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A meta-analysis of the effectiveness of process-oriented guided inquiry learning on students' academic achievement

Pamela C. Madiclum
De La Salle University
Taft Ave, Malate, Manila, 1004 Metro Manila, Philippines

Maricar Prudente
De La Salle University
Taft Ave, Malate, Manila, 1004 Metro Manila, Philippines

Abstract
Process-Oriented Guided Inquiry Learning (POGIL) is a student-centered approach that applies structured inquiry, collaborative learning, and teacher facilitation to promote deeper understanding and skill development among students. In this meta-analysis, the researcher investigates the effectiveness of POGIL in improving the academic achievement of students across various educational contexts. This study synthesized the findings from 10 research studies published between 2016 and 2022, yielding 13 effect sizes. The overall effect size (Hedge's g = 0.79) provides evidence of a statistically significant positive effect due to POGIL on student achievement compared to traditional teaching methods. Moderator analysis revealed consistent benefits in science and mathematics subjects, in junior and senior high school levels, and learning competencies (conceptual understanding, science process skills, and critical thinking). These advantages were apparent in both researcher-developed and standardized assessments. The findings affirm that POGIL not only enhances academic performance but also supports the development of higher-order thinking skills, which are essential for student success in science and mathematics education. Classic Fail-Safe N and funnel plot analysis confirmed the robustness of the results and that there was minimal risk of publication bias. These insights have implications for curriculum reform, instructional design, and teacher professional development. Future research is recommended to determine the effects of POGIL on affective and metacognitive domains, including student motivation, self-efficacy, and self-regulation. This meta-analysis offers substantial evidence for the incorporation of POGIL into the educational contexts represented in the included studies, underscoring its significance.

Keywords: process-oriented guided inquiry learning, student achievement, conceptual understanding, critical thinking skills

Introduction

Process-Oriented Guided Inquiry Learning (POGIL) utilizes active learning, structured inquiry, and collaborative teamwork to achieve content mastery and develop essential process skills of the students. In this model, students work in self-managed groups where members assume specific tasks to ensure student participation and accountability in the learning process. The learning resources for guided inquiry provide the students with relevant information, models, and specific scenarios that students must understand, interpret, and analyze, fostering a deeper connection and engagement with the resources and content. These materials are used alongside accompanying guide questions that lead students through cognitive progression that starts from exploration and concept development, all the way to application. This encourages them to build their own understanding instead of just following instructions. In this approach, the students not only enhance their conceptual understanding (Yilmaz, 2016; Kisworo & Gusman, 2019; Omoniyi, 2019; Alghamdi et al., 2020; Pradiyanasari et.al 2020; Samosir, 2022; Jummaro et al., 2024; Zemene et al., 2025) but also cultivate skills that allow them to learn how to communicate, think critically, and solve problems, all of which are important abilities when dealing with difficult situations in various classroom situations (Yilmaz et al., 2016).

In a POGIL classroom, students learn by actively engaging in a learning process that can be interactive and iterative, allowing them to enhance their understanding as they develop the important skills that they need. This dynamic process is significant for student success in inquiry-based learning environments since they need to learn not only the required knowledge but also how to think critically, collaborate with other students, and change their reasoning based on the new knowledge they acquire. POGIL directly addresses the persistent challenges of passive, lecture-centered classrooms by engaging students in active, collaborative, and inquiry-driven learning processes. The teacher monitors the way in which the students interact in teams, recognizes possible difficulties, and offers timely, targeted feedback to assist them in their learning experiences (Moog & Spencer, 2008). Instead of just providing students with information directly, the teacher assists them as they build their own knowledge by allowing them to engage in self-reflection, encouraging meaningful discussions, and adjusting their teaching strategies and practices to meet the needs of both individuals and groups of students. In this inquiry-based team structure, students learn that collaborating and analyzing problems is more important than simply obtaining the correct answer. They learn that asking critical questions, engaging in their learning experiences, and changing their personal perspective with the guidance of a knowledgeable facilitator and fellow students contributes to a meaningful learning experience. Its emphasis on logical thinking, teamwork, and shared responsibility develops a learning environment where students feel free to take risks, work together to grow and develop, and continue learning even when confronted with difficult tasks.

