21st century skills.

One of the suitable learning models to be integrated with the STEM approach is problem-based learning (PBL). This is because the science, technology, engineering and mathematics components contained in STEM can be applied in PBL activities (Rahmadani & Anugraheni, 2017). The PBL learning model emphasises students to be able to build their own knowledge in solving problems (Arends, 2012), and is proven to be able to improve higher-order thinking skills in solving contextual problems (Fajrilia, 2019). With the integration of PBL and STEM learning models, not only can it improve learning outcomes

(Cahyaningsih & Roektingroem, 2018; Maulidia et al., 2019; Ningsih, 2020), but it can also improve critical thinking skills (Ariyatun & Octavianelis, 2020; Cahyaningsih & Roektingroem, 2018), science literacy, and student character (Putri et al., 2020). Agussuryani et al. (2022) also explained that the integration of the STEM approach in learning has the potential to equip students' 21st century work skills through learning outcomes. Arisoy & Aybek (2021) further state that practising critical thinking skills in specific disciplines and subject areas contributes to developing students as strong critical thinkers.

The integration between PBL and STEM has been widely implemented in various subjects such as mathematics (Hadi, 2021; Inpinit, 2016; Kim et al., 2019); and Hadi, 2021), physics (Nurazmi & Bancong, 2021; Parno et al., 2019), biology (Amalya et al., 2021; Fadhillah et al., 2022; Hasanah et al., 2021) and chemistry (Ariyatun & Octavianelis, 2020; Prastika et al., 2022). Chemistry, as one of the scientific disciplines, has a central position in the STEM education framework. However, chemistry teaching methods often only emphasise the memorisation of facts and formulas, and ignore the inherent linkages between scientific concepts and real-world applications. Whereas chemistry material is not just memorisation, but requires an understanding of concepts that are interconnected in a meaningful way. Supardi & Putri further explained that learning chemistry requires a variety of diverse learning models. Thus, the STEM approach integrated with PBL is one of the appropriate learning strategies used in the chemistry learning process.

Several previous studies have examined the trend of PBL-integrated STEM research. Herman et al. (2023), examined the integration of PBL with STEM in science learning on critical thinking skills based on articles published in 2020-2021. Suciana et al. (2023) examines the integration of PBL with STEM on student learning outcomes through articles published in 2016-2021. Based on previous research, the integration of PBL with STEM can improve critical thinking skills (Ariyatun & Octavianelis, 2020; Febrianto et al., 2021; Mustofa et al., 2021; Rohmah et al., 2021) and student learning outcomes (Ariyatun & Octavianelis, 2020; Nurazmi & Bancong, 2021). However, studies on the integration of PBL with the STEM approach in chemistry subjects have not been carried out. Based on this, there are differences between previous research and this systematic literature review (SLR), namely the assessment of STEM integrated PBL focused on chemistry learning materials to improve critical thinking skills and student learning outcomes over the last 8 years (2017-2024). This study is important to do because it can be used as a consideration in using the STEM integrated PBL model as an alternative in chemistry learning to train critical thinking skills and student learning outcomes, which will have an impact on the quality of learning.

Methods

This research uses a systematic literature review or known as systematic literature review (SLR). SLR is a research methodology that is carried out by collecting and evaluating research on a particular topic, with the aim of identifying, reviewing, and evaluating all relevant research so as to answer the research questions that have been set (Triandini et al., 2019). This research consists of several stages adapted from Wahyudi & Putra (2022), namely the formulation of research questions, literature search, determination of inclusion and exclusion criteria, selection of literature, presentation, data processing, and conclusion drawing.

The formulation of research questions is carried out to assist in obtaining relevant information. There were two questions formulated in this study, namely: (1) "How much STEM-PBL implementation is applied to chemistry learning?"; and (2) "How is the

improvement of critical thinking skills and student learning outcomes after STEM-PBL implementation in chemistry learning?". Next, the data collection technique was carried out through literature search observations via the Google Scholar, Portal Garuda, and ERIC databases. The keywords used are "PBL-STEM integration", "STEM-PBL integration", "PBL integrated STEM approach implementation", and STEM integrated PBL implementation model".

