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STEM Integrated Problem Based Learning: The Implementation and Roles in Science Learning

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Abstract: This study aims to explore how the STEM integrated problem based learning model implemented and its role in science learning. Systematic literature review was the method used in this review. The Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) approach was adopted for this review. The search is based on the keyword "problem based learning", "STEM", "science learning", "chemistry learning", "physics learning", and "biology learning". All of 15 research articles reviewed in this paper were collected from well-known databases such as SCOPUS, ERIC, and Google Scholar. According to the review, STEM integrated PBL uses problem-based learning procedures to implement STEM education. STEM components (Science, Technology, Engineering, or Mathematics) are integrated in all five phases of problem-based learning. This review provides evidence that STEM integrated problem based learning can enhance students' critical thinking, science process skills, science literacy, achievement, problem solving skills, learning interest, learning motivation, and conceptual understanding in science learning. Therefore, science learning problems related to these variables have the potential to be overcome using STEM integrated PBL.

Keywords: problem-based learning, science learning, stem.

▪ INTRODUCTION

PBL can encourage students to think critically and solve problems in real-life situations. One benefit of this learning model is that it enables students to address real-world challenges, which helps them learn more valuable lessons (Muerza et al., 2024). It is intended that students' thinking concepts will be more mature when they have solving difficulties in their environment, which will be helpful after they graduate. The phases of PBL model are orientation of problems, organize students, assist independent and group investigations, develop and present real results, and analyze and evaluate the problem solving process (Arends, 2011).

The integration of science, technology, engineering, and mathematics (STEM) education is crucial for enhancing students' 21st-century skills (Arisa & Sitinjak, 2022). STEM is a disciplined science that are closely related to each other. Math is needed as a tool for data processing, along with science-based technology and techniques. It is anticipated that a STEM education approach will provide students with meaningful learning by systematically integrating knowledge, concepts, and abilities (Bahriah & Irwandi, 2018). In its implementation, STEM can be integrated with various learning models such as problem based learning (PBL), project based learning (PjBL), discovery learning, and inquiry-based learning (Karabulut et al., 2024; Nasir et al., 2022; Prastika et al., 2022; Purwaningsih et al., 2020). STEM integration with PBL gives students the chance to apply their knowledge to current challenges or problems in order to solve them (Arisa & Sitinjak, 2022; Nurazmi & Bancong, 2021; Parno et al., 2019; Shofiyah et al., 2024; Topsakal et al., 2022).

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Further studies have demonstrated that integrating the STEM approach with the PBL model is a valid and practical way to employ it in the learning process (Arifin, 2020; Oktaviani et al., 2020). Furthermore, in order to solve current challenges, STEM integrated PBL is frequently implemented in groups (Choo et al., 2011). PBL will combine the ideas of science, technology, engineering, and math to foster students' creativity as they work to find solutions to the problem (Dibyantini et al., 2018). STEM integrated PBL applies STEM education through problem-based learning stages. The PBL model and the STEM approach will help students to be independent in the learning process and direct student to be able to solve real-life problems (Muerza et al., 2024). STEM integrated PBL is an interdisciplinary technique that helps students to solve ill-structured, unclear and real-life problems (Dervić et al., 2018). PBL model with STEM approach is able to direct students to independently solve problems with scientific concepts and prepare them for using technology in daily life. This learning concept provides space for students to carry out scientific engineering to provide solutions to the problems at hand. Students who study STEM subjects get access to scientific experiences that help them learn and solve challenges creatively (Corlu et al., 2014).

