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Analysis of Effectiveness PBL-STEM to Improve Student's Critical Thinking Skills

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ABSTRACT

Objective: This study aims to analyze the effectiveness of PBL-STEM in improving students' critical thinking skills. **Method:** The method used in this research is the literature review method. A literature review is a type of research that collects data and information from various sources by collecting and analyzing. This study analyzes as many as two national and international articles that can be accounted for. The articles used were published in 2018-2022. The steps in this Literature review method are identifying topics, searching for and selecting relevant articles, analyzing and synthesizing the literature, and creating a conclusion. **Results:** (1) the application of the PBL model can improve students' critical thinking skills; (2) the integration of STEM in the learning process is also able to improve critical thinking skills because STEM provides opportunities for students to identify real-life problems and solve them, which is per the characteristics of PBL; (3) the integration between PBL and STEM can be applied and can provide more effective results in improving students' critical thinking skills. **Novelty:** ThisThis study discusses the analysis of how effective the integration of STEM and PBL from the latest journals so that this research can be used as a reference for making quality learning tools.

INTRODUCTION

Education in the 21st century is focused on students' thinking skills. However, one of the skills that are very useful in the current and future eras is critical thinking skills (Nuraeni et al., 2019). Critical thinking is analyzing and evaluating data or information (Arends, 2012). Critical thinking is a person's way of answering a question systematically and precisely. Therefore, critical thinking will make students intelligent in thinking about the environment around them (Arifah et al., 2021). Critical thinking is creating arguments systematically and proactively using information gathered through observation, experience, reflection, offering arguments, or communication as a foundation for taking action (Nafiah, 2014). Critical thinking focuses on patterns of what must be believed, what must be done, and what can be accounted for when making decisions (Septi et al., 2022). Critical thinkers can solve problems logically, provide clear answers to questions, and come to reasoned conclusions about what to do or believe; critical thinking abilities are necessary (Hidayati et al., 2021). Critical thinking skills are broken down into 12 categories, including asking and answering questions, analyzing arguments, deciding whether or not to believe sources, observing and evaluating reports on findings from observations, deducing and evaluating conclusions from deductions, inducing conclusions from inductions, determining the value of consideration, defining terms and evaluating them, identifying assumptions, deciding on an action, and interacting. These aspects are grouped into five indicators: providing simple explanations, building basic supporting skills, concluding, making further explanations, and organizing strategies and tactics.

Indicators of critical thinking are clarification, assessment, inference, and strategies. Clarification understands the problem by correctly mentioning all the data and the subject of discussion. Assessment is analyzing relevant and irrelevant information. Inference is forming conclusions by combining relevant information and then forming generalizations. Strategies are to determine alternative solutions that will be carried out to solve the problem (Putri et al., 2021). Al-Farisi et al. (2020) state that students who cannot understand the problem and mention the data in the problem show that the student still needs to fulfill the clarification indicator. If this happens, it will affect the ability to analyze relevant and irrelevant information (assessment) and will also affect students in analyzing alternative problem-solving (strategies), so this causes students to be less precise in making conclusions (inference). Facione (2015) says that critical thinking is thinking with a goal, such as proving something, deciphering something's meaning, and resolving issues. However, Facione (2015) divides the six indications that comprise the core of critical thinking skills into interpretation, analysis, inference, evaluation, explanation, and matching. This means critical thinking, namely interpretation to understand the meaning of something; analysis to understand more in a matter can be through data, information, and others; inference to conclude the collection of data and information; evaluation to assess the credibility of the resulting conclusions; explanation to state the truth, reasons, and evidence; and matching as the final stage, namely validation.

Critical thinking is crucial for students since it enables them to solve social, scientific, and practical problems effectively. Thinking skills can boost students' critical analytical power (Nasihah et al., 2019; Wayudi et al., 2020). The existence of information technology and expertise is no longer enough to overcome the challenges in this era. To be able to work effectively in the work environment and daily life, students must be able to solve problems in order to be able to make the right decisions (Susilawati et al., 2020). Critical thinking skills can be trained by selecting innovative learning models, one of which is Problem-Based Learning (PBL) (Mayasari et al., 2016).