The next stage is to determine the inclusion and exclusion criteria. This stage aims to facilitate the selection stage that has been obtained previously through several databases. The inclusion and exclusion criteria in this study are presented in Table 1.

Table 1. Inclusion and Exclusion Criteria

No	Category	Inclusion Criteria	Exclusion Criteria
1	Type of publication	Articles published in journal or proceeding	Articles published in website or blog, and other
2	Publication year	2017-2024	Less than 2017
3	Independent variabel	STEM integrated PBL	Not STEM integrated PBL
4	Dependent variabel	Critical thinking and learning outcome	Not Critical thinking and learning outcome
5	Field	Chemistry	Outside of chemistry

The next stage was literature selection. Selection was based on the criteria in Table 1. Articles that do not meet the inclusion criteria based on the selection results will be eliminated. The results of the articles obtained through the selection stage were then reviewed, processed and presented in tabular form. The findings of the various articles then analysed descriptively and compared to answer the formulation of research questions, then summarised to reach a conclusion.

The population in this study came from educational journals published in 20170-2024. Based on the search results, 41 articles were found that integrated the PBL model with a STEM approach. From the 41 articles, a research sample of 12 articles was obtained which met the inclusion criteria as shown in Table 1. The samples obtained were then analyzed descriptively.

Results and Discussion

Application of STEM integrated with PBL in Chemistry

The search results using several databases obtained as many as 38 articles on the integration between the STEM approach and the PBL learning model. The integration between the two is spread across various fields ranging from science, physics, mathematics, biology, and chemistry. The percentage of STEM integration with PBL in each field is presented in Figure 1.

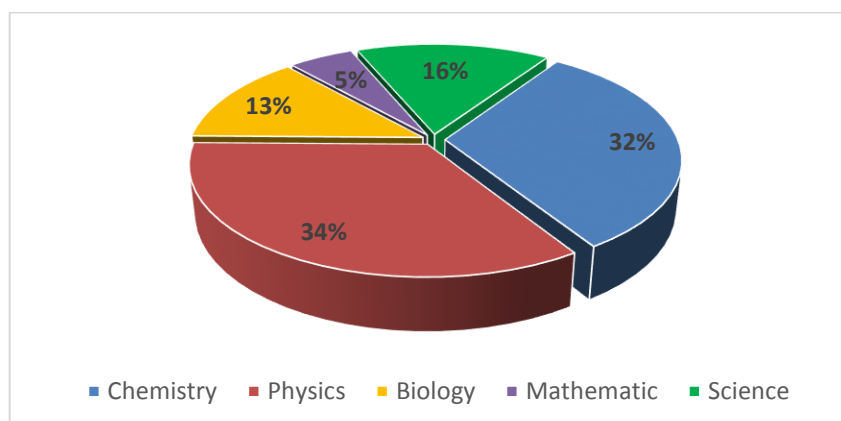


Figure 1. Percentage of PBL-integrated STEM Theme Articles in Various Fields

Figure 1 shows that the implementation of the STEM approach integrated with PBL in the field of chemistry obtained a percentage of 32% or 12 articles. These results show that the integration between PBL and STEM in chemistry learning activities has been done quite a lot compared to the fields of Biology, Mathematics, and Science. The large number of implementations of the PBL-integrated STEM approach in the field of chemistry is due to the fact that most chemical materials are abstract concepts, which cannot be seen directly with the naked eye (Stojanovska et al., 2017) causing some students to consider that learning chemistry is difficult to understand (Zakiyah et al., 2023). Moreover, chemistry education traditionally emphasizes memorization of theories, laws, and products, which can hinder students' ability to apply their knowledge to real-world problems, particularly those involving social issues (Ariyatun & Octavianelis, 2020). This traditional approach can also lead to disengagement among students, as they may not see the relevance of what they are learning to everyday life (Ariyatun & Octavianelis, 2020).