Providing students with structured inquiry tasks allows them to analyze patterns, evaluate evidence, and construct explanations, which are necessary skills that promote authentic scientific practice (Nadelson, 2009; Douglas & Chiu, 2012). This goes beyond content acquisition, where the cognitive and interpersonal practices essential for scientific reasoning and lifelong learning of students are addressed in the POGIL framework. Learners are encouraged to articulate their thought processes, challenge their thinking, and revise their understanding based on peer input and facilitator feedback as they engage with the models and guide questions provided to them. This process of investigation, reflection, and refinement strengthens metacognitive awareness and fosters independent learning, empowering students to assume responsibility for their own learning. The opportunity given to students to do a collaborative activity in the POGIL framework further enhances the students' accountability and interdependence, while each member of the team assumes a specific task and contributes to the group's progress (Fitriah et al., 2025). In doing so, students develop the essential communication, leadership, and teamwork skills that are significant lifelong learning skills, which they can use even beyond the classroom. This approach is especially significant in science education, where addressing challenges and collaborating efficiently in teams are both essential to authentic scientific investigation and innovation (Fitria & Hidayah, 2021). POGIL combines content mastery with process skill development, equipping students to excel academically while fostering critical thinking (Andriani et. al ,2019; Kisworo et.al., 2019; Kartono et.al., 2020; Muhammad et.al., 2020; Samosir, 2022; Hidayah et al., 2023; Fitriah et al., 2025), ethical collaboration, and confident adaptation to challenging situations.

The development of the students' science process skills (SPS) which are addressed in POGIL (Fitria & Hidayah, 2021); Samosir, 2022; Ali-Musa, 2024) are essential skills to scientific inquiry and include both basic and integrated process skills. These skills are not taught separately in a science classroom but are integrated within the structure of the guided inquiry activities, allowing students to apply these skills as they engage in achieving the learning competencies. In the learning opportunities provided in the classroom, the learners are actively involved in constructing meaning from models through being provided with data and problems, which they address by applying the SPS. When students analyze a data table, classify variables, or predict the outcome of a chemical reaction, they must integrate their prior knowledge with logical reasoning by applying both conceptual understanding and cognitive strategies to make sense of the information (Kisworo & Gusman, 2019). In the learning process, the teacher plays a critical role in scaffolding the students' learning experiences by posing probing questions, clarifying misconceptions, and encouraging students to articulate their thought processes. This instructional support given by the teacher ensures that learners will go beyond task completion and engage in self-reflection by utilizing scientific reasoning. The utilization of science process skills through POGIL cultivates higher-order thinking, enabling students to approach complex scientific problems with confidence, curiosity, and analytical precision. As students become more adept at evaluating evidence, constructing explanations, and revising their understanding, they build a well-defined cognitive framework that reflects the practices of real-world scientists and prepares them for future academic and professional challenges (Samosir, 2022).

POGIL not only assists learners to do good in their studies but it also assists them in developing both the abilities and mindset they need to learn for the rest of their lives and, more importantly, it enables them to work with others productively. At present, POGIL has gained growing interest among educators, although it has not yet reached the scale of more established inquiry-based models. While the number of published studies remains limited compared to broader active-learning frameworks, the existing literature demonstrates considerable breadth in scope and application. Research on POGIL spans multiple educational levels from elementary, high school and college levels, and also includes a wide range of disciplines including chemistry, biology, physics and mathematics. The diversity of outcomes examined further reflects the model's versatility and its alignment with the cognitive, affective, and collaborative dimensions of learning. Although POGIL studies remain moderate in number, their wide distribution across subjects, grade levels, and learning outcomes shows that the evidence base is growing. However, this diversity also highlights a key gap: the findings are scattered across disciplines, methods, and assessment types, making it difficult to determine POGIL's overall impact or the conditions under which it works best. A comprehensive analysis is therefore needed to integrate these fragmented results and provide a clearer understanding of POGIL's effectiveness.

