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Evaluating the Impact of Problem Based Learning on Student's Metacognition in Science Learning: A Meta-Analysis Review

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Abstract: This study aims to evaluate the impact of problem-based learning models on students' metacognition in science learning. This type of research is a meta-analysis using the PRISMA 2020 method. Articles from Scopus and Google Scholar databases were collected using Publish or Perish (PoP) software. From 8 articles that met the inclusion criteria, a total of 20 data were obtained to be processed in the meta-analysis. Data analysis was used with JASP software.The results of this metaanalysis research show that problem-based learning model provides moderate effectiveness on students' metacognition in science learning (r RE = 0.67; SE = 0.16; z = 4.24; $p < 0.001$). This shows that problem-based learning model can improve students' metacognition in science learning. Through PBL, students become more aware of their cognitive strategies and learn to organise them more effectively. Incorporating PBL into the science curriculum can significantly improve students' metacognition, leading to more independent and effective students. Therefore, widely adopting PBL in science education is recommended to achieve better learning outcomes.

Keywords: Meta-analysis review; Problem based learning; Student's metacognition in science learning

Introduction

Science education is essential in shaping student's understanding of the natural world, which includes physical and natural sciences that are key to fostering critical thinking and problem-solving abilities. The goal is to foster a thorough understanding of scientific concepts and processes, empowering students to utilize scientific knowledge in practical situations. Effective science learning requires engaging learning strategies. Such strategies include inquiry-based learning and hands-on experiments. According to National Research Council (2012), active learning approaches significantly improve students' understanding of scientific principles. Science learning involves the acquisition of knowledge through systematic study and experimentation. One example of skills that can support this science learning is the development of metacognitive skills, which enable students to manage their own learning processes, leading to more effective educational outcomes. Moreover, metacognitive skills are crucial for helping students plan, monitor, and evaluate their learning strategies, which enhances their understanding and retention of scientific concepts (Schraw et al., 2006; Zohar & Barzilai, 2013).

Metacognition, first introduced by Flavell in 1979, comprises two primary components: "metacognitive knowledge" and "metacognitive regulation". "Metacognitive knowledge," also known as "metacognitive awareness," refers to an individual's

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understanding or beliefs regarding person, task, and strategy variables (Flavell, 1976). This knowledge is divided into three parts: declarative, procedural, and conditional knowledge. The second component, metacognitive regulation, refers to the skills students use to manage their learning or thinking, including planning, monitoring, and evaluating. Thus, the two primary components of metacognition can be divided into six subparts: declarative knowledge, procedural knowledge, conditional knowledge, planning, monitoring, and evaluation.

Metacognition, commonly described as "thinking about thinking," is a complex concept involving our capacity to reflect on, comprehend, and manage our cognitive processes (Perales et al., 2023). This includes the awareness and regulation of one's cognitive activities, such as planning, monitoring, and evaluating learning and problem-solving strategies (Feng Teng, 2023). This regulatory system enables individuals to evaluate their learning needs, develop strategies to address them, and execute these strategies efficiently. Metacognition is not only about being aware of one's cognitive processes but also involves the active management and regulation of these processes before, during, and after engaging in a particular task or learning activity (Dayan, 2023). Metacognitive knowledge, one of the components of metacognition, includes understanding one's cognitive abilities, the nature of the tasks at hand, and the strategies that can be used to deal with these tasks (Hasibuddin, 2022). Another aspect, metacognitive awareness, is essential for deep learning and critical thinking, as it allows individuals to think about their own thinking or knowledge and how they understand a subject (Silistraru & Vetrila, 2023). This awareness is essential for self-directed learning, enabling students to plan, monitor, and evaluate their learning processes and outcomes (Templer, 2022).

Metacognitive skills are crucial for effective problem solving and critical thinking, enabling students to reflect on their thought processes and adapt their strategies. Research indicates that these skills enhance academic performance across various subjects (Schraw & Dennison, 1994). Improving metacognitive skills helps students become more autonomous and effective learners (Dunlosky & State, 2009). Therefore, developing metacognitive is one of the goals in education. One of the effective instructional strategies to develop metacognition is by using problem-based learning (PBL) model, which directly involves students in the learning process.