Teachers also experience obstacles in the chemistry teaching process, because not all students are actively involved in the learning process (Manurung & Zubir, 2023). A strategy that promotes active participation and makes learning more tangible is therefore crucial. This is where the integration of STEM with PBL becomes particularly beneficial. Purnamasari et al. (2020) found that STEM-PBL-based teaching materials significantly enhance the learning experience in chemistry, providing students with the necessary tools to better understand complex concepts. Similarly, Manurung & Zubir (2023) demonstrated that the STEM-PBL model is both valid and feasible, resulting in more effective learning outcomes. Oktaviani et al. (2020) also reported positive results, highlighting that this approach not only improves students' understanding of chemistry but also their problem-solving and critical thinking skills. Additionally, research by Ejiwale (2013) shows that the integration of STEM-PBL is beneficial not only for students but also for teachers. Teachers are better supported in delivering complex material through projects that are relevant to the students' daily lives. This makes the teaching and learning process more interactive and engaging.

The integration of PBL with STEM in chemistry education addresses the subject's inherent challenges by making abstract concepts more tangible and relevant, thus enhancing student engagement and comprehension. This approach not only aids in overcoming the difficulties faced by students and teachers but also prepares students with

the skills necessary for the 21st century, such as critical thinking, problem-solving, and collaboration. The research evidence strongly supports the efficacy of this educational strategy, indicating its potential for broader application in STEM education.

Implementation of STEM integrated with PBL in Chemistry Learning to Improve Student Competencies

The implementation of the STEM approach integrated with the PBL model has been carried out in various fields of research, one of which is in the field of chemistry as shown in Figure 1. The implementation of STEM-PBL is proven to improve student competencies such as learning outcomes (C1), critical thinking (C2), science competence (C3), learning activities (C4), science process skills (C5), concept understanding (C6) and self regulation (C7). The implementation of STEM-PBL in improving student competence in chemistry learning is presented in Table 2.

Table 2. Implementation of STEM-PBL in Improving Student Competence in Chemistry Learning

No.	Authors	Year	Material	C1	C2	C3	C4	C5	C6	C7
1	Adelita et al.	2017	Rate of reaction	✓						
2	Rihhadatul'aysi et al.	2018	Electrochemistry			✓				
3	Winda et al.	2019	Electrolyte solutions and colligative properties of solutions	✓						
4	Dotimineli & Mawardi	2020	Energy				✓			
5	Ariyatun & Octavianelis	2020	Colloidal systems		✓					
6	Awalin & Ismono	2021	Chemical equilibrium	✓				✓		
7	Negari	2021	Acid and base solutions		✓					
8	Khairunnisa et al.	2022	Colloidal systems		✓					✓
9	Prastika et al.	2022	Chemical equilibrium		✓				✓	
10	Ata et al.	2023	Rate of reaction		✓					
11	Manurung & Zubir	2023	Buffer solutions	✓						
12	Arisa & Sijinjak,	2024	Redox and electrochemical reactions		✓					
Total				4	6	1	1	1	1	1

Table 2 shows that there are seven competencies trained in chemistry learning using STEM integrated PBL, namely learning outcomes, science competency abilities, learning activities, critical thinking, science process skills, self-regulation, and concept understanding. Based on the articles found, learning outcomes and critical thinking skills

are the most trained competencies in chemistry learning, this is in line with what happens in the field of physics (Agustin et al., 2020; Maulidia et al., 2019; S. I. P. Ningsih, 2020b; Nurazmi & Bancong, 2021; C. D. Putri et al., 2020; Y. E. E. Putri et al., 2021; Rohali et al., 2023; Rohmah et al., 2021; Setyorini et al., 2021; Syarif et al., 2023; Zulfawati et al., 2022), biology (Amalya et al., 2021; Fadhilah et al., 2022; Febrianto et al., 2021; Kulsum et al., 2020; Ningsih et al., 2022) and science (Adiwiguna et al., 2019; Cahyaningsih & Roektingroem, 2018; Kartini et al., 2023; Zakiyah R et al., 2023)