In this study, the researcher synthesizes the findings of experimental investigations that investigate the effect of Process-Oriented Guided Inquiry Learning (POGIL) on science learning outcomes by doing a meta-analysis. By employing the statistical method of analysis, the study analyzes effect sizes from research to determine the overall effectiveness of POGIL. This approach allows for a comprehensive evaluation of POGIL across educational contexts, grade levels, and science domains. The paper presents a review of relevant literature published from 2016 to 2022. Although POGIL is widely used internationally, most published research comes from Southeast Asia and only few meta-analyses exist. Existing synthesis (Walker & Warfa, 2017) focus on Western, college-level samples, leaving a gap in understanding POGIL's effectiveness in secondary level, non-western context.

The meta-analysis aims to establish a clear and consolidated understanding of POGIL's impact on student learning. The synthesis integrates evidence from multiple contexts to reveal consistent patterns in POGIL's effectiveness and the conditions under which it produces the strongest outcomes. The results are expected to clarify how variations in subject area, grade level, targeted competencies, assessment types, and research sources shape the magnitude of POGIL's effects. In doing so, this study offers practical guidance for educators and curriculum designers and identifies directions for future research on inquiry-based science instruction.

Methodology

To guide the methodological procedures of this review, the meta-analysis was structured around the following research questions:

1. How effective is Process-Oriented Guided Inquiry Learning (POGIL) in improving students' academic achievement?
2. To what extent do the effects of POGIL on students' academic achievement vary according to the following moderating variables:
   a. academic discipline (Science vs. Mathematics),
   b. grade level (junior high school vs. senior high school),
   c. targeted competencies (conceptual understanding, science process skills, and critical thinking), and
   d. type of assessment (researcher-made vs. standardized tests)?

These research questions served as the organizing framework for the literature search, study selection, coding procedures, effect size computation, and moderator analyses. By explicitly aligning the methodological steps with these questions, the synthesis provides a coherent and transparent structure for evaluating the overall impact of POGIL and the conditions under which its effects vary.

Research Design

In determining the effectiveness of Process-Oriented Guided Inquiry Learning in enhancing the students' academic achievements, the researcher employed a meta-analysis. This approach analyzed quantitative findings using multiple independent studies, allowing a comprehensive evaluation of POGIL's impact. Specifically, this study examined variations in outcomes based on several moderating variables, including academic subject, educational level, targeted competencies, type of assessment instruments used, and the source of each study.

The researcher utilized the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for documenting the literature search, screening, eligibility criteria, and inclusion process to ensure validity and transparency in the synthesis. The PRISMA framework provided a structured protocol for reporting each phase of the review, thereby enhancing the credibility of the meta-analytic findings.

Data Search Strategy and Study Selection

A thorough literature review was conducted on related studies on POGIL to gather sufficient data for the review using electronic databases. The keywords 'Process Oriented Guided Inquiry Learning' were utilized as a search term, and a screening procedure was conducted utilizing the reference list obtained from the electronic search. The first screening obtained 1508 abstracts published from 2016 to 2022 related to POGIL. The screening procedure was conducted using the abstracts, methodology, assessment, and results obtained. A total of 57 abstracts were chosen, 45 of which were excluded. Experimental investigations, including pre-test post-test with a control group only, were included in the second screening. Only ten articles satisfied the predetermined inclusion criteria following the two-stage screening process using the PRISMA search approach. Figure 1 shows the findings of the literature search and the justifications for the exclusion of the study. Studies that used a well-defined technique for putting POGIL into practice were eligible to be included in the meta-analysis. Both original research publications and review papers, including those that used POGIL in interdisciplinary educational settings, were taken into consideration.

The studies included in this meta-analysis were chosen using a set of precise inclusion and exclusion criteria to guarantee scientific rigor and relevance. In particular, POGIL has to be used as the main instructional treatment in eligible research, along with a control condition for comparison. Only those employing a two-group experimental design—such as randomized controlled trials or quasi-experimental setups - were considered. This was to allow the direct evaluation of POGIL's impact relative to other instructional methods. In addition, the studies also had to incorporate learning activities explicitly delivered using the POGIL framework, provide a clear description of the participants (including sample size, educational level, and context), and report sufficient statistical data to enable the calculation of standardized effect sizes. As a secondary analysis of published studies, this meta-analysis did not require new ethical approval; only studies reporting appropriate ethical oversight were included."