Problem-based learning is a student-centred approach that uses real-life problems to develop problem-solving and critical thinking skills in learning, ultimately improving academic achievement and positive attitudes towards learning (Nicholus et al., 2023). PBL is rooted in constructivist theory, where students construct knowledge and develop higher-order thinking and self-learning skills through solving complex, unstructured problems (Schmidt et al., 2011). This model encourages students to engage in independent learning and collaborative problem solving. The PBL model helps train and prepare students from the start to recognise problems and think of appropriate and quick solutions (Hasanah et al., 2023). In PBL, students work in groups to solve complex problems, which encourages active learning and critical thinking. This method differs from traditional teaching approaches that rely heavily on memorisation. Originally, Barrows et al. (1981) developed PBL for medical education, but it has subsequently been adapted for a variety of educational contexts. PBL has been shown to increase student motivation and engagement in learning (Hmelo-Silver, 2004). In addition, PBL also aids students in cultivating essential skills like teamwork and communication (Schmidt et al., 2011). Understanding how PBL enhances these skills involves exploring the relationship between PBL and metacognition which reveals potential wider educational benefits.

The link between problem-based learning (PBL) and metacognition is vital, as PBL enables students to enhance their metacognitive skills by requiring them to organize, monitor, and assess their learning processes. This approach heightens their awareness of cognitive strategies and improves their ability to manage them. Numerous studies Hmelo-Silver (2004) and Schmidt et al. (2011) support this connection between PBL and metacognition. PBL provides students with the chance to practice and refine their metacognitive skills by requiring them to organize, monitor, and evaluate their learning experiences, which is a metacognitive process. Through PBL, students become more aware of their cognitive strategies and learn to organise them more effectively. This relationship between PBL and metacognition is supported by various studies (Hmelo-Silver, 2004; Schmidt et al., 2011). PBL's emphasis on self-directed learning is aligned with the goal of developing metacognitive skills. Therefore, integrating PBL in science learning can improve student's metacognitive skills. This relationship is further illustrated by several studies that have examined the impact of PBL on student's metacognitive skills, reinforcing its learning value.

The novelty of this study is that no previous research has explored the effect of problem-based learning model on students' metacognition in science education, although there are many studies on the model itself. Based on this, this study uses meta-analysis techniques to review previous research on the impact of problem-based learning models on student's metacognition in science learning. The study of statistical analysis methods known as "meta-analysis" combines the accuracy of several scientific studies with findings from a review of quantitative research. Retnawati et al. (2018) stated that the purpose of meta-analysis is to generate new hypotheses for investigation by evaluating statistical power, generalisability of results, accuracy in measuring impact, and lowering the danger of false negative results. Because there are few studies on how problem-based learning influences student's metacognition in science learning, researchers want to do a meta-analysis. Thus, the purpose of this study is to evaluate the impact of problem-based learning model on students' metacognition in science learning.

Method

Research Design

This research method, referred to as meta-analysis, entails the systematic collection, tracking, and statistical examination of primary (Apra et al., 2021; Aybirdi, 2023; Kaçar et al., 2021; Öztürk et al., 2022; Santosa et al., 2023) This study aims to quantitatively evaluate the existing research on how the problem-based learning model impacts student's metacognition in science learning.

