

Research Article

Measuring Elementary School Students' Mathematics Learning Mastery Through Problem-Based Learning: A Proportion Meta-Analysis of Classroom Action Research

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Achieving mathematics learning mastery at the elementary school level remains a significant challenge, requiring instructional approaches that support conceptual understanding and problem-solving abilities. This study aimed to estimate the pooled mastery proportion of elementary school students during Problem-Based Learning (PBL) implementation, examine between-study consistency, and evaluate the robustness of pooled estimates. A proportion meta-analysis was conducted on classroom action research (CAR) studies implementing PBL in elementary mathematics learning. Nineteen primary studies involving 448 students were included in the quantitative synthesis. Pooled mastery proportions were estimated using a random-effects meta-analysis of logit-transformed proportions. Between-study variance was estimated using Restricted Maximum Likelihood (REML), and 95% confidence intervals were calculated using the Hartung–Knapp adjustment. Estimates were subsequently back-transformed to the proportion scale. The results indicated that the pooled mastery proportion increased from 58.3% in Cycle I (95% CI: 53.0%–63.4%) to 85.5% in Cycle II (95% CI: 81.5%–88.7%), representing a descriptive increase of approximately 27.1 percentage points. Between-study heterogeneity was low in Cycle I ($I^2 = 8.4\%$) and was not detected in Cycle II ($I^2 = 0\%$). Leave-one-out sensitivity analysis confirmed the stability of pooled estimates after sequentially removing individual studies. Although all studies showed an increasing direction from Cycle I to Cycle II, the improvement should be interpreted as a change in mastery proportion during PBL implementation rather than evidence of a causal effect attributable solely to PBL, because the primary studies lacked control groups and involved repeated measurements of the same students. This study contributes evidence from a pooled mastery proportion perspective, which is more appropriate for synthesizing classroom action research outcomes than standardized effect-size approaches.

Keywords: Elementary Mathematics; Generalized Linear Mixed Model; Learning Mastery; Problem-Based Learning; Proportion Meta-Analysis.

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1. Introduction

Mathematics skills at the elementary school level are an important foundation in building numeracy literacy, mathematical reasoning, and problem-solving skills needed to face the demands of 21st-century education (OECD, 2024). However, achieving mathematical competence is still a global challenge. The results of PISA 2025 show that the mathematical skills of Indonesian students still face gaps compared to international standards (OECD, 2026), while national data show that some elementary school

students have not reached the minimum competency in numeracy (Kementerian Pendidikan Dasar dan Menengah, 2025). This condition emphasizes the importance of improving the quality of mathematics learning that is not only oriented towards mastering procedures, but also on understanding concepts, applying knowledge, and the ability to solve problems meaningfully.

Procedural memorization-oriented mathematics learning is not enough to build the ability to use concepts in new situations. Students need to engage in activities to understand the context, select relevant information, test strategies, explain reasons, and evaluate solutions. Problem-Based Learning (PBL) fits these needs because problems serve as a starting point for learning and guide students to build knowledge through inquiry. Barrows (1996) places authentic problems as the drivers of the learning process, while Hmelo-Silver (2004) shows that PBL can support flexible knowledge development, problem-solving skills, independent learning, and collaboration. Savery (2006) emphasizes that PBL is student-centered, while teachers act as facilitators in the process of investigation and reflection.

Meta-analytical evidence at the elementary school level generally supports the use of PBL. Sari and Hardini (2020) synthesized 15 national articles and found a positive direction of improving mathematics learning outcomes. With a more inferential approach, Suparman et al. (2021) combined 16 primary studies and obtained a high positive effect on the mathematical abilities of elementary school students compared to conventional learning (Hedges' $g = 1,050$). Nugraha and Suparman (2021) also showed that the duration of interventions and mathematics topics contributed to variations in the effectiveness of PBL in improving the mathematical critical thinking skills of elementary school students. These findings suggest that PBL is relevant, but the magnitude of the results obtained depends on the definition of outcomes, study design, and implementation characteristics.

However, there are methodological gaps that have not been addressed much. Previous meta-analyses in elementary schools generally used test scores, standardized mean differences, or comparisons of PBL with other models. Meanwhile, the CAR literature in Indonesia often reports learning success through the percentage of students who achieve the Mastery Learning Criteria (MLC) or Learning Goal Achievement Criteria (LGAC) in each cycle. These outcomes are statistically different from the average grades. Considering the average score as a proportion of completeness can result in measurement errors and invalid meta-analytic estimates.

The second gap relates to the repetitive structure of CAR. Cycle II is not an independent intervention, but an action that has usually been corrected through reflection on Cycle I. Therefore, the synthesis of the proportion of completeness per cycle can answer a different question from the comparative meta-analysis, namely how high the proportion of students who achieve the standard of completeness at each stage of implementation and how consistent the pattern is across different classes. To date, the meta-analytical evidence of PBL in elementary school students has focused more on standardized effect size than pooled mastery proportion, which directly represents classroom completeness.

