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The Influence of Problem Based Learners on Students' Mathematical Thinking Ability in Understanding and Applying Polya Stages

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Keywords
Problem Based Learning; Mathematical Thinking Skills; Meta-analysis

Abstract
The purpose of this study is to determine the influence of problem-based learning on students' mathematical ability in understanding and applying polya stages. This research is a type of quantitative research with a meta-analysis approach. The sample of this study comes from 13 studies indexed by Sinta or Scopus published in 2021-2024. The data collection technique is direct observation with the PRISMA data selection method. The data analysis in this study is a quantitative analysis by calculating the effect size value with the help of the JASP application. The results of the study concluded that the problem-based learning model provided a significant impact on students' mathematical thinking ability in understanding and applying polya stages with a value of (d = 1.042; p < 0.001) with a medium effect size category

1. INTRODUCTION

The ability to think mathematically has an important role in everyday life because it is the basis for complex and logical problem-solving. In many situations, individuals are faced with problems that require data analysis, pattern identification, as well as decision-making based on available information(Abdullah et al., 2010). Mathematical thinking allows one to understand problems in depth, formulate appropriate solutions, and critically evaluate outcomes. For example, this ability is needed in managing personal finances, completing calculations in technical work, and designing strategic solutions in management (Aljaberi, 2015). In an increasingly data- and technology-driven world, mathematical thinking skills are essential skills that support individual success in various areas of profession and life (Asnur et al., 2024).

In the context of education, mathematical thinking skills not only help students understand mathematical concepts, but also practice higher-order thinking skills, such as analysis, synthesis, and evaluation. This ability is the foundation for learning other subjects that require logic and problem solving, such as science and technology (Widiana et al., 2018; Arfiana & Wijaya, 2018). Furthermore, mathematical thinking skills help students develop mental resilience in facing challenges, by thinking systematically and focusing on solutions (Olatide, 2015). Therefore, it is important for the education world to pay more attention to the development of these skills through learning approaches that encourage students to actively think, such as Problem-Based Learning, in order to equip them with relevant skills in facing real-life challenges (Anwar & Rahmawati, 2017).

Mathematics education has a central role in building logical, critical, and systematic thinking skills in students. In mathematics learning, students are trained to identify problems, analyze data, and draw conclusions based on the principles of structured logic (Hendriana et al., 2018). This process helps students develop a logical mindset that is not only relevant in understanding mathematics, but can also be applied in various aspects of daily life. In addition, math education encourages students to think critically by evaluating solutions, identifying mistakes, and improving the problem-solving process. This ability is the basis for students to face challenges that require in-depth analysis and sound decision-making (Suparman et al., 2022; Putra et al., 2020).

Furthermore, mathematics education teaches students to think systematically, that is, to arrange clear and regular steps in solving problems. This approach trains students to not only focus on the end result, but also understand the process that goes through to achieve it (Putra et al., 2020). This ability to think systematically is an important provision in dealing with complex problems in the real world, such as in project management, data analysis, or even strategic decision-making (Jahudin & Siew, 2024). Thus, mathematics education not only aims to master numbers and formulas, but also to form individuals who are able to think logically, critically, and systematically in various aspects of life (Marchy et al., 2022).

Students' difficulties in understanding and applying the stages of mathematical problem solving, as outlined in the Polya model, are a challenge that is often encountered in mathematics learning. The Polya model, which consists of four main steps (understanding the problem, planning a solution, executing the plan, and evaluating the results), requires the ability to think logically, critically, and systematically (Hilmiyati et al., 2024). Many students have difficulty in the first stage, which is understanding the problem. This is due to the lack of students' ability to analyze available information, identify important elements, or understand the context of the problem in depth. As a result, subsequent steps such as planning and executing solutions become ineffective, due to inaccurate initial understanding. In addition, at the stage of planning solutions, students often face difficulties in choosing the right strategy or method to solve the problem (Youna Chatrine Bachtiar et al., 2023). Their lack of experience in implementing various problem-solving approaches makes them more likely to try methods on a trial-and-error basis, which is often inefficient. Another difficulty arises at the evaluation stage, where students tend to neglect the steps to re-examine the solutions that have been created (Prapti et al., 2023). This habit reduces students' ability to identify mistakes and learn from the process. This overall challenge demonstrates the need for learning approaches that encourage active student engagement, such as Problem-Based Learning, to help them understand and apply the Polya stages more effectively. Therefore, it is necessary to have a learning model to encourage mathematical thinking skills in understanding and applying the stages of polya, namely the problem-based learning model (Fitriani et al., 2022).