PBL is a learning model that uses real problems in daily life. PBL aims for students to build scientific knowledge (Husniarti et al., 2022). PBL requires students to instill scientific thinking and develop mental thinking, which is much needed in 21st-century learning (Diani et al., 2019). In addition, the application of PBL in learning can improve creative thinking skills (Herdiawan et al., 2019), communication skills (Nurhayati et al., 2019), and student motivation (Arief & Sudin, 2016). The PBL model can also increase students' self-confidence in participating in learning (Isabela et al., 2021). The syntax of the PBL model is divided into five, consisting of student orientation toward problems, organizing students to study, guiding individual and group investigations, developing and presenting works, and analyzing and evaluating the problem-solving process (Arends, 2012).

The syntax of the PBL model consists of identifying problems, defining problems through thinking about problems and selecting relevant information, developing solutions through identifying alternatives, brainstorming and checking differences of view, taking strategic action, and reviewing. Moreover, evaluate the effects of the solutions made (Amsal, 2021). Meanwhile, the steps for solving problems in PBL learning are at least eight stages, namely identifying problems, collecting data, analyzing data, solving problems based on data, choosing ways to solve problems, planning the implementation of problem-solving, testing the plans set, and carrying out action to solve the problem (Nurwahid & Shodikin, 2021).

PBL is suitable for creating a good learning environment. PBL prepares participants' students to think critically and analytically and discover by using various sources (Herzon et al., 2018). In addition, PBL has benefits for teachers. It can help teachers be creative and innovative in delivering meaningful material to students with the development of science and technology that grow so fast (Nasir et al., 2023). PBL has several advantages over other models. Namely, students can get used to solving problems and are challenged to solve problems not only in learning but also in daily life; students are used to discussing and interacting with group mates, and students are used to solving problems by conducting experiments (Handayani et al., 2022; Novianti et al., 2021). However, PBL also has disadvantages, namely that it cannot be applied to every subject, so this model is more suitable for use in lessons related to problem-solving, and teachers have difficulty dividing assignments because there is a high level of diversity in one class (Sulastry et al., 2023).

PBL has three types of learning. It is cognitive, collaborative, and content learning (Prayogi & Estetika, 2019). The focus of cognitive learning is the ability to think critically, creatively, and innovatively. Communication and teamwork skills are the main focuses of collaborative learning. Interdisciplinary knowledge in science, technology, engineering, and mathematics (STEM) is the main focus of content learning (Mulyani, 2019). STEM is a learning approach that integrates science, technology, engineering, and mathematics to develop students' creativity through daily problem-solving (Winarni et al., 2016). STEM focuses on connecting knowledge between disciplines which is not enough if done separately. STEM is an interdisciplinary learning approach that unites the four fields of science, technology, engineering, and mathematics and eliminates the previous barriers that separate them. (Smith et al., 2022).

STEM activities in learning can be described from their abbreviations, including science in the form of facts, concepts, and procedural science contained in the basic competencies to be studied; technology in the form of technology used and or developed; engineering in the form of engineering activities covering what products are designed, the tools and materials needed, testing product optimization, evaluating product results; mathematic in the form of mathematical activities needed in calculations, such as applied mathematical concepts, required theorems or formulas (Angin, 2020; Yasifa et al., 2023). The application of STEM in learning must emphasize several aspects, including asking questions and explaining problems, developing and using models, designing and carrying out research, interpreting and analyzing data, using mathematical and computational thinking, making explanations and designing solutions, and participating in evidence-based argumentation activities. Obtain information, provide evaluations, and convey information (Fathoni et al., 2020).