Students are encouraged to use critical thinking skills when solving problems through STEM integrated PBL. Students have the ability to create a tool that solves a problem. Word, PowerPoint, and other current technologies were used in the tool's design. Students are not only limited to designing tools but can also explain how chemical concepts and reactions occur in their tool designs. STEM subjects help students develop their critical thinking skills and problem-solving abilities (Hebebci & Usta, 2022; Rahmayani et al., 2024). Students can answer the questions and integrate their knowledge to solve problems in daily life and relate them to the subject matter concepts. PBL model with STEM approach is able to direct students to independently solve problems with scientific concepts and be able to take advantage of technology. Applying STEM integrated PBL to topics and having students analyze real-life problems might help students become improved at critical thinking (Rizki & Suprapto, 2024). STEM integrated PBL improves academic success by fostering student creativity, peer engagement, communication skills and confidence in problem-solving. Students in the STEM integrated PBL can actively participate in their education, in contrast to traditional teaching techniques that required them to be passive learners (Funa & Prudente, 2021). In science learning, it is essential to improve students' ability to explore, analyze phenomena, and think scientifically while encouraging active and critical thinking. The PBL technique can be effectively implemented in science education to address real-world topics like STEM and socio scientific concerns (Lubis et al., 2022; Nguyen, 2020; Rehmat & Hartley, 2020).

In the last five years, there have been several systematic literature reviews investigating various implementations of problem-based learning models and stem integration in learning (Akcay & Benek, 2024; Larkin & Lowrie, 2023; Le et al., 2023; Roslina et al., 2022). Systematic literature review conducted by Akcay and Benek (2024) investigated the role of PBL in science learning. The results showed that PBL had a positive impact on 34 different skills. Attitude, scientific process skills, and problem-solving skills were the most commonly examined variables, in that order (Akcay & Benek, 2024). Another study was also conducted by Roslina et al. (2022). The literature review is about STEM-PJBL in physics education. The results show that the use of

STEM-PJBL has a positive impact on cognitive, skills, attitude aspects and that STEM-PJBL can be integrated into media or materials teaching such as modulary, worksheet, the implementation of STEM with robots, as well as teacher awareness (Roslina et al., 2022).

The study by Le et al. (2023) examined the integrated STEM approaches and associated outcomes of K-12 student learning. The findings also revealed that the associated outcomes of K-12 student learning differed among the integrated STEM approaches (Le et al., 2023). Another study was also conducted by Larkin & Lowrie (2023) to review the level of STEM integration seen in the study, the role of techniques in such integration, and the teaching approaches used in the study. The result also encourage researchers to explore the use of teaching approach such as problem-based or project-based learning that provide opportunities for authentic integration (Larkin & Lowrie, 2023).

Based on the description, this systematic literature review aims to examine the role of STEM integrated PBL in science learning. It also explores the STEM integrated PBL learning designs used in the research articles. The implementation of STEM integrated PBL in the research articles selected in this review involved students from secondary and higher education levels. Therefore, this review can provide guidance in the process of designing and integrating STEM into PBL. In addition, this review can provide guidance on PBL design regarding the implementation of STEM integrated PBL in the field of science. The research questions that guided the writing of this article include:

1. How is STEM integrated PBL implemented in science learning?
2. What is the roles of STEM integrated PBL in science learning?

▪ METHOD

Research Design

The research method used is a systematic literature review. A systematic literature review is a methodological research process that identifies, assesses and rigorously analyzes relevant literature. It also collects and analyzes data to answer pre-formulated research questions (Liberati et al., 2009). The review applied systematic methods to assess and synthesize all relevant original scientific studies related to the defined research questions. The review reduced bias by using explicit and methodological techniques in analyzing research articles as well as other relevant data, resulting in accurate findings on which to base an assessment (Moher et al., 2009; Snyder, 2019). This study has employed the systematic literature review methods proposed by Liberati et al. (2009); Moher et al. (2009) based on the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) approach, which includes an identification process (keywords, search criteria, database, records extracted), screening (inclusion and exclusion criteria), eligibility (quality assessment) and includes records (Moher et al., 2010).

