Meta Analysis: The Effect of Challenge Based Learning on Mathematics Thinking Ability

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Abstract

This research aims to analyse the effect of implementing the Challenge Based Learning (CBL) model on students' mathematics thinking ability through a meta-analysis approach. Although mathematics plays an important role in developing students' mathematics thinking ability, international studies such as PISA show that mathematical skills in Indonesia are low. One strategy to improve these skills is through innovative learning models, one of which is CBL. CBL combines problem-based learning, project-based learning, and real-life contexts to solve relevant challenges. Based on a systematic literature search using predefined inclusion criteria, data collection techniques, and effect size analysis, the application of CBL has been proven effective in improving mathematics thinking ability such as creative thinking, critical thinking, mathematical reasoning, and numeracy literacy. Meta-analysis combines data from relevant studies by calculating the effect size to evaluate the impact. The results of the analysis show that the CBL model has a very high influence on students' mathematics thinking ability, with an average effect size of 4.028, which is classified as very high. The t-test also confirmed that there was a significant difference between the pretest and posttest scores ($t_{count} = 35.05 > t_{table} = 19.97$), confirming that CBL had an effect on improving mathematical thinking skills. Based on these findings, the CBL model is recommended as a learning model to improve mathematics thinking skills in mathematics education.

Keywords: Challenge Based Learning, Mathematics Thinking Ability, Creative Thinking, Critical Thinking, Mathematics Reasoning, Numeracy Literacy

Introduction

Mathematics is one of the subjects that plays an important role in shaping students' thinking ability. In line with this, Utami et al. (2018) argue that mathematics is a science that plays an important role in shaping students' mindsets, requiring them to have mathematics skills as a tool for problem solving. This is supported by the objectives of the mathematics subject compiled by the Ministry of Education, Culture, Research, and Technology's Curriculum and Assessment Standards Agency of Indonesia in 2022, namely (1) Mathematics understanding and procedural skills, (2) Mathematics reasoning and proof, (3) Mathematics problem solving, (4) Mathematics communication and representation, (5) Mathematics connections, and (6) Mathematics dispositions.

Although important, international studies show that Indonesian students' achievements in Mathematics thinking are low. International studies such as *the Programme for International Student Assessment* (PISA) reveal that mathematics results in Indonesia remain low year after year and are below the global average. Data from the last five PISA studies in 2009, 2012, 2015, 2018, and 2022 were 371, 375, 386, 379, and 366, respectively

(Nugrahanto & Zuchdi, 2019; Solihin et al., 2024; Yuda & Rosmilawati, 2024).This decline indicates that Indonesia's mathematics scores continue to decline, with 2022 recording the lowest score in the last five periods.

Facts on the ground show that there are various factors contributing to students' low mathematical thinking skills. In classroom learning practices, students tend to rely on memorisation methods and focus more on the examples given by teachers, making it difficult for them to tackle problems that require deeper and more contextual thinking (A'dadiyyah & Malasari, 2023). In addition, the application of conventional learning models, which are still dominant in schools, is also one of the causes of low mathematical thinking skills. Conventional learning makes students passive and only receive information from teachers procedurally, which encourages students to memorise formulas and steps to solve problems without understanding the concepts in depth (Rejeki et al., 2025). This condition shows the need to apply more effective learning strategies to improve students' mathematical thinking skills.

One strategy that is widely used to improve Mathematics ability is the application of innovative learning models. One such model that has been developed is *Challenge-Based Learning* (CBL)**.** The CBL learning model is a new form of learning that combines problem-based learning, project-based learning, and contextual learning focused on solving real-life problems (Fairazatunnisa et al., 2021). Meanwhile, according to Ayu & Ardiansyah (2023) CBL is a collaborative learning experience in which teachers and students work together to propose solutions to real problems and take action. These characteristics make CBL

A number of studies have examined the application of *Challenge Based Learning* (CBL) at various levels of education in Indonesia, showing positive results in several mathematical thinking skills, including several key aspects, namely logical thinking, critical thinking, and abstract thinking (Putri & Hadi, 2025). CBL has been proven to have a significant effect on mathematical concept understanding, representation ability, mathematical reasoning, mathematical literacy, critical thinking, creative thinking, numeracy literacy, and mathematical problem solving (Haqq, 2016, 2017; Kurniati & Arafah, 2025; Mahfiroh & Adi Satrio Ardiansyah, 2023; Maisaroh et al., 2023; Pamungkas et al., 2025; Susilawati, 2020; Winasis et al., 2025), both at the primary and secondary school levels The integration of CBL with STEM and software assistance such as GeoGebra has also been reported to increase learning effectiveness (Kurniati & Arafah, 2025; Najizah &

Sutarto, 2025). In fact, several studies have found CBL to be superior to other learning models.