Students can design, produce, and use technology while developing their cognitive, manipulative, and affective skills through STEM in the classroom. So, integrating STEM into science education is a good idea (Permanasari, 2016). Students can learn how to use their knowledge to create designs to address environmental issues by employing technology through STEM-based learning (English, 2016). In addition, to meet the demands of the 21st century, students who will become the next generation must be familiar with science, technology, engineering, and mathematics and have critical and creative thinking skills (Baucum & Capraro, 2021; Marlina et al., 2021). Based on this, this learning can be integrated with the STEM approach to support the effectiveness of learning using the PBL model. The relationship between PBL, STEM, and critical

thinking skills can be studied further using the literature review method from several previous research articles.

RESEARCH METHOD

The method used in this research is the literature review method. A literature review is a type of research that collects data and information from various sources by collecting and analyzing (Fadli, 2021). A literature review is critical writing, constructive analysis of literature in a particular field by summarizing, classifying, analyzing, and comparing with a scientific text or previously published literature (Haerazi et al., 2021). A literature review is a study of articles, books, and other sources related to a particular problem area of research or theory and provides a descriptive summary and critical evaluation of those works (Ramdhani et al., 2014). The steps of this method are shown in **Figure 1**.

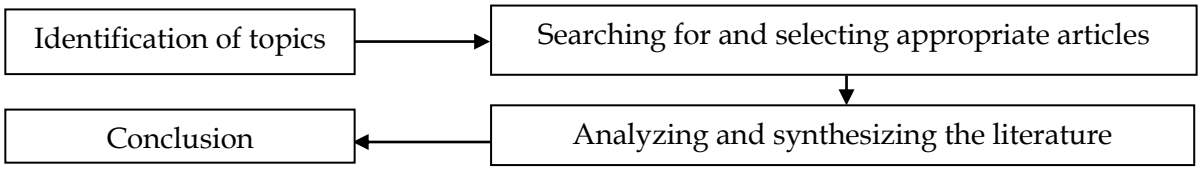

Figure 1. Research flowchart (Ramdhani et al., 2014).

This research will focus on national or international articles in the range of publications from 2018-2022. The first step is identifying the topic; the topic used in this research is PBL-STEM can improve students' critical thinking skills. The second step is to find and select articles. Article search is done by visiting scientific article websites that match the search criteria. The results of selecting articles in this step are shown in **Figure 2**.