Search Strategy

This systematic literature review uses a search strategy to identify and select relevant, high-quality literature to answer the study questions. Relevant studies was conducted through internet search engines, primarily using the Scopus, ERIC, and Google Scholar databases. Published scientific research articles were searched and reviewed between February and July 2024. Published papers after that period are not considered in this review. The keywords used for the selection of research articles were *"problem based* *learning", "STEM", "science learning", "chemistry learning", "physics learning", and "biology learning".*

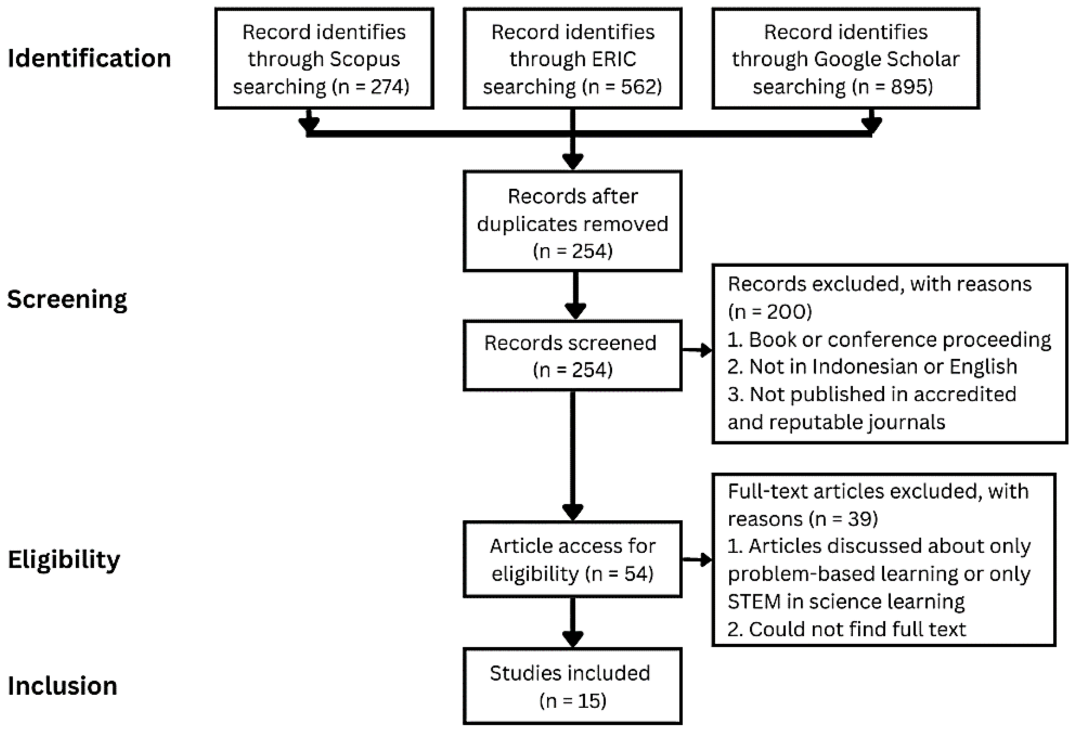

Figure 1. PRISMA flow diagram for searching and extracting data from the literature Adapted from Moher et al. (2009)

Inclusion and Exclusion Criteria

The inclusion criteria for the selected research articles were as follows: (1) research articles focusing on STEM integrated PBL in science learning, (2) involvement of STEM integrated PBL in science learning, (3) articles involving participants from secondary to higher education, including university students, (4) research articles published between 2018 and 2023, (5) articles published in accredited and reputable journals, and (6) articles written in Indonesian or English. The selected research articles were not limited to experimental studies but also included mixed methods or qualitative studies. Articles were excluded if they did not meet the inclusion criteria, which focused on the roles of STEM integrated PBL in science learning. Articles that addressed other disciplines were excluded. To determine exclusions, it was necessary to read the summaries or abstracts of the publications in depth and in-depth, resulting in n=15 publications to be studied.

Data Analysis

The thematic analysis procedure described by Clarke and Braune (2013) was used to determine emerging themes. This is a qualitative data analysis technique that entails reviewing the data set and looking for emerging themes across the data. The six steps of thematic analysis are as follows: (1) familiarization with the data; (2) initial coding; (3) search for topics; (4) evaluation of themes; (5) representation of themes; and (6) interpretation of results (Clarke & Braun, 2013).