However, differences in research design and implementation context mean that findings still vary, so a meta-analysis is needed to obtain more comprehensive conclusions. Meta-analysis is a statistical technique that summarises several similar studies in order to obtain quantitative data guidelines (Pasambo & Radia, 2022). This method allows the combination of previous research results to obtain a more reliable effect size. In addition, this method also provides a standardised effect size so that it can be compared objectively. By analysing many studies at once, meta-analysis can reduce individual bias and produce stronger conclusions.

This research aims to systematically analyse the effect of the CBL model on students' mathematics thinking ability based on several journal articles. Through a meta-analysis approach, this study seeks to synthesise and quantify the effect sizes of previous research findings in order to provide stronger and evidence-based conclusions. In this research, mathematics thinking ability is operationally defined as a set of higher-order cognitive abilities related to mathematical learning, which include creative thinking ability, mathematics reasoning ability, critical thinking skills, and numeracy literacy skills. These four abilities represent key dimensions of students' mathematical thinking and are examined based on the outcome measures reported in the selected studies included in the meta-analysis.

Method

This study is a quantitative meta-analysis using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. These guidelines are used because they have been proven to increase transparency and repeatability in literature studies (Moher et al., 2009). Meta-analysis was conducted by reviewing, summarising data, and analysing several previous research results (Saputri & Wardani, 2021)

The literature search process was conducted using the Google Scholar, Scopus, Semantic Scholar, and ERIC platforms. The keywords used were a combination of several keywords, namely "challenge-based learning", "kemampuan", and "mathematics". The search focused on articles published between 2015 and 2025, The period 2020–2025 was chosen to represent recent research relevant to curriculum development, the integration of technology in learning, and innovative learning approaches such as Challenge Based

Learning (CBL), which has grown in popularity over the last five years.. The search results were then exported and filtered to remove duplicate articles.

Inclusion criteria were used to limit the research variables examined and were established to ensure data consistency and the validity of the meta-analysis, allowing the effect of CBL on mathematical thinking ability to be accurately analysed and compared. The inclusion criteria for this study include 1) Research articles with experimental methods that use the CBL model in experimental classes, 2) Examining Mathematics Thinking Ability as the main dependent variable, 3) The research population is students at the primary and secondary education levels in Indonesia, 4) Presenting statistical data that can be used to calculate effect size.

The meta-analysis research stages used in this study were 1) Defining the research problem, namely the CBL model on Mathematics Thinking Ability in primary and secondary schools, 2) Identifying and collecting literature on the Google Scholar, Scopus, Semantic Scholar, and ERIC platforms using the keywords "challenge-based learning", "ability", and "mathematics", then determining the publication period of the articles (2020–2025). 3) Screening the literature by reading the titles and abstracts to ensure relevance, removing duplicates, and focusing the research on studies with experimental or quasi-experimental designs, 4) Assessing eligibility by reading the full text of the articles and ensuring that the inclusion criteria were met, including the availability of statistical data, 5) Calculate the effect size of each study using the reported statistical data, then combine them to obtain a pooled effect size. 6) Analyse previously published research reports based on a review of the methods and data analysis used, so that conclusions can be drawn.

Effect Size is a score used to measure an effect (Cohen, 1988). The formula for determining effect size is as follows

$$ES = \frac{\overline{x_E} - \overline{x_C}}{SD_{pooled}}$$

Explanation:

ES : effect Size

$\overline{x_E}$: post-test mean score

$\overline{x_C}$: pre-test mean score

SD_{pooled} : pooled standar deviation

With the following formula for pooled standar deviation

$$SD_{pooled} = \sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}}$$

Furthermore, Cohen (1988)states that *the effect size* can be interpreted into categories in Table 2 as follows.