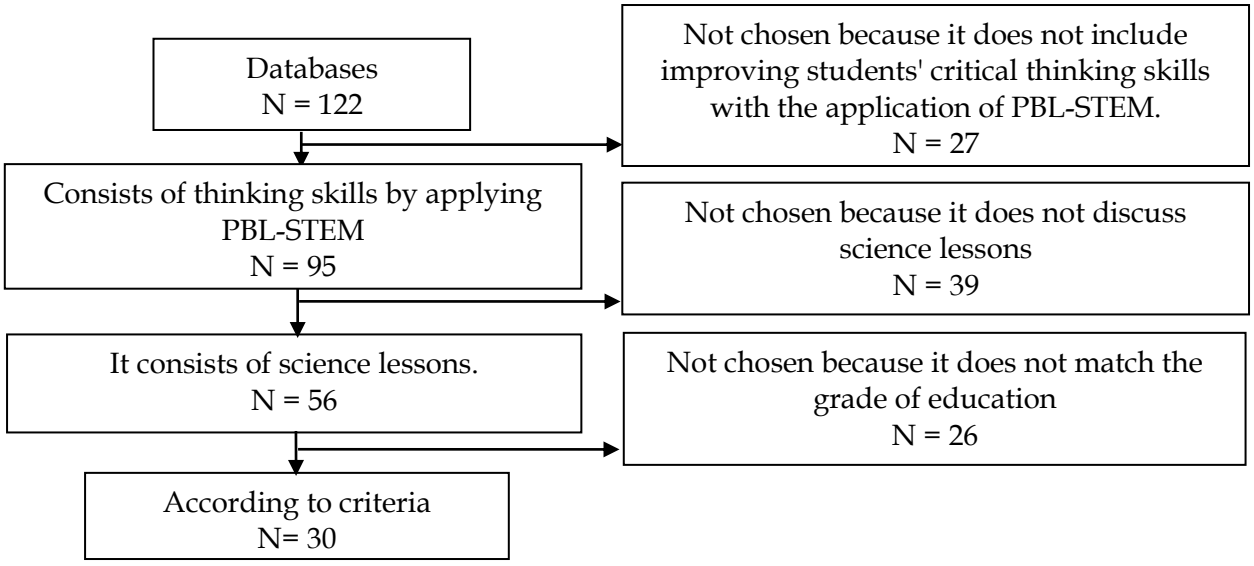

Figure 2. Literature review information diagram.

Synthesize a collection of articles by integrating the information obtained. The third step is analyzing and synthesizing the literature, and the 30 articles that have been chosen, then analyzing and identifying information that is per the research conducted. The analysis results are presented in the form of tables, and the integration results will be presented in the discussion. In the fourth step, the researcher outlines the conclusions of the study.

RESULTS AND DISCUSSION

Results

Based on search results of national and international articles that have been determined, it is then analyzed based on three interrelated discussions. The discussion will be presented on the effect of the PBL model on students' critical thinking skills, the effect of the Integration STEM on students' critical thinking skills, and the effect of PBL-STEM on students' critical thinking skills.

The Effect of the PBL Model on Students' Critical Thinking Skills

The results of an article study on the effect of PBL on students' critical thinking skills are presented in **Table 1.**

Table 1. Results of the effect of PBL on students' critical thinking skills.

Author	Results
Pusparini et al. (2018)	The experimental class had a higher percentage of students with critical thinking skills (82.8%) than the control class (73.3%), and the results of hypothesis testing obtained sig data < α, which is 0.000 < 0.05, so H0 is rejected, and H1 is accepted. There is proof that the PBL model improves students' critical thinking skills.
Marhamah et al. (2020)	Applying the Problem-Based Learning model significantly positively affects students' critical thinking skills. This is evidenced by the results of the average value obtained before getting treatment (pretest), which is 52.71795, while after getting treatment with the application of the PBL model (post-test) is 70.87. At the same time, the analysis of the data obtained is the significance value of the data 0.00 <0.05.
Windari & Yanti (2021)	Integrating aspects of critical thinking skills which include analytical thinking skills, synthesis, solving problems, concluding, and evaluating or assessing into the syntax of PBL can improve students' critical thinking skills in class XI.
Pujianti & Rusyana (2020)	Application of the PBL model can improve students' critical thinking skills. The student's critical thinking skills increased in the medium category, 0.67.
Dakabesi & Luoise (2019).	Compared to traditional models in the control class, the PBL model's empirical review and post-test of critical thinking skills in the experimental class demonstrated a positive effect in enhancing critical thinking skills. The critical thinking skills demonstrate these test results, which show that the average of the experimental class is higher than the control class (M = 37.55, SD = 14.13), while the control class has the lowest average score with a post-test score of critical thinking skills (M = 31.84, SD = 13.09). This indicates that the two study groups differ (t = 2.349, p = 0.02).
Kasmiati & Tiwow (2020)	Students' critical thinking skills obtained from the questionnaire instrument in the experimental class were 82.95% higher than the students' critical thinking skills in the control class, namely 73.43%, and students' critical thinking abilities obtained from the description test instrument in the experimental class, 79.42%, these results were higher than the critical thinking skills of students in the control class, namely 58.02%. The test results using parametric statistical analysis with the t-test on the right side obtained a count value of 6.83 and a stable value of 2.04, which indicates that the count> table value, then H0 is rejected, and H1 is accepted. This means that students' critical thinking skills in the reaction rate material of the experimental group are higher than students' critical thinking abilities in the chemical reaction rate material in the control class.