The high critical thinking skills trained using the STEM-PBL approach can be due to critical thinking being a 21st century skill, apart from problem solving, communication, collaboration, and creativity (Fathurohman et al., 2021; Zubaidah & Corebrima, 2020). Critical thinking is one of the skills that is needed now and in the future (Nuraeni et al., 2019) in order to compete and adapt in the era of revolution 4.0 (Ananda & Salamah, 2021). Critical thinking skills can increase students' analytical power (Nasihah et al., 2020; Wayudi et al., 2020) and their sensitivity to the situation in the surrounding environment (Arifah et al., 2021). So that this skill is a very important skill for students to have. This is what makes critical thinking skills a popular skill to be trained in learning activities with various potential models or approaches, including using the PBL model integrated with the STEM approach. The results of research conducted by Rushiana et al. (2023) also showed that there are various learning models used as an effort to improve students' critical thinking skills, where the PBL model is the most widely used learning model after the project-based learning model.

Learning outcomes are also widely studied in the field of chemistry after critical thinking skills. Learning outcomes are changes in a person's abilities after receiving learning experiences (Tanjung & Nababan, 2016). Forms of change as a result of learning can be in the form of changes in knowledge, understanding, attitudes and behaviour, as well as skills and abilities (Prastika, 2020). Learning outcomes can be seen from students' mastery of the subjects they take, and are the result of the interaction of some of the factors that influence the learning process as a whole (Anggraini & Imaniyati, 2018). Thus, it can be said that students can get good learning outcomes if various factors that support successful learning can be fulfilled. This is in accordance with what Salsabila & Salsabila & Puspitasari (2020) explained that student learning outcomes are influenced by internal factors (from within students) and external factors (from outside students). Of the two factors, external factors are considered to have an important role in developing the potential of students to improve learning outcomes (Pratiwi & Meilani, 2018).

The problem that often occurs in chemistry learning is that learning activities are still teacher-centred compared to students, this happens not only at the high school level (Erlina et al., 2019; Jamilah et al., 2021; Supadmi et al., 2017) but also at the university level which results in low learning outcomes (Winda et al., 2019). This can cause the STEM approach integrated with PBL to be widely implemented to improve learning outcomes in chemistry learning (Adelita et al., 2017; Awal & Ismono, 2021; Manurung & Zubir, 2023; Winda et al., 2019). However, the problems in chemistry learning are not only in critical thinking skills and learning outcomes. Learning activities (Dotimineli & Mawardi, 2021), science competence (Rihhadatul'aysi et al., 2018), science process skills (Awal & Ismono, 2021), concept understanding (Prastika et al., 2022), and self-regulation (Khairunnisa et al., 2022) are also skills that are still a problem in learning chemistry, so the STEM-PBL approach is also an alternative to improve these various skills.

Effectiveness of STEM-PBL in Improving Critical Thinking Skills and Student Learning Outcomes

Various studies on the implementation of STEM-PBL have proven to improve various skills. The effectiveness of STEM-PBL implementation on critical thinking skills and student learning outcomes is presented in Table 3.

Table 3. Effectiveness of STEM-PBL on Critical Thinking Skills and Student Learning Outcomes in Chemistry Learning

Author	Result
Adelita et al. (2017)	The learning outcomes of students taught with PBL-STEM obtained a higher average score (83.25) compared to students who were not taught with STEM-PBL (77).
Winda et al. (2019)	There is a significant difference between student groups taught with PBL-STEM compared to students taught with conventional models, with a t_{count} value (7.39) > t_{table} (1.67)
Ariyatun & Octavianelis (2020)	There was an increase in students' critical thinking skills in the experimental class based on the average N-gain of 0.56 (moderate category), and the control class of 0.33 (moderate category).
Awalin & Ismono (2021)	Student learning outcomes increased based on pretest (51), and posttest (83.33) scores, and obtained an N-gain value of 0.62 with a moderate category.
Negari (2021)	The average value of chemical critical thinking skills in the group of students taught with the PBL-STEM learning model is greater (7.162), compared to the group taught with the conventional learning model (4.015).
Khairunnisa et al. (2022)	The implementation of the STEM-based PBL model with virtual reality media can improve critical thinking skills with an N-gain value of 0.71 (high category).
Prastika et al. (2022)	There is a difference in the average critical thinking skills of students in the experimental and control classes. The experimental class obtained a score of 85.74, while the control class obtained a score of 80.83.
Ata et al. (2023)	There is a significant difference between groups of students taught using the PBL-STEM method and students taught with conventional methods based on the results of the Mann Whitney test.
Manurung & Zubir (2023)	The learning outcomes of students who follow the learning process using PBL-STEM-based e-modules are higher than conventional methods.
Arisa & Sitinjak (2024)	There was an increase in students' critical thinking skills before and after implementing PBL-STEM based on the pretest value (86.9) and posttest value (91.57).