The study offers two novelties. First, all candidate reports are re-audited to ensure that the synthesized outcomes truly reflect the number or proportion of students who meet the completeness criteria, not the average score. Second, the main synthesis used proportional meta-analysis with logit transformations and random-effects models. Variance between studies was estimated using Restricted Maximum Likelihood (REML), while pooled estimate uncertainty was evaluated using the Hartung–Knapp approach.

This approach was chosen because the research outcome was in the form of a proportion of completeness, not a standardized mean difference.

Based on these phenomena and gaps, this study answers three questions: (1) what is the combined proportion of elementary school students who achieve the mathematics completeness criteria in Cycle I and Cycle II of PBL; and (2) how much variation between studies is in these proportions. The purpose of the study is to estimate the pooled mastery proportion in both cycles, evaluate the consistency of results between studies, and assess the robustness of conclusions through sensitivity analysis.

2. Method

2.1 Research Design

This study uses a meta-analysis design, a quantitative research approach that synthesizes results from multiple primary studies on similar topics or outcomes. Meta-analysis provides a more comprehensive empirical picture than relying on a single study (Borenstein et al., 2009; Cooper et al., 2019). The primary study synthesized in this study is a Classroom Action Research (CAR) study that applies Problem-Based Learning (PBL) in mathematics learning in elementary schools.

2.2 Data Sources and Search Strategies

The dataset is derived from a Google Scholar search using Publish or Perish with a yield limit of up to 200 records and a publication period of 2021-2026. The combination of terms used includes "Problem Based Learning" or "PBL", "mathematics", "elementary school", "learning outcomes" or "learning completeness", and "Classroom Action Research". The search was directed to national scientific publications that provide the full text. The results of the screening found 19 studies to be extracted.

2.3 Criteria Inclusion

The study meets the inclusion criteria if: (1) the subject is an elementary school student; (2) PBL is the main learning model in mathematics subjects; (3) the research design is a CAR with at least two cycles; (4) the number of students in the class is reported; (5) the research results are published through Sinta-indexed national journals or Sinta-indexed national scientific proceedings; and (6) the number of students who achieved MLC/LGAC in Cycle I and Cycle II is available or can be reconstructed without ambiguity. The term "completeness criteria" in this article is used as an umbrella term for MLC, LGAC, or the completeness limit set in each study.

Studies are excluded from the main analysis if the reported number is the grade point average, not the proportion of completeness, or if the reported percentage cannot be reconstructed into the number of students completing that is consistent with the class denomination. Studies that provide a proportion or percentage of completeness may still be included in the synthesis if the denomination sample size is clearly reported and the completeness data are available separately for Cycle I and Cycle II.

Table 1. Study Sample Data

No	Author (Year)	N	Cycle I (%)	Cycle II (%)	Journal	Index
1	Mudiana et al. (2021)	12	67,50%	88,30%	Jurnal Ilmiah Pendidikan Profesi Guru	Sinta 2
2	Hardianti et al. (2025)	26	58%	88%	Jurnal Inovasi, Evaluasi, dan Pengembangan Pembelajaran	Sinta 5
3	Utomo & Hardini (2023)	27	81,48%	88,85%	Jurnal Ilmiah Ilmu Pendidikan	Sinta 4
4	Ulya & Siswanto (2024)	26	46%	85%	Attadrib: Jurnal Pendidikan Guru Madrasah Ibtidaiyah	Sinta 3
5	Nuryati et al. (2023)	15	41,67%	83%	Jurnal Ilmiah Pendidikan Asia	Sinta 5
6	Rachmawati et al. (2021)	28	50%	89%	Educative Journal Of Education Research	Sinta 3
7	Tarigan et al. (2024)	24	45%	82%	Jurnal Ilmiah PGSD FKIP Universitas Mandiri	Sinta 5
8	Ndole & Ana (2021)	16	62,50%	87,50%	Jurnal Pendidikan Matematika	Sinta 4
9	Kustianti (2022)	18	50%	83%	Jurnal Sakinah Of Islamic and Social Studies	Sinta 5
10	Astuti et al. (2021)	31	54,84%	83,87%	Mimbar Ilmu	Sinta 2
11	Maryamah et. (2026)	20	68,20%	78,60%	JagoMIPA: Jurnal Pendidikan Matematika dan IPA	Sinta 3
12	Handayani et al. (2024)	16	68,80%	82,40%	Social, Humanities, and Educational Studies SHEs: Conference Series	Sinta 4
13	Ratna & Suheni (2021)	35	60,00%	85,71%	CJPE: Cokroaminoto Juornal of Primary Education	Sinta 4
14	Sari et al. (2024)	27	52%	89%	Prosiding Seminar Nasional Pendidikan Profesi Guru	Sinta
15	Sariasih (2023)	27	68,52%	78,68%	Indonesian Journal Of Instruction	Sinta 3
16	Setiana & Muslim (2024)	19	66%	87%	As-Sabiqun: Jurnal Pendidikan Islam Anak Usia Dini	Sinta 4
17	Widari et al. (2025)	28	64,30%	96,40%	Jurnal Inovasi Pendidikan Sains dan Terapan	Sinta 4
18	Nurjannah & Setiyadi (2022)	26	73%	89%	Journal Of Islamic Primary Education	Sinta 5
19	Merici (2023)	27	48%	89%	Prima Magistra: Jurnal Ilmiah Kependidikan	Sinta 2