Data Collection Procedure

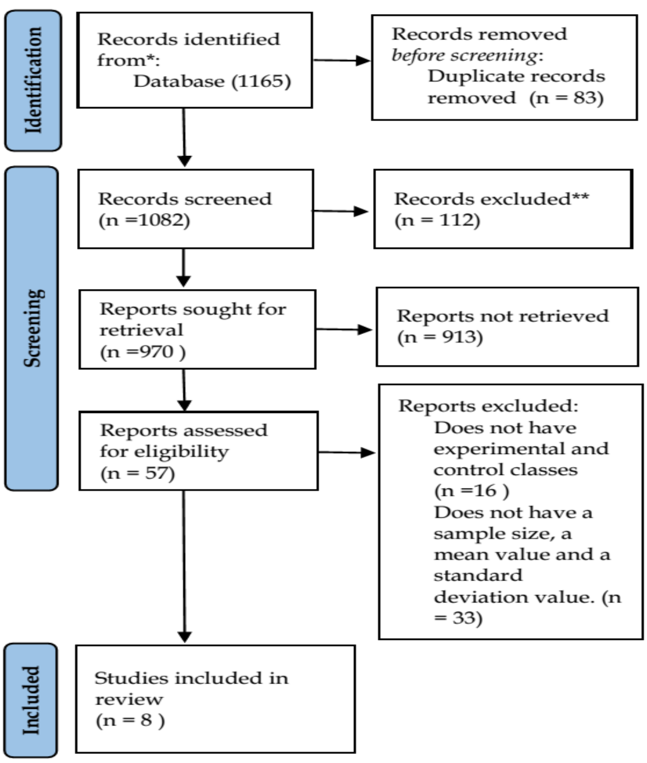

Figure 1. Data selection process through the PRISMA 2020 method

This research employs the PRISMA 2020 method, which encompasses the stages of identification, screening, and inclusion (Page et al., 2021) which can be seen in Figure 1. The initial stage of research research in the identification section involved information sources from various databases such as Scopus and Google Scholar, with articles collected using Publish or Perish (PoP) software by typing keywords ("problem based learning" OR "PBL") AND ("metacognition" OR "metacognitive") in the "new google scholar search" and "new scopush search" sections so that 1165 initial data were obtained. After being entered into the mendeley application, some articles were discarded due to duplication. Furthermore, these articles were selected through several eligibility criteria so that the final articles would be analysed.

Eligibility Criteria

The eligibility criteria for articles included in this meta-analysis in the screening section were: 1) research published between 2013 and 2024; 2) data from journals or proceedings; 3) studies focused on science learning; 4) use of an experimental method with both experimental and control classes; and 5) reports providing complete data for effect size calculation, including sample sizes, mean values, and standard deviation values. At the includeed stage, 8 articles were found that met the inclusion criteria.

Data Coding

In meta-analysis, coding plays a crucial role. It simplifies data analysis and facilitates the study process. Coding based on data characteristics includes the following elements: 1) author, 2) subject, 3) year of publication, 4) effect size, and 5) standard error.

Data Analysis

In meta-analysis research, the calculation of effect size values is a pivotal aspect of data analysis (Borenstein et al., 2009; Chamdani et al., 2022; Glass, 1976). According to , the statistical analysis procedures involve: 1) determining the effect size of the primary study, 2) selecting the estimation model via a heterogeneity test, 3) assessing publications for bias, and 4) calculating the p-value to test the hypothesis. In this study, data analysis was conducted using JASP 0.18.3.0 software. The criteria for effect size, as outlined by {Formatting Citation} , are presented in Table 1.

Table 1. Cohen's Effect Size Criteria

Effect size	Cateory
$0.00 \leq d \leq 0.20$	Low
$0.20 \leq d \leq 0.80$	Moderate
$d \geq 0.80$	High

Result and Discussion

Based on the results of the data selection process through the PRISMA 2020 method related to keywords that have been typed in research on problem-based learning models on students' metacognitive in science learning and after going through several eligibility criteria, only 8 articles meet the inclusion criteria. Some of the causes of the few articles obtained from this inclusion stage include because many of the initial articles did not discuss in the scope of science, in the article did not have experimental and control classes and many articles did not report complete data to calculate effect size such as including the number of samples of experimental and control classes, mean values and standard deviation values. Of the 8 articles, two compared a single experimental class (PBL) with two control classes, resulting in two data points from each article. Another two articles compared experimental and control classes across six sub-components of metacognition (declarative knowledge, procedural knowledge, conditional knowledge, planning, monitoring, evaluation), yielding 12 data points. In total, 20 data points were collected for the meta-analysis. The final data analysis, as presented in Table 2, took into account the research code's characteristics, the subject, the year of publication, the effect size, and the standard error.