Author	Results
Wenno et al. (2021)	Applying the PBL model increases students' thinking skills, as evidenced by higher student learning outcomes compared to classes taught with conventional learning.
Yulfiani & Muchlis (2021).	The findings show that students' critical thinking skills have been trained by applying the PBL model. This is evidenced by the pretest-posttest results of students obtaining a percentage of N-Gain score ≥0.3, and 90.63% of students are in the high category, and 9.38% are in the medium category.
Hermawan (2022)	The sig value was obtained based on the study's results by calculating independent sample t-test statistical tests on critical thinking skills. = 0.000 < sig. = 0.05. This means that learning activities with the PBL model affect students' critical thinking skills.
Setiawan & Islami (2020)	The application of the PBL model can improve students' critical thinking skills. This is evidenced by the research results showing an increase in students' critical thinking skills in all indicators. Significant improvement in this study was found in the self-correct and Analyzed indicators.
Agnesa et al. (2022).	Problem-based learning can be an effort to improve critical thinking skills in biology learning.

The Effect of The Integration of STEM on Students' Critical Thinking Skills

The results of an article study on the effect of STEM on students' critical thinking skills are presented in **Table 2.**

Table 2. Results of the effect of STEM on students' critical thinking skills.

Author	Result
Khoiriyah et al. (2018)	STEM learning can improve students' critical thinking skills because, in their learning, students play a role in solving problems and determining solutions. Learning with the STEM approach is more effective in improving students' critical thinking skills than conventional learning approaches, besides that STEM learning can significantly improve students' critical thinking skills by up to 95.00%
Ritonga & Zulkarnaini (2021)	The application of STEM can improve students' critical thinking skills. In the experimental class, there is an increase in pretest and post-test students' critical thinking skills. Meanwhile, the results of the T-test for students' critical thinking skills obtained ρ (0.000) < α (0.05). It can be concluded that STEM learning is more effectively used to improve students' critical thinking skills than conventional learning.
Lestari & Muhajir (2021)	With an average N-Gain score of 0.62, which falls into the medium category, a STEM approach can help students' critical thinking abilities. The indication of providing clear explanations showed the highest increase in critical thinking abilities, whereas the indicator of managing strategies and tactics showed the lowest increase.
Herwanti (2021)	The STEM approach can develop students' critical and creative thinking skills to increase learning outcomes in Electrochemical Cell material; this is based on the mean value of critical and creative thinking skills in cycles I and II, showing an increase of 80.69.
Sandi (2021)	The study's results on the analysis of t-test data obtained t-count = 7.94 and t-table = 1.05, so that t-count > t-table, besides that the normalized N-gain data obtained an average = 0.72. Based on this, the STEM approach positively

Author	Result
	influences understanding the concept of electroplating through critical thinking skills.
Linh et al. (2018).	Learning activities by applying the STEM approach can improve students' critical thinking skills. Several other findings were also presented, including STEM ability directly proportional to academic achievement and gender, significantly affecting the increase in students' critical thinking skills.
Nurmawati et al. (2021)	STEM education that involves parent and teacher cooperation is acceptable for use as an alternate form of instruction in the new normal period since it can help pupils develop their critical thinking abilities
Hacioglu & Gulhan (2021)	This study explained that critical thinking skills increased after the STEM learning activities were carried out.
Mater et al. (2020).	STEM-based activities are crucial in developing critical thinking skills using various discovery methods, inquiry, problem-solving, and learning projects that fully develop students' personalities.
Yaki (2022)	STEM integration improves students' critical thinking skills in this population. This is because students are actively involved in the learning process by collaborating in solving a problem.

The Effect of PBL- STEM on Students' Critical Thinking Skills

The results of an article study on the effect of PBL-STEM on students' critical thinking skills are presented in **Table 3**.

Table 3. Results of the effect of PBL-STEM on students' critical thinking skills.