2.4 Re-Examination and Data Extraction

All studies that met the inclusion criteria were re-examined to ensure that the data used truly represented the completeness of student learning. The data extracted included authors, year of publication, number of students, and the proportion of students who met the completeness criteria in Cycle I and Cycle II. The research outcome was defined as the proportion of students who met the learning completeness criteria, not the grade average or standardized effect size, because the CAR studies analyzed generally reported learning success in the form of the percentage of students who achieved the MLC, LGAC, or other completeness criteria set in each study.

Quantitative synthesis was carried out using random-effects meta-analysis of proportions. The proportion of completeness of each study was analyzed on a logit scale, then the combined estimate was transformed back to a proportional scale to obtain a pooled mastery proportion. The random-effects model was chosen because the primary study came from different classes, schools, teachers, mathematics materials, completeness criteria, and PBL implementation conditions, so conceptually there were variations between studies that needed to be accommodated (Borenstein et al., 2010; Viechtbauer, 2010).

Variance between studies was estimated using Restricted Maximum Likelihood (REML). The 95% pooled estimate confidence interval was calculated using the Hartung–Knapp approach to provide a more conservative estimate of uncertainty in the random-effects model (IntHout et al., 2014). Heterogeneity between studies was evaluated using Cochran's Q , I^2 , and τ^2 . The 95% prediction interval was used to describe the range of proportions of completeness that could be statistically expected in a new study with comparable characteristics. Interpretation of I^2 was performed carefully as a measure of relative inconsistency between studies (Higgins et al., 2003).

The pooled proportions of cycle I and cycle II were analyzed separately. The difference in pooled proportion between cycles was reported as a descriptive difference in percentage points, rather than as a standardized effect size or paired difference test results, as both cycles came from the same student and correlations between measurements were not consistently available in the primary study. As an additional analysis, the exact sign test was used to assess the consistency of the direction of change from Cycle I to Cycle II, while the entire meta-analysis was performed using R 4.5.2 software with the meta and metafor packages (Viechtbauer, 2010; Balduzzi et al., 2019).

2.5 Sensitivity Analysis and Robustness Assessment

Sensitivity analysis was performed to evaluate the stability of the pooled proportion estimate to the influence of individual studies. Robustness examination was performed using the leave-one-out sensitivity analysis approach by taking out one study in turn and recalculating the combined estimate using the main analysis model. This approach was used to assess whether there were specific studies that had a substantive influence on the synthesis results (Viechtbauer & Cheung, 2010).

The stability of the estimate was assessed based on the change in the pooled proportion value after each study was excluded. If the change in the estimate was relatively small and did not change the direction or main interpretation of the study, then the results of the meta-analysis were considered to have an adequate level of robustness.

3. Result

3.1 Data Characteristics and Changes in Learning Completeness

The meta-analysis included 19 primary studies involving 448 students. Each study included 12 to 35 students, averaging 23.58 students. All studies used a Classroom Action Research (CAR) design and reported the proportion of mathematical completeness in Cycle I and Cycle II. All 19 studies showed an increase in completeness from Cycle I to Cycle II.

Descriptively, the proportion of completeness in Cycle I ranged from 41.67% to 81.48%, with an unweighted average of 59.25%. In Cycle II, the proportion of completeness increased to 78.60% to 96.40%, with an unweighted average of 86.02%. The increase in study level ranged from 7.37 to 41.33 percentage points. The average unweighted increase was 26.76 percentage points, with a median of 29.03 percentage points.

The results of the examination of the consistency of the increase in 19 studies showed that the value of Cycle II was higher than that of Cycle I, with the Exact sign test yielding $p < 0.001$. These results showed consistent improvement across studies, although the mark test was used only as an additional analysis because it did not account for differences in precision between studies.