Table 2. Effect Size and Standard Error of 21 Data Sets

Article code	Subject	Publication year	Effect size	Standard error
MA 1a	Biology	2015	1.54	0.26
MA 1b	Biology	2015	1.60	0.26
MA 2a	Natural science	2018	0.38	0.28
MA 2b	Natural science	2018	0.60	0.29
MA 2c	Natural science	2018	0.32	0.28
MA 2d	Natural science	2018	0.65	0,29
MA 2e	Natural science	2018	0.40	0.28
MA 2f	Natural science	2018	0.30	0.28
MA 3	Physics	2017	1.51	0.27
MA 4	Biology	2023	1.17	0.27
MA 5	Natural science	2024	1.68	0.45
MA 6a	Biology	2018	-1.13	0.26
MA 6b	Biology	2018	-0.72	0.26
MA 7	Chemistry	2019	0.53	0.26
MA 8a	Chemistry	2013	0.79	0.26
MA 8b	Chemistry	2013	0.61	0.25
MA 8c	Chemistry	2013	0.81	0.26
MA 8d	Chemistry	2013	0.97	0.26
MA 8e	Chemistry	2013	1.02	0.26
MA 8f	Chemistry	2013	0.59	0.25

Table 2 shows the results of the analysis of the characteristics of articles published in 2013-2024 in science learning. Of the 20 data analysed, there are 2 data whose effect size is negative. This is just a sign to show that the control class results are higher than the experimental class results (for Cohen's effect size criteria, this negative sign remains absolute). The effect size values of the 20 data analysed ranged from 0.30 to 1.68. Based on Cohen's effect size category, there are nine research data in the large category (55%) and eleven research data in the medium category (45%). The criteria for each of these data can be seen in the Cohnen's effect size criteria table contained in Table 1 which has been displayed previously. Then, after obtaining the effect size value and standard error value of the 20 data, the effect size value and standard error of the 20 data were entered into the JASP software for further analysis.

Table 3. Heterogeneity Test Results

	Q	df	p
Omnibus test of model coefficients	17.10	1	< .001
Test of residual heterogeneity	128.34	19	< .001

Once data processing with JASP software is finalized, the subsequent step involves conducting a heterogeneity test and selecting the appropriate estimation model to calculate the average effect size from the 20 data results. Table 3 presents the outcomes of the heterogeneity test and the chosen estimation models, both random and fixed.

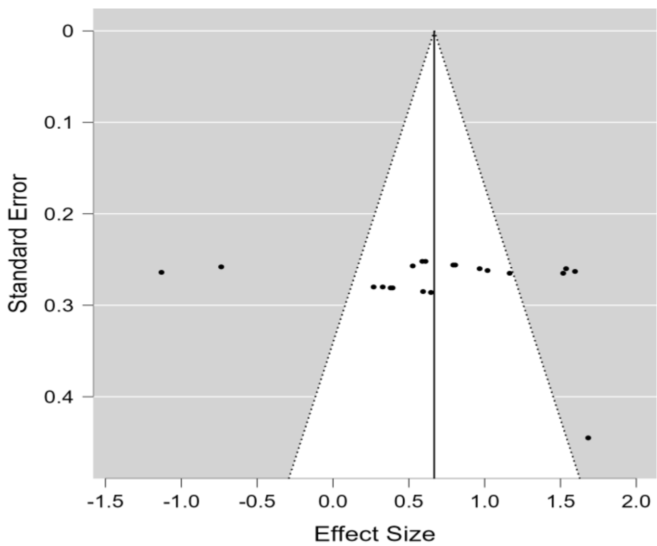

Figure 2. Funnel plot of standard error

Table 3 presents the results of the heterogeneity test, which yielded a Q value of 128.34, significantly higher than the threshold value of 17.10, with a p value <0.001. This indicates that the effect sizes analyzed are heterogeneously distributed, validating the use of the random effects model for evaluating the average effect size across the 20 studies in the meta-analysis. Subsequently, publication bias was assessed for the 20 included studies using funnel plots of standard errors and Rosenthal Fail Safe N (Bernard et al., 2014; Juandi et al., 2021; Li & Wang, 2022; Suryono et al., 2023), with the biased results depicted in Figure 2.