Author	Results
Octafianellis et al. (2019)	STEM-integrated PBL learning can influence critical thinking skills. Students' critical thinking skills increased with an average value of 71.73 which is included in the high criteria.
Prastika et al. (2022)	The study results explained differences in students' critical thinking skills, which could be shown in the average students' critical thinking tests, namely 85.74 for the experimental class using STEM-integrated PBL and 80.83 for the PBL control class.
Ariyatun & Octavianelis (2020)	Based on the study results, the STEM-integrated problem-based learning model can improve students' critical thinking skills, as indicated by the results of the N-gain and t-test in the experimental and control classes.
Zulfawati et al. (2022)	The problem-based learning model integrated with the STEM approach effectively improves students' critical thinking skills in the low effectiveness category.
Putri et al. (2020)	The results showed that the application of PBL, which was integrated using STEM, could be carried out well, and there was an increase in students' critical thinking skills, as evidenced by the N-gain value of 72.00%.
Hasanah et al. (2021)	Implementing the PBL model combined with STEM-based LKPD can improve students' critical thinking skills. In addition, there are differences in students' critical thinking skills between the experimental class and the control class.
Nurazmi & Bancong (2021)	The results obtained from the research show a significant difference between students' Physics critical thinking skills by applying the

Author	Results
	STEM-integrated Problem-Based Learning model and conventional learning models.
Rohmah et al. (2021)	Students' critical thinking skills have increased after being treated using STEM-based PBL. This has been proven by an increase in the average score of critical thinking skills tests of 22.42%.
Mustofa et al. (2021)	Students' critical thinking ability by implementing PBL-STEM is higher than in classes using conventional learning models. This is evidenced by the existence of a t-test which produces a p-value of 0.000 or less than 0.05, which means that H0 is rejected. Besides that, the post-test results were very good, namely 72.30, and there was also a significant difference between the control and experimental classes, as seen from the p-value, which was 0,000 less than the alpha.

Discussion

Based on the results of the study of the ten articles on point 1 in the result. It was found that the PBL model showed positive effect in improving students' critical thinking skills (Agnesa & Rahmadana, 2022; Dakabesi & Luoise, 2019; Hermawan, 2022; Kasmiati et al., 2020; Marhamah et al., 2020; Pusparini et al., 2021; Setiawan & Islami, 2020; Wenno et al., 2021; Windari & Yanti, 2021; Yulfiani & Muchlis, 2021). In addition, the effect of the PBL model on critical thinking skills was also found in the medium category (Pujianti & Rusyana, 2020). Based on the analysis obtained, the increase in students' critical thinking skills is due to the PBL model providing opportunities for students to develop their critical thinking skills through complex problem-solving processes in small group discussions. In addition, the characteristics of the PBL model can support the achievement of increasing critical thinking skills because PBL has learning stages that provide space for students to think critically in finding concepts and solving problems related to the material presented by the teacher (Pujianti & Rusyana, 2020). This also aligns with Rusman's (2013) opinion, which states that problem-based learning is a learning approach used to stimulate higher-level thinking, including students' critical thinking skills in situations oriented to real-life problems. In addition, Dakabesi & Luoise (2019) explained that the PBL model presents complex problems that will increase students' curiosity so that they are involved in investigations. In carrying out investigations, the research framework is regulated by students so that learning activities are student-centered.

Other findings state that the problem-based learning model as learning model has a good effect on the learning process. Namely, students are more enthusiastic, enthusiastic, and motivated to take part in learning, so it impacts increasing students' conceptual understanding of the material being studied. This is in line with the results of research conducted by Aristawati et al. (2018), which stated that there were differences in understanding the concept of learning between students who studied using the problem-based learning model and students who studied with the direct learning model. The learning atmosphere with the problem-based learning model can minimize student boredom in the learning process because students are allowed to set their learning strategies (Albina et al., 2022). While teachers still dominate the direct learning model, this is no longer a mainstay in applying learning models in the classroom to improve applying problem-based concepts. Agnesa & Rahmadana (2022)

states that the application positively affects in combination with media or other learning models and positively affects critical thinking skills.