The Problem based learning model is an innovative learning model that puts students at the center of learning, encouraging them to actively think, solve problems, and discuss collaboratively (Arifin, 2020). In PBL, students are faced with authentic problems that are relevant to real life, which they must solve through a process of exploration and analysis. This method allows students to develop critical and creative thinking skills, as they must formulate problems, design solutions, and evaluate the results independently or in groups. This approach also helps students build a deeper understanding of learning concepts, as they are directly involved in the process of finding solutions, rather than just passively receiving information (Chu & Takahashi, 2024).

In addition, PBL encourages students to discuss and work together in teams, which hones communication, collaboration, and conflict management skills. Through group discussions, students can exchange ideas, defend arguments logically, and accept different perspectives (Arifin, 2020). This approach also strengthens interpersonal skills and builds students' confidence in conveying their ideas. In the context of mathematics learning(Boonsathirakul & Kerdsomboon, 2023) , PBL provides an effective framework for understanding and solving complex problems, including the application of Polya stages. With students' active involvement in every stage of the learning process, PBL not only enhances cognitive abilities, but also equips them with 21st-century skills that are essential for facing future challenges (Oktarina et al., 2021).

Research by Hmelo-Silver (2004), PBL is effective in building problem-solving skills because students are directly involved in the process of identifying, analyzing, and solving problems. This study highlights how PBL provides a meaningful learning context, making it easier for students to understand mathematical concepts and apply them in real-life situations. Similar findings were also expressed by Dochy et al. (2003), who concluded that students who learn to use PBL have a deeper understanding and are able to think critically than students who use traditional learning methods.

In the context of mathematical problem solving, research by Kaur (2017) shows that the Polya stages—understanding the problem, planning the solution, executing the plan, and evaluating the results—become easier to apply through the PBL approach. This study reveals that PBL encourages students to better understand the context of the problem before formulating a solution, so that the results achieved are more effective and relevant. In addition, research by Prihatnani & Hidayat (2020) states that the use of PBL helps students develop logical and systematic thinking skills that are important in solving mathematical problems. Based on this previous research, there is a gap in understanding how much PBL affects students' ability to effectively implement all stages of Polya, which is the focus of this study

2. RESEARCH METHODS

This study uses a meta-analysis approach to investigate the influence of Problem Based Learning (PBL) on students' mathematical thinking ability in understanding and applying the Polya stages. The meta-analysis method was chosen to synthesize and integrate the results of previous research related to the topic (Tamur et al., 2020; Zulkifli et al., 2022; Zulyusri et al., 2023; Ichsan et al., 2023; Nurtamam et al., 2023), with the aim of obtaining a comprehensive picture of the effectiveness of PBL in the development of mathematical thinking skills. The research process will begin with a systematic search of scientific articles from various electronic databases such as Google Scholar, ERIC, Scopus, and Web of Science, using specific keywords that include Problem Based Learning, mathematical thinking skills, and Polya stages.

Inclusion criteria for the articles to be analyzed include publications in accredited journals within the last 3 years, research using experimental or quasi-experimental designs, and a focus on mathematics education at the secondary school level. The article selection process will be carried out through several stages: initial screening based on title and abstract, then followed by full-text assessment of the article, and data extraction using standard instruments. The variables to be analyzed include effect size, PBL intervention characteristics, research context, and indicators of students' mathematical thinking ability based on Polya stages. Data analysis will use the statistical method of random effects model to estimate the combined effect, taking into account heterogeneity between studies through the Cochran Q and I-squared tests. Furthermore, the effect size criteria in this study can be seen in Table 1.