Studies involving other learning methodologies not grounded in POGIL were excluded. Additional exclusion criteria were applied to filter out studies that lacked a direct focus on POGIL, including studies that did not measure science achievement as a learning outcome, those that were published before 2016, and those that presented unusually large effect sizes that would already be considered statistical outliers. Only studies involving junior high school and senior high school students met the inclusion criteria; no primary-level or college level studies qualified for inclusion in the final data set. These selection parameters ensured that the meta-analysis was grounded in high-quality, comparable evidence, allowing the assessment of POGIL's effectiveness. A total of 10 papers and 13 effect sizes were selected for the meta-analysis based on the inclusion and exclusion criteria. A total of 1508 publications were found using Publish or Perish, as shown in Figure 1: 1000 articles from Google Scholar, 122 articles from SCOPUS, and 386 articles from Semantics.

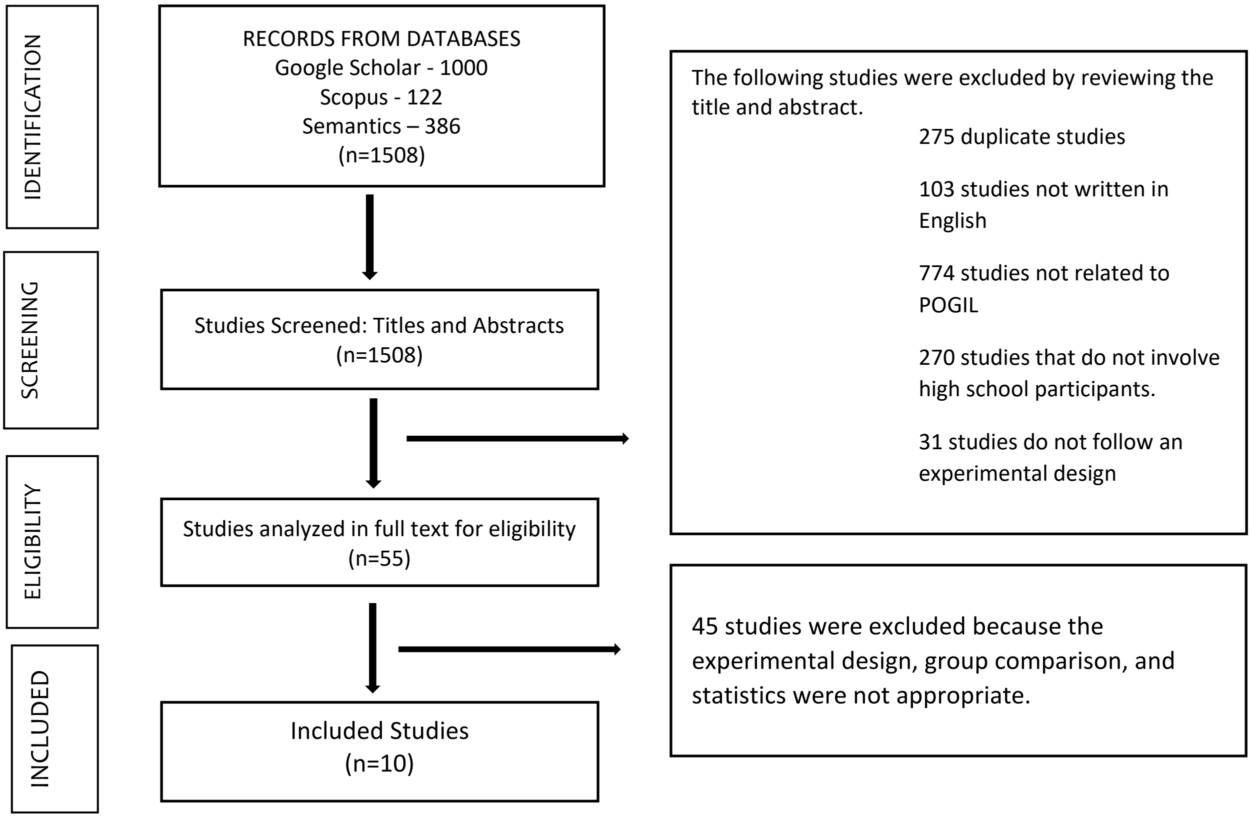

Figure 1: Flow Chart of the Literature Search

Data Evaluation Procedure

In this meta-analysis, the treatment characteristics were categorized to determine significant variables influencing learning outcomes. These included the students' grade level (junior high school or senior high school), academic discipline (classified as either Science or Mathematics), targeted learning competencies (conceptual understanding, science process skills, and critical thinking skills), the type of assessment used (standardized tests or researcher-made instruments), and the geographic location of the study. This analysis helped to determine how various contextual factors may moderate the effectiveness of POGIL, thereby enhancing the interpretability and generalizability of the findings.

To determine the impact of POGIL on student achievement, the researcher employed effect size calculations to measure the standardized mean differences between the treatment and control groups. Specifically, Hedge's g was used as the metric for effect size as it provides a more accurate estimate when dealing with small sample sizes. For statistical analysis, the researcher utilized Meta-Essentials v.1.5, a specialized software developed by Hak, Rhee, and Suurmond (2018) for conducting meta-analyses. This tool facilitated the computation of effect sizes and enabled moderator