As illustrated in Figure 2, performing the Rosenthal Fail Safe N (FSN) test is crucial due to the difficulty in assessing the symmetry of the funnel plot, with the FSN test results detailed in Table 4. Table 4 indicates that k equals 20, making 5k + 10 equal to 110. Additionally, with a significance target of 0.050 and p < 0.001, the Fail Safe N value is 854,00. This meta-analysis data demonstrated resistance to publication bias, with no data added or removed, resulting in a Fail Safe N greater than 5k + 10. To determine the p-value, the summary or mean effect size was calculated, as shown in Table 5.

Table 4. Rosenthal Fail Safe N (FSN) Test Results

	Fail-safe N	Target significance	Observed significance
Rosenthal	854.00	0.050	< .001

Table 5. Summary Effect Size Test Results

	Estimate	Standard error	z	p	95% Confidence interval	
					Lower	Upper
Intercept	0.67	0.16	4.24	< .001	0.36	0.98

Table 5 details the effect size values derived from the random effects model (r RE = 0.67; SE = 0.16; z = 4.24; p < 0.001), revealing that the problem-based learning paradigm significantly enhances student's metacognition in science learning at the 95% confidence level, with effect size values ranging from 0.36 to 0.98. This medium-category impact (r RE = 0.67) underscores the positive influence of problem-based learning on student's metacognition in science learning.

This study supports the findings of other researchers, namely research (Anjelina et al., 2021; Hidayah et al., 2022; Siagian et al., 2019; Yuan et al., 2020) who found that the use of the PBL model can improve student's metacognitive skills. Several other studies have also examined the impact of PBL on students' metacognitive abilities. For example, a study by Sungur et al. (2010) found that PBL significantly improved student's metacognitive awareness and regulation. Their research showed that PBL helped students develop better planning and monitoring strategies. Similarly, research by Loyens et al. (2008) showed that students in PBL environments exhibited higher levels of metacognitive regulation compared to students in traditional environments. In addition, Pekrun et al. (2002) showed that PBL environments promote emotional regulation, which is closely related to metacognition. This research highlights the interrelationship between cognitive and emotional processes in learning. These contemporary studies further validate the effectiveness of PBL in fostering metacognitive skills.

PBL usually starts by introducing students to an open-ended, real-world problem. Students then work together to determine their learning needs and create solutions, with the instructor acting as a facilitator rather than the main source of information (Prince & Felder, 2006). The essence of PBL lies in providing students with authentic and meaningful problem situations to improve their problem-solving abilities (Yanto et al., 2021). The approach is characterised by being student-directed, fostering intrinsic motivation, promoting active and deep learning, incorporating peer teaching, drawing on student's pre-existing knowledge, encouraging reflection, developing collegial learning skills, supporting a research-oriented curriculum, and valuing timely feedback for self-assessment and peer assessment (Major & Mulvihill, 2017).

PBL is designed to facilitate the development of higher-order competences and transferable skills that are increasingly demanded by various sectors of activity (Ertmer & Simons, 2006). PBL allows students to solve problems in a variety of ways, encourages open-ended learning, and promotes deep learning (Nugraha et al., 2018). Furthermore, PBL seeks to enhance students' problem-solving abilities through self-directed learning and collaborative efforts while promoting lifelong learning habits (Kamala et al., 2022; Zahra & Samsi, 2022). In PBL, students are motivated by complex and real problems that encourage them to identify and research the concepts and principles needed to solve the problem (Albanese & Dast, 1993). Students utilize prompts from cases or problem scenarios to establish their own learning goals, highlighting self-directed learning and problem-solving skills (Wood, 2003). The PBL process usually involves steps such as problem analysis, discovery, solution presentation, reflection, and evaluation (Ashnam et al., 2022).