Tabel 1. Kriteria Nilai Effect Size

Effect Size	Category
$0.0 \leq ES \leq 0.2$	Low
$0.2 \leq ES \leq 0.8$	Medium
$ES \geq 0.8$	High

Source :(Wantu et al., 2024; Ali et al., 2024; Solissa et al., 2023)

3. RESULT AND DISCUSSION

Based on the results of data search through the database, 24 studies/articles met the inclusion criteria. The effect size and error standard can be seen in Table 2.

Table 2. Effect Size and Standard Error Every Research

Code Jurnal	Years	Effect Size	Standard Error
R1	2023	0.88	0.20

R2	2023	1.23	0.42
R3	2023	0.93	0.34
R4	2022	0.75	0.29
R5	202	0.48	0.21
R6	2021	0.33	0.14
R7	2024	1.19	0.38
R8	2024	1.67	0.41
R9	2024	0.82	0.29
R10	2024	0.61	0.17
R11	2023	0.93	0.37
R12	2024	0.79	0.30
R13	2024	0.94	0.41

Based on Table 2, the effect size value of the 24 studies ranged from 0.49 to 2.91. According to Borenstein et al., (2007) Of the 24 effect sizes, 4 studies had medium criteria effect sizes and 9 studies had high criteria effect size values. Furthermore, 13 studies were analyzed to determine an estimation model to calculate the mean effect size. The analysis of the fixed and random effect model estimation models can be seen in Table 3.

Table 3. Fixed and Random effect

	Q	df	p
Omnibus test of Coefficients Model	47.925	1	< 0.001
Test of Residual Heterogeneity	62.092	23	< 0.001

Based on Table 3, a Q value of 62.092 was obtained higher than the value of 47.925 with a coefficient interval of 95% and a p value of 0.001 <. The findings can be concluded that the value of 13 effect sizes analyzed is heterogeneously distributed. Therefore, the model used to calculate the mean effect size is a random effect model. Furthermore, checking publication bias through funnel plot analysis and Rosenthal fail safe N (FSN) test (Tamur et al., 2020; Badawi et al., 2022; Ichsan et al., 2023b; Borenstein et al., 2007). The results of checking publication bias with funnel plot can be seen in Figure 2.

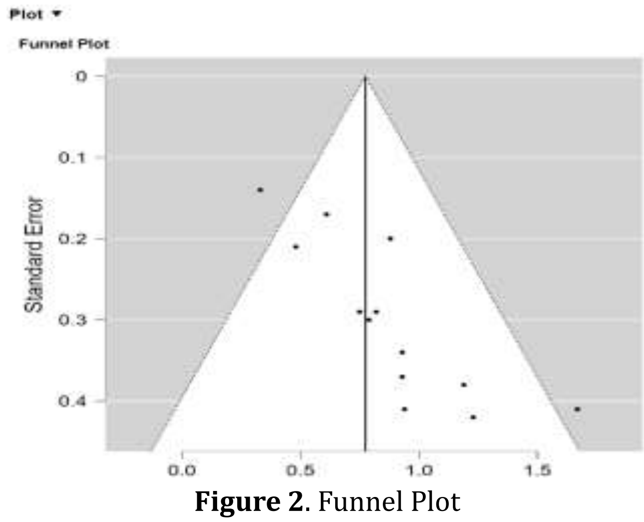

Figure 2. Funnel Plot

Based on Figure 2, the analysis of the funnel plot is not yet known whether it is symmetrical or asymmetrical, so it is necessary to conduct a Rosenthal Fail Safe N (FSN) test. The results of the Rosenthal Fail Safe N calculation can be seen in Table 4.