▪ RESULT AND DISSCUSSION

The results of data extraction obtained description of 15 articles characteristics based on educational level, research methods, and main findings in Table 1. The research methods used in research articles on STEM integrated PBL consist of quantitative (13 studies), qualitative (1 study), and mixed (2 studies) approaches. The most widely used research method in articles is the quantitative (experimental) method (13 studies) which explains in detail how the implementation and roles of STEM integrated PBL in science learning. The thematic analysis process resulted in two themes, including the implementation in science learning and the effects for students. Meanwhile, the meta-theme is implementation and roles of STEM integrated PBL in science learning.

Table 1. Article characteristics

Authors	Educational Level	Research Methods	Main Findings
(Awalin & Ismono, 2021)	11th grade science students	quasi-experimental	An increase for all indicators of Science Process Skills including observing and concluding in the high category. Meanwhile, the skills of formulating problems, formulating hypotheses, determining variables, and analyzing data can be categorized as moderate.
(Bahriah & Irwandi, 2018)	4th semester undergraduate students of Chemistry Education	quasi-experimental	The model of problem-based learning integrated science, technology, engineering, and mathematics (STEM) provides a positive contribution towards the enhancement of student's science literacy.
(Rihhadatul'aysi et al., 2018)	12th grade science students	quasi-experimental	There is an influence of Problem Based Learning (PBL) model integrated with Science, Technology, Engineering, and Mathematics (STEM) on students' competence in Electrochemistry
(Febrianto et al., 2021)	secondary school students	quasi-experimental	Critical thinking skills of students who are taught with problem-based virtual learning with STEM approach assisted by Schoology on Environmental Pollution material in moderate category, so the learning is effective.
(Usman et al., 2023)	secondary school students	quasi-experimental	The STEM Problem-Based Learning (STEM-PBL) have a significant and favorable impact on students' biology achievement and that students in the experimental group retained more Biology information compared to the control group.

(Arisa & Sitinjak, 2022)	12th grade science students	qualitative descriptive	An increase in students' critical thinking skills in solving everyday problems. Students can also design tools to solve problems and integrate various disciplines.
(Sarı et al., 2018)	secondary school students	mixed method	Integration of PBL with STEM positively affects students’ attitudes and career perceptions that are in the pursuit of their future career.
(Zulfawati et al., 2022)	10th grade science students	pre-experimental	The PBL with STEM approach was effective in improving the students’ critical thinking skills and grow a problem-solver character.
(Prastika et al., 2022)	11th grade science students	quasi-experimental	There are differences in students’ conceptual and critical thinking based on initial abilities in the group that learned by Problem Based Learning-STEM with the group that learned using Problem Based Learning strategy
(Syukri & Ernawati, 2020)	12th grade science students	quasi-experimental	The use of the PBL based STEM approach can increase student interest in learning.
(Nurazmi & Bancong, 2021)	10th grade science students	quasi-experimental	There is a significant difference between the critical thinking skills of students who were taught using the integrated STEM-PBL model and the conventional learning model.
(Topsakal et al., 2022)	secondary school students	mixed method	Problem-based STEM education created a positive effect as cognitive maturity and innovativeness in the students’ feelings, thought, and behaviors. STEM education is highly effective in developing the skills that are expected from individuals in the 21st century such as problem-solving, critical thinking, and social interaction.
(Hasanah, Ritonga, et al., 2021)	10th grade science students	quasi-experimental	There were differences in the learning motivation of students in the experimental class and the control class on environmental pollution material
(Parno et al., 2019)	10th grade science students	quasi-experimental	The practical implementation of PBL-STEM model had a medium impact than PBL class. Furthermore, PBL-STEM and PBL had a huge impact compared with the conventional class in increasing the students’ problem-solving skills.