The results of research from various previous researchers seen in Table 3. show that the STEM approach integrated with the PBL model has a positive impact on students' critical thinking skills and learning outcomes in chemistry learning. This result is in accordance with what happens in physics, biology, mathematics, and science learning which shows that there is an increase in critical thinking skills and learning outcomes after implementing STEM-PBL learning (Cahyaningsih & Roektingroem, 2018; Fadhilah et al., 2022; Maulidia et al., 2019; Setyorini et al., 2021; Wahyuni et al., 2022). This can be due to the learning phase PBL STEM allows for elaboration, cooperation and collaborative interaction of students in analyzing problems and the reporting process (Ariyatun & Octavianelis, 2020), and provides motivation for students to create technological engineering to solve the problems presented (Awalin & Ismono, 2021). Furthermore, Negari (2021) explained that PBL integrated with STEM is able to build students' thinking power and experience so that it helps students prepare skills for the world of work.

Critical thinking skills and learning outcomes after applying STEM-PBL learning show different improvements, ranging from the moderate category (Ariyatun & Octavianelis, 2020; Awalin & Ismono, 2021) to the high category (Khairunnisa et al., 2022). This difference can be caused because in the group of students who obtained a higher score increase, STEM-PBL learning was carried out with the help of virtual reality media. Based on Supriadi & Hignasari (2019) research, virtual reality media can improve student learning outcomes. Most teachers also stated that virtual reality media can stimulate students' critical thinking skills (Oktarizka, 2024). Virtual reality can make the environment that cannot be seen directly by students become real (Ghali et al., 2012). Virtual reality has also been widely recommended as a technological breakthrough that has great potential to facilitate the learning process (Sun et al., 2010)

The increase in critical thinking skills and learning outcomes in the moderate to high category after STEM-PBL learning is applied, contrary to the results of research conducted by Rohmah et al. (2021). The results showed that there was an increase in students' critical thinking skills after being taught with STEM-PBL learning with a low category. Although there was a low increase, almost all students experienced an increase in grades. Some of the factors that cause the low improvement in critical thinking skills after STEM-PBL implementation include: (1) the lack of students' prior knowledge of the material; (2) the teacher was not optimal in delivering the learning material because students could not understand the material well; (3) the lack of facilities that support the learning process, namely the projector so that the teacher cannot display the learning video (Rohmah et al., 2021). In addition, based on research conducted by (Negari, 2021), learning independence also affects students' critical thinking skills. It was found that groups of students with high learning independence taught with the PBL-STEM learning model, obtained higher critical thinking skills compared to students who had low learning independence. Based on this, it can be said that although STEM-PBL learning can improve students' skills and learning outcomes, the improvement that occurs can vary depending on various factors, both internal factors (from within students), and external factors (from outside).

Conclusion

Based on the results of the research and discussion, it can be concluded that the integration between PBL and STEM in chemistry learning activities has been done quite a lot compared to other fields. Most of the PBL-STEM integration has been proven effective for improving critical thinking skills and student learning outcomes, both in the low to high categories. This is because each step in PBL-STEM learning allows for elaboration, cooperation, collaborative interaction of students in analysing problems in the learning process, and provides motivation for students to create technological engineering. So that STEM-PBL learning can be used as an alternative in learning chemistry.

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