analysis, which was used to group and compare the studies based on coded attributes such as academic discipline, grade level, and type of assessment. The software also supported the identification of heterogeneity among the studies, allowing the researcher to assess the variability in outcomes and explore potential contextual influences. Additionally, forest plots were generated to visually represent the distribution and strength of effect sizes across the included studies, enhancing the interpretability of the findings and supporting the robustness of the conclusions drawn. Table 1 presents relevant information that offers contextual and methodological insights into the assessment procedure conducted.

Table 1: Summary of the Research Studies on POGIL

Author and Year of Publication	Experimental			Control			Source of Study	Academic Discipline	Level	Learning Outcome	Type of Test	Location
	N	M	SD	N	M	SD						
1. Yilmaz (2016)	56	7.48	3.09	59	3.98	3.53	Journal	Chemistry	SHS	Conceptual Understanding	Researcher made	Turkey
2. Kisworo & Gusman (2019)	30	77.87	7.85	30	72.56	7.7	Journal	Chemistry	SHS	Conceptual Understanding	Researcher made	Indonesia
3. Omoniyi (2019)	33	12.63	2.32	27	10.84	2.26	Journal	Chemistry	SHS	Conceptual Understanding	Standardized	Nigeria
4. Alghamdi et al. (2020)	114	28.45	4.89	75	25.97	6.62	Journal	Chemistry	JHS	Conceptual Understanding	Standardized	Saudi
5. Pradiyanasari et.al (2020)	33	81.3	9.62	31	71.8	9.74	Journal	Physics	JHS	Conceptual Understanding	Researcher made	Indonesia
6. Samosir (2022)	30	70.56	11.03	27	61.88	12.52	Journal	Physics	SHS	Conceptual Understanding	Researcher made	Indonesia
7. Fitria & Hidayah (2021)	30	82.67	6.06	32	74.54	7.53	Journal	Biology	JHS	Science Process Skills	Researcher made	Indonesia
8. Samosir (2022)	30	66.32	10.29	27	61.88	12.52	Journal	Physics	SHS	Science Process Skills	Standardized	Indonesia
9. Andriani et. al (2019)	24	80.69	10.91	25	74.78	9.23	Journal	Physics	JHS	Critical Thinking	Standardized	Indonesia
10. Kisworo et.al (2019)	30	75.31	1.55	30	71.32	2.19	Journal	Chemistry	SHS	Critical Thinking	Researcher made	Indonesia
11. Kartono et.al (2020)	32	73.13	9.78	32	68.2	9.82	Journal	Mathematics	JHS	Critical Thinking	Researcher made	Indonesia
12. Muhammad et.al (2020)	30	66.91	8.58	30	55.91	7.35	Journal	Mathematics	JHS	Critical Thinking	Researcher made	Indonesia
13. Samosir (2022)	30	65.03	13.97	27	56.44	14.27	Journal	Physics	SHS	Critical Thinking	Standardized	Indonesia