(Shamdas, 2023)	11th grade science students	quasi-experimental	PBL joined with STEM fundamentally affected the decisive reasoning abilities of senior secondary school understudies in Science subjects contrasted with customary learning.

Theme 1. Implementation in Science Learning

Studies show that STEM-integrated PBL is widely used in science learning, including chemistry, physics, and biology. An overview of the implementation of STEM integrated PBL in science learning is shown in Table 2.

Table 2. STEM integrated PBL in science learning

Science Learning Subject	Study	Percentage (%)
Chemistry (electrochemistry, chemical equilibrium, chemical kinetics)	(Arisa & Sitinjak, 2022; Awalin & Ismono, 2021; Bahriah & Irwandi, 2018; Prastika et al., 2022; Rihhadatul'aysi et al., 2018)	33.3
Physics (application of engineering)	(Nurazmi & Bancong, 2021; Sari, 2020; Syukri & Ernawati, 2020; Topsakal et al., 2022; Zulfawati et al., 2022)	33.3
Biology (environmental pollution, diffusion and osmosis, optical instruments)	(Febrianto et al., 2021; Hasanah, Pada, et al., 2021; Parno et al., 2019; Shamdas, 2023; Usman et al., 2023)	33.3
Total		100

The first stage in PBL, orientation of problems, is important and requires teacher creativity. Arisa & Sitinjak (2020) suggested that at this stage, the teacher must be able to design or guide students to real-life problems. Problems that can encourage students to understand the concept of learning material. In addition, in its implementation, STEM integrated PBL is often carried out in groups to find solutions to existing problems (Arisa & Sitinjak, 2022). Students are divided into groups to ensure students can work together and discuss. Working in groups will help students to learn the concept better because there is an exchange of ideas between group members and this can help students recall the concept that they have learned (Choo et al., 2011).

Based on the review, the problem is presented in the form of a scenario or an engineering problem. By asking appropriate questions to students about the problem statement, they are allowed to gain insights about the problem. Sub problems are determined. By means of brainstorming, what is already known about the problem and what should be known about it are elicited. Meanwhile, prior knowledge is associated with the new topic. By achieving the goals of the STEM disciplines, students can demonstrate their problem-solving solutions at this level. There are aspects in the STEM applications where students can apply their understanding of how to approach problems systematically and use reason to solve them. The study by Topsakal et al. (2022) suggested that the problem given to students in practicing STEM integrated PBL should allow for multiple solutions (Topsakal et al., 2022). The review results suggest that the Science component of STEM has an important role in the first stage of PBL. The Science component leads students to be able to understand the concept of a problem, explain the principles of a design, explain the chemical reactions that may occur from a problem, and analyze a factor in a phenomenon.

The second stage in PBL, organize students, includes conducting research about what should be learned to find a solution to the problem and collection of information and sources. One of the uniqueness of STEM integrated PBL, questions will be presented and packaged as an analysis of real-life problems. It may inspire students to become more perceptive, involved, and driven to find answers to the teacher's inquiries. Based on the review, Science, Technology, or Mathematics components are usually integrated at this stage. The Science component is used to apply the understanding of chemical properties to the materials or tools used and develop experimental hypotheses. The Technology component is used to access initial information by utilizing ICT. According to study by Syukri & Ernawati (2020), students are stimulated to be interested in the learning process through the use of technological products. The Mathematics component is used to calculate related size estimates before conducting experiments in the third stage of PBL.

The third stage in PBL is assist independent and group investigations. Through this stage teachers encourage students to obtain appropriate, accurate information, carry out experiments and seek explanations and solutions. Students initiate their own learning processes to present (produce) the possible solutions to the problem. This stage serves as a bridge between knowledge and discovery for creative solutions to the problem. It involves active processes such as forming hypotheses for the solution of the problem, planning and conducting experiments to test the hypotheses (determining variables, tools and equipment). The study results suggest that the Engineering and Mathematics components are generally integrated at this stage. The Engineering component aims to design innovative tools, create simulators as a visualization of concepts, and manufacture NH3 Haber Bosch, sulfuric acid by contact process, and nitric acid by Ostwald process in reaction rate material. In the Engineering component, students are also required to be able to determine experimental tools, select experimental materials, and design experiments. Meanwhile, the Mathematics component intends to do something related to formulas such as determining the reaction order, reaction rate constant, concentration, equilibrium, and degree of dissociation.