Tabel 1. Analyzed Articles

Interval	Category
$ES < 0.15$	Negligible effect
$0.15 \leq ES < 0.40$	Low effect
$0.40 \leq ES < 0.75$	Moderate effect
$0.75 \leq ES < 1.10$	High impact
$1.10 \geq ES$	Very high effect

This research aims to determine the effect of using CBL model on mathematics thinking ability so it is necessary to test the hypothesis using t-test. The t-test formula used is as follows.

$$t = \frac{\bar{x}_2 - \bar{x}_1}{\sqrt{\frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

Explanation:

$\bar{x}$: Pre-test mean value

$\bar{x}_2$: Post-test average score

n_1 : Number of students in the pretest

n_2 : Number of post-test students

n_2 : Number of post-test students

s_1^2 : Pretest variance

s_2^2 : Post-test variance

The hypothesis used is as follows

$H_0 : \mu_1 = \mu_2$ (no significant effect)

$H_1 : \mu_1 \neq \mu_2$ (there is a significant effct)

The testing criteria are to accept H_0 if $t_{count} < t_{table}$

Results and Discussion

Based on the predetermined inclusion criteria, 4 samples were found to meet the criteria. The number of articles that met the inclusion criteria for each type of mathematical thinking ability was limited due to the strict application of criteria, so that in this study only one article was found for each type of ability. The data from the articles that met the criteria are presented in Table 2 below.

Tabel 2. Analyzed Articles

No	Article Title	Author Name and Year of Publication	Mathematics Thinking Ability Measured	Data Code
1	Differences in Creative Thinking and Mathematics Reasoning Abilities Using the CBL Model Assisted by the *Kahoot* Application	Utari et al. (2023)	Creative Thinking Ability	A1
2	The Difference in Creative Thinking and Mathematics Reasoning Abilities Using the CBL Model Assisted by the *Kahoot* Application	Utari et al. (2023)	Mathematics Reasoning Ability	A2
3	The Effect of *Geogebra-Assisted Challenge-Based Learning* Model on Critical Thinking Skills in Analysing Primary School Students	Kurniati & Arafah (2025)	Critical Thinking Skills	A3
4	Implementation of the *Challenge-Based Learning* Model on Improving Numeracy Literacy in Students	Nurjanah (2025)	Numeracy Literacy Skills	A4

Based on the articles collected, data was obtained as the basis for conducting the meta-analysis. The data was then presented in Table 3, which contains the results of the analysis regarding the improvement in mathematics skills in the application of the Challenge Based Learning (CBL) model.

Tabel 3. Result of Analysis

No	Data Code	The Effect of *Challenge-Based Learning*					
		Pre-test	SD_1	n_1	*Post-test*	SD_2	n_2
1	A1	67.97	6.63	31	78.81	8.19	31
2	A2	61.35	6.31	31	89.26	7,831	31
3	A3	63.00	6.36	26	82.60	6.05	25
4	A4	1.53	2.88	36	75.42	13.49	36

The analysis of the effect of implementing the CBL model on students' Mathematics Thinking Ability was conducted by calculating the effect size. Based on the data obtained from, the effect size was calculated to determine the extent of the CBL model's effect on improving students' mathematics thinking ability. The results of the calculation were then grouped into categories according to the classification proposed by Cohen (1988), as shown in Table 4.

Tabel 4. Result of Effect Size

Data Code	*Effect Size*	Category
A1	1.455	Very High
A2	3,925	Very High
A3	3,156	Very High
A4	7,575	Very High
Average	4.028	Very High

Based on the table above, it can be seen that all studies had *a* very high *effect size*. *The* average *effect size* of all previous studies was 4.028, which is classified as very high. Therefore, it can be concluded that the CBL model has a very high influence on students' Mathematics Thinking Ability. The skill that was most influenced was numeracy literacy. Furthermore, a t-test was conducted to determine the difference in *pretest* and *posttest* scores in Mathematics thinking ability before and after being given treatment with the CBL model. A summary of the t-test results is presented in the following table.

Tabel 5. Result of t-test

	Average	df	t_{count}	t_{table}	Criterion
pretest	45.98387	$124 + 123 - 2 = 245$	35.05174	1.969694	$t_{count} > t_{table}$ H_0 rejected
post-test	81.22187				

Based on the results of the t-test that has been conducted, it was found that the value of the t-test ($t_{count} = 35,02$) was greater than the critical value of the $= (\mathrm{t_{table}}) = 1,65$ at a significance level of 0.05 with a degree of freedom (df) of 245. This indicates that the null hypothesis (H_0) is rejected. Thus, it can be concluded that there is a significant effect between the mean pretest and posttest scores on mathematics thinking ability after being treated with the CBL model.