Table 2. Proportion of Completeness, Logit Transformation, and Intercyclical Change

Study	N	Cycle I (%)	Logit I	SE I	Cycle II (%)	Logit II	SE II	Δ poin %
Mudiana et al. (2021)	12	58.33	0.336	0.586	83.33	1.609	0.775	25.00
Hardianti et al. (2025)	26	58.00	0.323	0.397	88.00	1.992	0.604	30.00
Utomo & Hardini (2023)	27	81.48	1.482	0.495	88.85	2.076	0.611	7.37
Ulya & Siswanto (2024)	26	46.00	-0.160	0.393	85.00	1.735	0.549	39.00
Nuryati et al. (2023)	15	41.67	-0.336	0.524	83.00	1.586	0.687	41.33
Rachmawati et al. (2021)	28	50.00	0.000	0.378	89.00	2.091	0.604	39.00
Tarigan et al. (2024)	24	45.00	-0.201	0.410	82.00	1.516	0.531	37.00
Ndole & Ana (2021)	16	62.50	0.511	0.516	87.50	1.946	0.756	25.00
Kustianti (2022)	18	50.00	0.000	0.471	83.00	1.586	0.627	33.00
Astuti et al. (2021)	31	54.84	0.194	0.361	83.87	1.649	0.488	29.03
Maryamah et al. (2026)	20	68.20	0.763	0.480	78.60	1.301	0.545	10.40
Handayani et al. (2024)	16	68.80	0.791	0.540	82.40	1.544	0.656	13.60
Ratna & Suheni (2021)	35	60.00	0.405	0.345	85.71	1.791	0.483	25.71
Sari et al. (2024)	27	52.00	0.080	0.385	89.00	2.091	0.615	37.00
Sariasih (2023)	27	68.52	0.778	0.414	78.68	1.306	0.470	10.16
Setiana & Muslim (2024)	19	66.00	0.663	0.484	87.00	1.901	0.682	21.00
Widari et al. (2025)	28	64.30	0.588	0.394	96.40	3.288	1.014	32.10
Nurjannah & Setiyadi (2022)	26	73.00	0.995	0.442	89.00	2.091	0.627	16.00
Merici (2023)	27	48.00	-0.080	0.385	89.00	2.091	0.615	41.00

3.2 Results of Proportional Meta-Analysis

Quantitative synthesis was carried out using a random effects model with a Restricted Maximum Likelihood (REML) estimator. The proportion of each study was analyzed on a logit scale, then the aggregate results were transformed back to the proportion scale. The confidence interval of the pooled estimate used the Hartung-Knapp approach with conservative correction of standard errors.

Table 3. Results of Meta-Analysis of Mastery Proportions

Statistics	Cycle I	Cycle II
Studies, k	19	19
Total students	448	448
Pooled proportion	0.585	0.855
Pooled mastery	58.3%	85.5%
95% CI	53.0%-63.4%	81.5%-88.7%
Cochran's Q	19.26	6.140
df	18	18
p heterogenitas	0.353	0.996
I^2	8.4%	0.0%
τ^2	0.0030	0.0000
95% prediction interval	52.5%-64.4%	81.6%-88.8%

In Cycle I, the pooled mastery proportion was 58.3% (95% CI: 53.0%–63.4%). Heterogeneity was very low, with $I^2 = 8.4\%$, $\tau^2 = 0.0030$, and Cochran's $Q(18) = 19.26$, $p = 0.353$. The prediction interval was 52.5%–64.4%. Thus, variation in completeness in Cycle I was relatively small after accounting for sampling error.

In Cycle II, the proportion of pooled mastery increased to 85.5% (95% CI: 81.5%–88.7%). Heterogeneity was not detected on the scale of analysis used, with $I^2 = 0\%$, $\tau^2 \approx 0$, and $Q(18) = 6.14$, $p = 0.996$. The prediction interval was 81.6%–88.8%. These results showed that completeness in Cycle II was relatively high and very consistent across the study sets analyzed.

Based on the estimate, the pooled proportion increased by about 27.0 percentage points from Cycle I to Cycle II. This change was descriptive, not an effect size of 0.27 or a paired-difference test, because Cycle I and Cycle II came from the same student and the primary study did not report correlations between cycles.

3.3 Forest Plot

The forest plot shows a clear shift from Cycle I to Cycle II (see Fig. 1 and Fig. 2). The dotted vertical line shows the pooled proportion in each cycle. The forest plot for Cycle I shows the results of synthesizing 19 studies on the proportion of students who achieved the MLC. The proportion values ranged from 40% to 80%, indicating variation in achievement across studies. The combined analysis showed a pooled proportion of 0.59, with a confidence interval of 53.0%–63.4%. Variations across studies suggest differences in research characteristics, learning context, and teaching style. MLC achievement in Cycle I still needs improvement to achieve more optimal results.

The Cycle II forest plot synthesized results from 19 studies, with MLC achievement ranging from 0.79 to 0.96. Compared to Cycle I (0.59), there was an increase of 27 points. These results showed that the learning intervention in Cycle II increased students' MLC achievement. Variation between studies was still visible, but all studies showed a consistent trend of increasing achievement.