Problem-based learning (PBL) has been widely researched for its effectiveness in enhancing student's metacognitive skills (Asmi et al., 2019; Chen et al., 2017; Fitriyani & Duran Corebima, 2015; Kuvac & Koc, 2019; Ramdoniati et al., 2018; Shamdas, 2023, 2024; Tosun & Senocak, 2013; Zulfiani et al., 2018). These skills, which include the conscious regulation of cognitive processes, significantly improve problem-solving abilities (Mufhtih et al., 2021). Studies have demonstrated that implementing PBL positively influences student's metacognitive abilities and science process skills (Awaliah & Ikhsan, 2021).

Metacognition is used to increase one's awareness of their thinking and learning processes. With this awareness, individuals can control their thoughts through planning, monitoring and evaluating what they learn (Rahmadhni & Chatri, 2023). Metacognition significantly contribute to minimizing misconceptions during the problem-solving process in science education (Nasrudin & Azizah, 2020). In addition, the development of metacognitive skills is essential to identify one's level of awareness, train heuristic problem solving, and improve problem solving skills (Utami et al., 2020). Metacognitive skills empower students to organize, manage, evaluate, and reflect on their learning process, helping them identify their strengths and areas needing improvement (Sartina et al., 2022). Research has also highlighted the importance of metacognitive skills in enhancing creative thinking and originality in student work (Safitri & Kuntjoro, 2018). Metacognitive skills are essential for individuals in solving problems effectively (Yusnaeni & Corebima, 2017).

Metacognition, which has strong roots in cognitive and educational psychology, refers to an individual's awareness of and control over their cognitive processes. It involves knowledge of one's thinking, the ability to monitor and regulate cognitive activity, and the capacity to reflect on and evaluate one's learning strategies (Craig et al., 2020; Ramadhanti & Yanda, 2021; Schaeffner et al., 2020). Metacognitive ability includes various dimensions such as metacognitive awareness, regulation, and evaluation, which enable individuals to assess their progress, choose appropriate strategies, and make decisions about their learning process (Huda et al., 2016; Nurhidayah, 2022; Safitri & Suryani, 2022). Moreover, metacognition plays an important role in various domains including problem solving, memory, communication, and personality development (Setiawan et al., 2020).

Therefore, science learning, metacognition and problem-based learning are interconnected in promoting effective learning. Science learning benefits from engaging learning strategies that enhance understanding and application. Metacognition is crucial for students to effectively manage their learning process, and problem-based learning provides a practical method to enhance both cognitive and metacognitive skills. Research consistently shows that PBL improves student's metacognitive abilities, making it a valuable method in science education. Integrating PBL into the science curriculum can result in more effective and independent students, ultimately improving educational outcomes. This interconnected approach ensures that students are well-equipped to navigate complex scientific concepts and real-world problems, preparing them for future challenges. The long-term benefits of PBL, as evidenced by continuous improvements in metacognitive strategies and deeper cognitive engagement, highlight its potential in promoting lifelong learning and critical thinking in students. This metaanalysis aims to synthesise existing research on the effectiveness of PBL in promoting metacognition, providing a comprehensive overview of its impact and implications for science learning practices.

Conclusion

The results of this metaanalysis research show that problem-based learning model provides moderate effectiveness on students' metacognition in science learning (r RE = 0.67; SE = 0.16; z = 4.24; $p < 0.001$). This shows that problem-based learning model can improve students' metacognition in science learning. Through PBL, students become more aware of their cognitive strategies and learn to organise them more effectively. Incorporating PBL into the science curriculum can significantly improve students' metacognition, leading to more independent and effective students. Therefore, widely adopting PBL in science education is recommended to achieve better learning outcomes.

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Conflicts of Interest
The authors declare no conflict of interest.

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