The results of this research also show a clear difference between the combined pretest and posttest scores. The average pretest score was 45.97, while the average posttest score increased to 81.22. Thus, there was a very significant increase in students' Mathematics problem-solving abilities after applying the CBL model with the help of digital learning media.

The CBL model has been proven to have a positive influence on mathematics thinking ability, one of which is creative thinking. Research conducted by Utari et al. (2023)shows that the CBL model can significantly improve students' creative thinking skills compared to conventional learning. This is evidenced by an effect size of 1.455, which is classified as very high. The CBL model requires students to collaborate with teachers in proposing ideas or solutions to a problem. This is in line with the statement by Johnson & Adams (2011)which states that CBL requires teachers and students to work together to propose solutions to real problems. In line with this, Mukarromah et al. (2020)explain that CBL is a learning model that creates a space where students can think creatively and actively seek solutions to solve existing problems. Creative thinking skills will also develop, considering that in the Solution step, students develop innovative ideas for the challenges given (Ardiansyah et al., 2024).

In addition to creative thinking skills, Mathematics reasoning skills also improved after students were treated with the CBL model. Research by Utari et al. (2023)shows that the CBL model can significantly improve mathematics reasoning skills. This is demonstrated by the effect size value obtained, which is 3.925, which is also classified as very high. According to them, CBL can be developed in situations that are as flexible and creative as possible so that it can hone students' Mathematics reasoning skills to find solutions in everyday life. The same thing was stated by Haqq (2017)that CBL can significantly improve the reasoning and mathematics reasoning abilities of high school students. The CBL model can also improve mathematics concept comprehension abilities, and these abilities are closely related to students' Mathematics reasoning abilities (Haqq, 2016).

Furthermore, the CBL model has also been proven effective in improving students' critical thinking skills. Research by Kurniati & Arafah (2025)shows that CBL has an effect size of 3.156 and falls into the category of very high influence. A number of other studies also mention that the CBL model has been proven effective in improving students' critical thinking skills (Mukarromah et al., 2020; Najizah & Sutarto, 2025; Sardi et al., 2022).This effectiveness is inseparable from the syntax in the CBL model, namely guiding questions, guiding activities, and guiding resources, which are able to improve critical thinking skills because this syntax accustoms students to choosing which strategy is suitable for solving challenges (Mukarromah et al., 2020).In line with this, Najizah & Sutarto (2025) state thatthe syntax in the CBL model creates scaffolding activities that provide opportunities for students to discuss with their peers and allow for mutual assistance. Students' critical thinking skills will also develop, given that the Big Idea and Essential Question syntax require students to ask related questions (Ardiansyah et al., 2024).

In addition to creative and critical thinking skills, numeracy literacy skills also improve through the application of the CBL model. Research by Nurjanah (2025)shows an effect size in the application of the CBL model of 7.575, which is classified as very high. The CBL model provides students with the opportunity to solve contextual problems, reason, and use concepts from the provided guidelines, thereby influencing students' Mathematics literacy (Hutauruk & Ardiansyah, 2024).

Based on various research results that have been reviewed, it can be concluded that the CBL model has been proven effective in improving various aspects of students' Mathematics Thinking Ability. This model not only influences creative and critical thinking skills, but also strengthens students' Mathematics reasoning and numeracy literacy through collaborative, contextual, and intellectually challenging learning processes (Fairazatunnisa et al., 2021).

Conclusion and Suggestion

Based on the results of a meta-analysis of four mathematics thinking ability, including creative thinking, mathematics reasoning, and numeracy literacy, an effect size of 4.028 was obtained, which is classified as very high. These results indicate that the Challenge Based Learning (CBL) model has a very high impact on improving students' mathematics thinking ability. This is reinforced by the t-test results, which show that $t_{count} > t_{table} = 35.05174 > 1.969694$, so that H_0 is rejected and there is a significant difference between the pretest and posttest mean scores. The combined pretest mean of 45.98387 increased to 81.22187 on the posttest, confirming that the application of the CBL model consistently improves students' mathematics thinking ability. Thus, it can be concluded that the CBL model has a very large and significant effect on students' mathematics thinking ability, including creative thinking, critical thinking, mathematics reasoning, and numeracy literacy, and is recommended as an effective learning model for improving other mathematics thinking ability in mathematics learning.

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