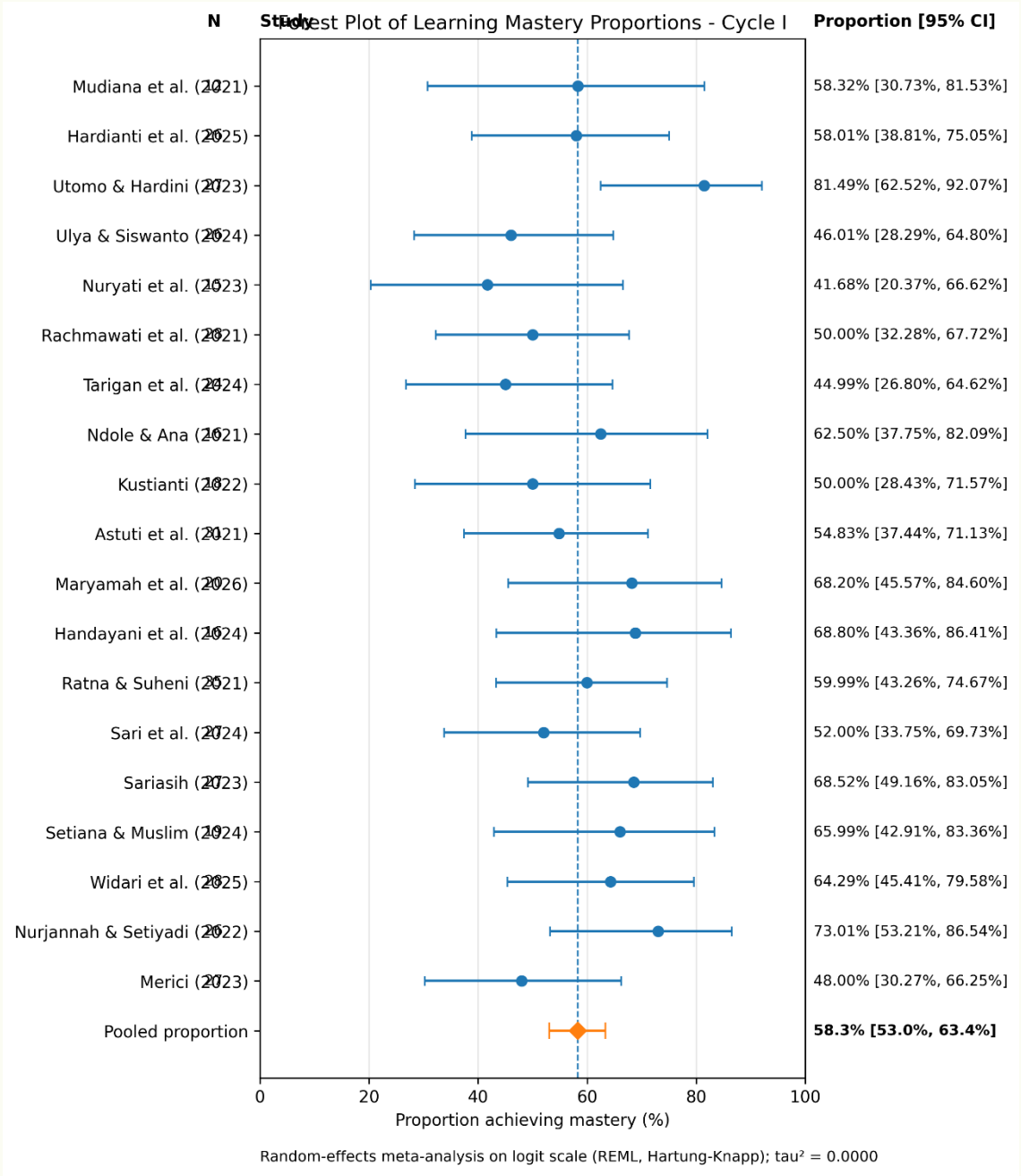


Figure 1. Forest Plot of Cycle I

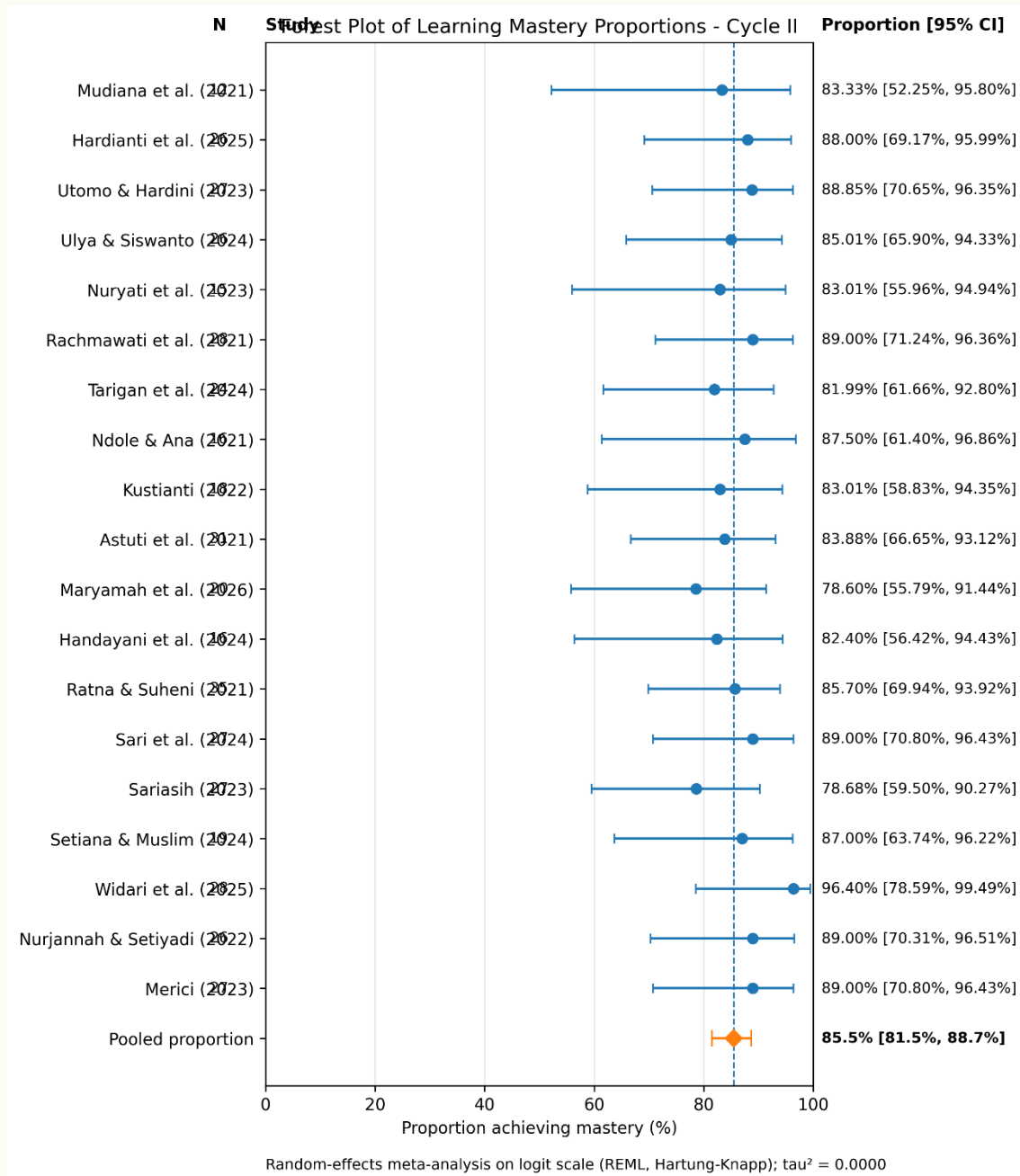


Figure 2. Forest Plot of Cycle II

3.4 Robustness of Meta-Analytic Estimates

Sensitivity analysis was performed using leave-one-out sensitivity analysis. Each study was excluded individually. The pooled proportion was then recalculated using the same random-effects model as the main analysis. The aim was to assess the effect of each study on the combined estimates (Viechtbauer & Cheung, 2010).

In Cycle I, the pooled proportion ranged from 57.4% to 59.4%, compared with the main estimate of 58.3%. The lowest score was obtained when Utomo and Hardini (2023) were excluded. The highest score was obtained when Ulya and Siswanto (2024) were excluded. The maximum change was 1.2 percentage points. In Cycle II, the pooled proportion ranged from 85.3% to 86.2%, compared with the main estimate of 85.5%. The

lowest score occurred when Widari et al. (2025) was excluded. The highest score was obtained when Sariasih (2023) was excluded. The maximum change was 0.9 percentage points.

Table 4. Analysis of Leave-One-Out Sensitivity to Pooled Proportion

Sensitivity Analysis	Cycle I	Cycle II
Main pooled proportion	58.3%	85.5%
Estimate range after removing one study	57.4%–59.4%	85.3%–86.2%
Maximum change from the main estimate	1.2 percentage points	0.9 percentage points

These results show that the estimates are relatively stable. None of the studies substantively changed the meta-analysis results. The common-effect and random-effects estimates were also almost identical. However, the random-effects model was still used because the context of the school, class, teacher, material, completeness criteria, and PBL implementation differed between studies. The proportion of completeness remained higher in Cycle II than in Cycle I. These findings show a consistent pattern across the study set. The findings are not interpreted as causal evidence of PBL only.