Based on the analysis of the nine articles on point 2 in the result. Both National and International, it was found that the STEM approach can improve students' critical thinking skills (Hacioglu & Gulhan, 2021; Herwanti, 2021; Khoiriyah et al., 2018; Linh et al., 2019; Mater et al., 2020; Nurmawanti et al., 2021; Ritonga & Zulkarnain, 2021; Sandi, 2021; Yaki, 2022) besides that, the effect of STEM on critical thinking skills was also found in the medium category (Lestari & Muhajir, 2021). Based on the analysis obtained from the ten articles, there is the same premise that the increase in critical thinking skills is due to the STEM approach being able to provide students with opportunities to identify problems according to the facts and solve problems that occur in real life (Hacioglu & Gulhan, 2021; Herwanti, 2021; Khoiriyah et al., 2018; Linh et al., 2019; Nurmawanti et al., 2021; Ritonga & Zulkarnain, 2021; Sandi, 2021) and provide conclusions to construct new understandings that have been found based on the experiences that have been carried out in the process learning (Lestari & Muhajir, 2021). (Mater et al., 2020) found that the integration of STEM in learning can increase motivation to learn and be able to solve problems. In addition, STEM integration also shows an indirect impact, namely collaboration between students in class, that increases interest in learning (Mater et al., 2020).

Based on the analysis of the nine articles on point 3 in the result. It states that the learning process using PBL, integrated with STEM, can influence students' critical thinking skills. The PBL model can be integrated with the STEM approach because in PBL learning, students can explore their understanding through the stimuli that can be given using the STEM approach (Ariyatun & Octavianelis, 2020; Hasanah et al., 2021; Mustofa et al., 2021; Nurazmi & Bancong, 2021; Octafianellis et al., 2021; Prastika et al., 2022; Putri et al., 2020; Rohmah et al., 2021; Zulfawati et al., 2022) Both can be integrated and produce more effective results because PBL can provide opportunities for students to determine their understanding (Dakabesi & Luoise, 2019). besides that, the STEM approach also has characteristics in encouraging students to identify problems according to facts and solve problems that occur in real life (Hacioglu & Gulhan, 2021; Khoiriyah et al., 2018; Nurmawanti et al., 2021; Ritonga & Zulkarnain, 2021; Sandi, 2021) and provides conclusions to construct new understandings found based on experiences that have been carried out in the learning process (Lestari & Muhajir, 2021). Meanwhile, other findings state that PBL-STEM integration also provides positive responses from students so that students can accept and like the learning process (Rohmah et al., 2021). Based on this explanation, they can improve students' critical thinking skills more effectively. Therefore, this research can be used as a reference in making learning tools. However, this research is limited to only discussing the effect of PBL with STEM integration on critical thinking skills; it is hoped that there will be research that discusses the effect of PBL with STEM integration on other thinking skills such as creative thinking skills, argumentation skills, and others in order to create more literature.

CONCLUSION

Fundamental Finding: Based on the results of the article analysis, it can be concluded that several important points include the application of the PBL model can improve students' critical thinking skills, STEM integration in the learning process is also able to improve students' critical thinking skills because STEM provides students with

opportunities to identify real-life problems and find a solution, which is by the characteristics of PBL so that the integration between PBL and STEM can be applied and can provide more effective results in improving students' critical thinking skills. **Implication:** This research is expected to be used as a basis for making learning devices that are by the characteristics of PBL-STEM, so it is hoped that they will produce quality learning tools. **Limitation:** This research is limited to only discussing the effects of PBL-STEM on critical thinking skills. **Future Research:** Therefore, it is hoped that there will be further research that discusses the effect of PBL-STEM on other thinking skills, such as creative thinking skills, argumentation skills, or others, so that there will be more literature.

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