Cited from research by Arisa & Sitinjak (2022), STEM integrated PBL can help students design a tool that can solve the problem. This success is inseparable from the characteristics of STEM integrated PBL, which uses real-life problems and disciplines from STEM. Students may be able to create a product in the engineering component of STEM that solves problems in order for the process to go past the problem analysis phase. Given the task of designing a problem-solving tool, design can challenge students' critical thinking about unique ideas and innovation to find solutions (Arisa & Sitinjak, 2022).

Students need to prepare themselves for exploring technology advancements. The way to support the implementation of STEM is in the form of familiarizing activities with STEM approach in the classroom by utilizing IT. The swift progress of technology in education has simplified the process for educators and students to create learning material (Aldresti et al., 2023; Simanjuntak et al., 2022). It’s also urged of students to become IT experts in order to contribute to the solution of current problems. STEM integrated PBL requires students to create items in addition to creating a completed product that solves problems. As a result, students must investigate the idea of content that can resolve current problem (Arisa & Sitinjak, 2022).

The fourth stage in PBL is develop and present real results. At this stage, students can develop and present the work that has been made. In implementing STEM integrated PBL, students also produce simple reports. The study results show that the Technology component is commonly integrated at this stage. In addition to producing solutions, students also produce products in the form of problem-solving tool designs. Writing a report requires a range of academic abilities from students, including writing science concepts and mathematical abilities to outline the procedures in a systematic manner (Arisa & Sitinjak, 2022). In the last stage, analyze and evaluate the problem solving process, groups present their designs in the learning environment and discuss what should be done to improve the design.

Theme 2. The Effects for Students

STEM integrated PBL develops some of the most important characteristics of students in science learning. According to several studies, STEM integrated PBL encourages students to think critically in finding solutions to problems. Through STEM, students are trained to be able to think critically, students can have the ability to solve problems (Arisa & Sitinjak, 2022; Nurazmi & Bancong, 2021; Shamdas, 2023; Topsakal et al., 2022; Zulfawati et al., 2022). Study by Zulfawati et al. (2022) showed that each student has the basic ability to solve problems and provide alternative solutions or ideas, accordingly to the student’s level of understanding. Students have the freedom to develop activities in finding concepts, identifying, and solving problems so that students can work actively in groups (Prastika et al., 2022).

Table 3. Roles of STEM integrated PBL in science learning from the studies

Roles	Study	Percentage (%)
science process skills	(Awalin & Ismono, 2021)	6.6
science literacy	(Bahriah & Irwandi, 2018)	6.6
competence	(Rihhadatul’aysi et al., 2018)	6.6
critical thinking skills	(Arisa & Sitinjak, 2022; Febrianto et al., 2021; Nurazmi & Bancong, 2021; Prastika et al., 2022; Shamdas, 2023; Zulfawati et al., 2022)	46.6
achievement	(Usman et al., 2023)	6.6
attitudes and career perceptions	(Sarı et al., 2018)	6.6
conceptual	(Prastika et al., 2022)	6.6
learning interest	(Syukri & Ernawati, 2020)	6.6
problem solving skills	(Parno et al., 2019; Topsakal et al., 2022)	13.3
learning motivation	(Hasanah, Ritonga, et al., 2021)	6.6
Total		100

Utami et al. (2017) found that STEM integrated PBL develops students’ science process skills through the real-life problems. The aspects of science process skills are observe, formulate problems, make a hypothesis, controlling variables, analyzed and interprete the data (Utami et al., 2017). Students will observe the phenomena that the teacher present before coming up with a problem. Then, students can ask scientific questions in the form of problem formulations based on the phenomena that have been observed (Awalin & Ismono, 2021).