4. Discussion

4.1 Improving Learning Mastery in PBL Implementation

The meta-analysis showed that implementing PBL in elementary school mathematics CAR was followed by a consistent increase in completeness from Cycle I to Cycle II. The pooled proportion in Cycle I of 58.3% increased to 85.5% in Cycle II, or an increase of about 27.2 percentage points based on estimates that had not been rounded. All 19 studies showed the same direction of change. Thus, the increase was not driven by one or two studies with very high scores, but by a pattern that emerged across the entire set of studies analyzed.

These findings should be interpreted in light of the study design and statistical power. The values 0.583 and 0.855 are not standardized effect sizes for PBL compared with the control group, but the pooled proportion of students who achieved learning mastery during PBL implementation. Therefore, the correct conclusion is that learning completeness increased from Cycle I to Cycle II during PBL implementation. The claim that PBL produced an effect size of 0.855, or the effect size of the strong category, does not correspond to the scale of the data analyzed.

4.2 Compatibility with PBL Meta-Analysis in Elementary Schools

This study's findings align with Sari and Hardini (2020), who conducted a meta-analysis of 15 articles on PBL and mathematics learning outcomes among elementary school students. The study found increased learning outcomes across all synthesized studies and reported PBL's positive influence on mathematics learning outcomes. This study supports these general conclusions while providing evidence from different perspectives. Sari and Hardini (2020) focused on changes in learning outcomes, while this study estimated the proportion of combined completeness in each CAR cycle.

This study's findings also align with Suparman et al. (2021). A meta-analysis of 16 primary studies in elementary school students yielded Hedges' $g = 1.050$, which shows a positive effect of PBL on mathematical ability compared to conventional learning. This fit is important because Suparman et al. (2021) used a standardized comparative design and effect measure, while this study used CAR completeness data. Nonetheless, two

different statistical approaches yield the same conclusions about the potential of PBL in elementary school mathematics learning.

Numerically, the pooled proportion of 0.855 in this study could not be directly compared with Hedges' $g = 1.050$ or the effect size reported in the previous meta-analysis. Maintain statistical scale differences to avoid misleading interpretation. The pooled proportion answers the degree of completeness, while Hedges' g answers the magnitude of the standardized differences between the groups or conditions being compared.

3.3 Why Does Mastery Increase in Cycle II?

The increase in the pooled proportion from 58.3% to 85.5% can be attributed to the results of the combination of PBL characteristics and CAR's reflective mechanisms. In PBL, problems are used as a starting point for learning; students identify necessary information, develop strategies, discuss, and evaluate solutions. Barrows (1996), Hmelo-Silver (2004), and Savery (2006) place student activities, problem-solving, and teacher facilitation as fundamental elements in PBL.

In Cycle I, teachers and students are still adapting to the PBL structure. Teachers may still need to improve learning quality, group divisions, starter questions, time allocation, media, or scaffolding. Cycle II in CAR is not simply a repeat of Cycle I. Teachers use the results of observation and reflection in Cycle I to improve actions in the next cycle. Therefore, a higher pooled proportion in Cycle II makes sense if understood as a result of students' experience in PBL and improved implementation quality.

Nugraha and Suparman (2021) support this interpretation. A meta-analysis of elementary school students showed that the duration of PBL application and the mathematics topics contributed to variation in outcomes in mathematical critical thinking skills. The findings showed that PBL success depended not only on the model label, but also on how, on what material, and for how long the model was implemented.

Ruli and Indarini (2022) also found that PBL is related to improved critical thinking skills in elementary school mathematics learning. This result is relevant because identifying problems, determining strategies, evaluating procedures, and giving reasons are cognitive processes that support students' success in solving math problems and achieving mastery learning.

3.4 Homogeneity of Findings and Their Differences with Previous Meta-Analyses

The statistical heterogeneity in this study was relatively low. The I^2 value was 8.4% in Cycle I and 0% in Cycle II. This value indicates low relative variation in the analyzed study set. This study did not directly compare the I^2 value with the previous meta-analysis because outcomes, sample size, design, sampling variance, and inclusion criteria differed.

Suparman et al. (2021) and Nugraha and Suparman (2021) reported heterogeneity in PBL meta-analyses with different outcomes and designs. This study used the proportion of complete CAR studies on elementary school mathematics learning. Differences in outcomes, study design, sample characteristics, and inclusion criteria can result in different heterogeneity structures. Therefore, we did not use I^2 values between meta-analyses as a basis for comparing consistency.

However, a low I^2 does not mean all studies are identical. Learning mastery criteria can differ across schools, as well as mathematics materials, implementation quality, teachers, student characteristics, and possibly media use. Because the primary study

dataset does not uniformly capture learning mastery criteria and implementation characteristics, these substantive variations cannot be tested as moderator variables.

4.5 Yield Durability

Leave-one-out sensitivity analysis showed the stability of the pooled estimate. In Cycle I, the pooled proportion remained between 57.4% and 59.4% after removing each study in turn. In Cycle II, the estimate remained between 85.3% and 86.2%. None of the single studies changed the direction or substantive significance of the study conclusions.