Tabel 4. Fail Safe N

File Drawer Analysis			
	Fail Safe N	Target Significance	Observed Significance
Rosenthal	531	0.050	< 0.001

Based on Table 4, the Fail Safe N value of 2504 is greater than the value of 5k + 10 = 5(13) + 10 = 65, so it can be concluded that the analysis of 13 effect sizes in this data is not biased by publication and can be scientifically accounted for. Next, calculate the p-value to test the hypothesis through the random effect model. The results of the summary effect model analysis with the random effect model can be seen in Table 5.

Tabel 5. Summary/ Mean Effect Size

Coeficient						
	Effect Size	Standard Error	z	p	Coeficient Interval	
					Lower	Upper
Intercept	0.778	1.052	8.204	< 0.01	0.586	1.32

Based on Table 5, the problem-based learning model provides a significant impact on students' mathematical thinking ability in understanding and applying polya stages with a value ($d = 0.778$; $p < 0.001$) with a moderate effect size category. A learning model designed to improve students' critical and analytical thinking skills by presenting real problems as a starting point for learning. In the context of mathematics, PBL has great potential to help students understand and apply the stages of problem solving proposed by Polya (Brijlall, 2015). The Polya stage, which includes understanding the problem, planning the solution, executing the plan, and reviewing the results, is an important foundation in the development of mathematical thinking skills. With PBL, students can be actively involved in the learning process, allowing them to explore, analyze, and solve problems with a more structured approach (Suparman et al., 2022; Putra et al., 2020).

The implementation of PBL in mathematics learning provides opportunities for students to collaborate in solving problems. In this process, the teacher acts as a facilitator who guides students through each stage of Polya (Jahudin & Siew, 2024). This approach encourages students to identify and understand problems in depth before designing solutions. In addition, PBL helps students relate mathematical concepts to real-life situations, thereby increasing the relevance of learning (Marchy et al., 2022). This increased understanding contributes to their ability to design effective settlement strategies. PBL provides opportunities for students to hone their thinking skills at each stage of Polya. In the first stage, which is to understand the problem, students are trained to analyze relevant information, identify the necessary data, and formulate the problem clearly (Hanny Nurhikma Prapti et al., 2023). Furthermore, at the stage of planning a solution, students can discuss with peers to explore different possible approaches. The third stage, which is implementing the plan, involves implementing the steps that have been designed to solve the problem. Finally, the outcome review stage requires students to reflect on their solutions, evaluate the accuracy of the results, and look for ways to improve if needed (Ahdhianto et al., 2020).

Mathematical thinking skills include various aspects such as analysis, synthesis, evaluation, and logical reasoning. PBL, with its problem-solving-based approach, encourages students to develop these abilities in more depth. When students are faced with complex problems, they must use higher-order thinking skills to identify patterns, make generalizations, and develop logical arguments (Mulyono & Hadiyanti, 2018). This process not only improves their conceptual understanding but also the ability to apply mathematics in a variety of contexts. In addition, the application of PBL can improve mathematics learning outcomes, including students' mathematical thinking skills. By using PBL, students not only learn to solve problems but also develop metacognition, which is awareness of how they think and learn. In addition, PBL provides a space for students to explore innovative solutions and foster independence in learning (Astriani et al., 2017; Maulyda et al., 2019). Success in implementing PBL is highly dependent on teachers' support in creating a conducive learning environment and motivating students to be actively involved.

Conclusion

From the results of this meta-analysis, it can be concluded that the problem-based learning model provides a significant impact on students' mathematical thinking ability in understanding and applying polya stages with a value ($d = 0.778$; $p < 0.001$) with a high effect size category. Through PBL, students are actively involved in the learning process, from identifying problems, designing solutions, to evaluating results. This approach not only improves the understanding of mathematical concepts, but also helps students develop critical, analytical, and reflective thinking skills. In addition, by presenting contextual problems, PBL is able to increase students' motivation and involvement in learning, so that they are more confident in facing complex mathematical problems.

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