Previous study by Bahriah & Irwandi (2018) stated that STEM integrated PBL influences students' literacy skills. It provided a positive effect to the teaching and learning process which became more interactive and innovative, and also enhance the students' science literacy. A wider knowledge of scientific and mathematical ideas and how they apply to real-life situations can be achieved through STEM integrated PBL. The indicators of students' science literacy, namely explaining scientific phenomenon, designing and evaluating scientific investigation, and interpreting data and scientific evidence. Problem based learning do some learning stages that can develop those three indicators. In developing and presenting the work stage, students are directly involved with the evidence obtained based on the experiment that they had done. It is required for students to have training in presenting and utilizing scientific data as proof.

Study by Usman et al. (2023) found that STEM problem-based learning significantly improved mean achievement of students in learning of diffusion and osmosis concepts of biology. It can support students to learn actively and improve students' learning, as a result, increases students' achievement (Usman et al., 2023). Students are assisted in using the methods for problem-solving they have acquired from their prior knowledge and experiences when problem-based activities are implemented. People will require the ability to solve problems in their life. Furthermore, the two most important ideas for students to understand in the problem-based learning process are choosing and making a decision. Students are better at addressing difficulties because they think more critically and exhibit more practical attitudes (Topsakal et al., 2022).

According to Syukri & Ernawati (2020), giving problems at the beginning of learning makes students challenged to solve these problems and increased their learning interest. The interest referred to is a feeling of preference, a feeling of attraction, attention, focus, perseverance, effort, knowledge, skills, motivation, behavioral regulators, and the results of a person's or individual's interaction with certain content or activities (Syukri & Ernawati, 2020). STEM integrated PBL also enhances students' learning motivation. It makes students more active in solving problems and students are more enthusiastic in conducting experiments (Hasanah, Pada, et al., 2021). Besides that, the integration of technology and engineering aspects in science learning can encourage students to be better concepts and make the learning process more meaningful (Prastika et al., 2022).

Meta-theme. Implementation and Roles of STEM integrated PBL in Science Learning

STEM integrated PBL is more complex and emphasizes various disciplines. Students are encouraged to be able to connect their knowledge of material principles from other disciplines with STEM. The implementation of STEM integrated PBL is a STEM component (Science, Technology, Engineering, and Mathematics) integrated into the stages of problem based learning. STEM integrated PBL uses problem-based learning procedures to implement STEM education. STEM components are integrated in all five phases of problem-based learning (Febrianto et al., 2021). Students are inspired to develop technical engineering to address the challenges that are posed by STEM integrated PBL instruction (Awalin & Ismono, 2021). According to the review, the component of science in STEM is the science concept in life. The technology component is the use of ICT in learning, both as a learning medium and as a learning resource. Engineering component is learning through the practicum. Where students are asked to determine tools or materials and design experiments. The mathematical component is the formula of the material concept.

STEM integrated PBL develops some of the most important characteristics of students in science learning. STEM integrated PBL encourages students to think critically in finding solutions to problems. It also develops students' science process skills through the real-life problems. A broader understanding of scientific and mathematical concepts and their real-world applications can be gained through this model learning. In addition, STEM integrated PBL can also improve students' competence, critical thinking skills, achievement, career attitudes and perceptions, conceptualization, interest in learning, problem-solving skills, and learning motivation.

▪ CONCLUSION

The implementation of STEM integrated PBL is a STEM component (Science, Technology, Engineering, and Mathematics) integrated into the stages of problem based learning. STEM integrated PBL is more complex and emphasizes various disciplines. STEM integrated PBL uses problem-based learning procedures to implement STEM education. STEM components are integrated in all five phases of problem-based learning. This review provides evidence that STEM integrated problem based learning can enhance students' critical thinking, science process skills, science literacy, achievement, problem solving skills, learning interest, learning motivation, and conceptual understanding in science learning. Therefore, science learning problems related to these variables have the potential to be overcome using STEM integrated PBL.

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