The findings of the primary study Widari et al. (2025) showed the highest completeness rate in Cycle II at 96.4%. When the study was issued, the pooled proportion only dropped to around 85.3%. Thus, the high estimate in Cycle II is not an artifact of one extreme study. The similarity between common-effect and random-effects models also suggests that combined estimates are relatively insensitive to model specifications when heterogeneity is very low.

4.6 Interpretation of Robustness of Meta-Analytic Estimates

The robustness assessment in meta-analysis aims to ensure that synthesis conclusions are not overly influenced by a single study with extreme characteristics. Through leave-one-out sensitivity analysis, researchers can evaluate the stability of combined estimates by observing changes when each study is excluded (Viechtbauer & Cheung, 2010). In this study, the stability of the estimates showed that the pattern of mathematical learning completeness obtained from the synthesis of the CAR study did not depend on the contribution of one particular study. This finding matters because classroom action research has diverse contextual characteristics, such as differences in students, teachers, mathematics materials, learning environments, and strategies for improving actions between cycles. Therefore, the stability of the estimates reinforces that the completeness patterns reflect general trends in the study set analyzed, rather than the influence of a particular study.

The robustness assessment showed that the pooled mastery proportion estimate was not dominated by any single study. These findings showed the stability of the estimation to the influence of individual studies, but did not validate the selection of effect sizes or statistical models. The proportional meta-analysis used the characteristics of the primary study outcomes, namely the proportion of students who met the learning completeness criteria. Robustness in this study also does not indicate a causal relationship between PBL and increased completeness. In the CAR design, changes between cycles can be influenced by teacher reflection, improved learning strategies, student learning experience, and adaptation processes during learning. Therefore, the robustness assessment supports the stability of the estimates, while interpreting PBL effectiveness still needs to account for the limitations of the primary research design (Viechtbauer & Cheung, 2010).

4.7 Research Contributions

This study complements the previous elementary school-level PBL meta-analysis in terms of outcomes and implementation context. Sari and Hardini (2020) show that PBL is associated with improved mathematics learning outcomes. Suparman et al. (2021) show a positive influence on mathematical skills compared to conventional learning. Nugraha and Suparman (2021) show that learning duration and topics can affect variations in PBL effectiveness.

This study adds evidence on the level of learning completeness in implementing CAR-based PBL. The pooled mastery proportion increased from 58.3% in Cycle I to 85.5% in Cycle II, with the same direction of improvement in all 19 studies. In addition,

this study also found a pattern of completeness development when the implementation of PBL was carried out in elementary school mathematics learning through a cycle of reflection and improvement.

4.8 Limitations of Interpretation

First, all studies used CAR without a control group. Therefore, the increase from Cycle I to Cycle II cannot be attributed exclusively to PBL. Repeated learning experiences, exercises, maturation, media changes, and improvement of teacher actions can also contribute to increased completeness. Second, Cycle I and Cycle II data came from the same participants. Because the authors did not report correlations between measurements, this meta-analysis could not optimally test for paired changes. Report a difference of about 27.2 percentage points as a descriptive change in the pooled proportion. Third, mastery learning criteria are not uniformly available across studies. A student who is declared complete in mastery learning criterion 65 is not fully equivalent to a student who is declared complete in mastery learning criterion 75. Future research should include mastery learning criteria, classes, mathematics topics, media use, and PBL duration as moderator variables. Fourth, factual literature searches were conducted only through Google Scholar using Publish or Perish, so primary studies worthy of analysis may have been missed because they were not identified.

5. Conclusion

A meta-analysis of 19 CAR studies involving 448 students showed that the combined proportion of students who achieved mastery learning criteria in Problem-Based Learning-based mathematics learning increased from 58.3% in Cycle I (95% CI 53.0%-63.4%) to 85.5% in Cycle II (95% CI 81.5%-88.7%), or an increase of about 27.1 percentage points descriptively. All studies showed increased completeness from Cycle I to Cycle II. Heterogeneity between studies was low in Cycle I ($I^2 = 8.4\%$) and not detected in Cycle II ($I^2 = 0\%$). Leave-one-out analysis showed that pooled estimates remained stable when each study was removed in turn. This showed that the level of completeness in mathematics learning increased and became more consistent during the implementation of CAR-based PBL in Cycle II. However, because the study did not use control groups and the intercycle data were paired, the increase could not be attributed exclusively to a causal effect of PBL.

These findings support using PBL to improve mathematics learning in elementary schools, especially when implemented reflexively and continuously improved from one cycle to the next. However, the results do not prove a causal effect of PBL because the primary design lacks a control group and uses repeated measurements on the same students. The main contribution of the research lies in the synthesis of proportion-based completeness. Further research should use multi-database searches, standardized risk-of-bias appraisal, complete Mastery Learning Criteria reporting, and a comparative design or individual data to test major changes more robustly.

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