Results

An analysis was conducted by the researcher for each study population using the key statistical indicators extracted from the original articles. This was done to determine the statistical significance and consistency of the findings across the studies. These indicators included the mean scores, standard deviations, and standard errors for both the control and experimental groups. These were used to provide a precise calculation of the effect sizes and comparative outcomes. Table 2 presents the results of the heterogeneity analysis, where the Q statistic exceeds the degrees of freedom ($Q > df$) and the p-value is less than 0.05 ($p < .05$), indicating statistically significant heterogeneity among the included studies.

Table 2: Overall Effect Sizes

No. of Effect size	z-value	p-value	Effect Size Hedges' g	CI Limit	Standard Error	Test of Heterogeneity			
						Q-value	df	P_Q	I^2
13	12.04	0.000	0.79	0.64-0.94	0.07	59.67	12	0.000	74.86%

The meta-analysis produced a pooled effect size of Hedges' g = 0.79, with a 95% confidence interval of 0.64 to 0.94. This indicates a moderate to large positive effect due to POGIL on student achievement. The standard error of 0.07 suggests that the estimate is precise. This also provides clear evidence addressing RQ1, demonstrating that POGIL effectively improves student achievement across the sampled studies. The overall effect was also statistically significant ($z = 12.04$, $p < 0.001$), demonstrating that the positive impact of POGIL is unlikely to be due to chance. The test of heterogeneity showed substantial variability among the included studies which indicates that the effect sizes differ more than expected from sampling error alone, suggesting that several factors may influence the magnitude of POGIL's effectiveness.

Figure 2 below presents a forest plot to visually represent the distribution and strength of the effect sizes across the included studies. Each row in the forest plot represents a single study, with a point marker indicating the effect size estimate and a horizontal line showing the 95% confidence interval. The x-axis in the figure shows the scale of the effect sizes. Larger bullets indicate studies that have a stronger impact on the total effect size. The size of each bullet represents the study's relative weight in the meta-analysis, which is based on variables like sample size and variance.

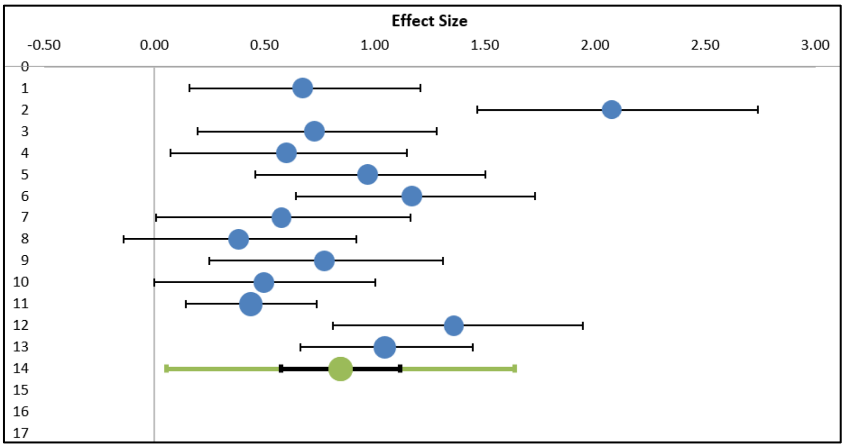

Figure 2: Forest Plot of the POGIL Meta-Analysis Results

In the forest plot, most studies show positive effects with effect sizes clustering between 0.40 and 1.20, indicating consistent benefits of POGIL across contexts. Only minor variations are observed in the width of the confidence intervals, suggesting that most studies provide reasonably precise estimates. One study shows a noticeably larger effect size but its confidence interval remains within the range, indicating that it is not an extreme outlier. Overall, the plot visually confirms that the majority of studies favor POGIL over traditional instruction.

The effect sizes of academic discipline, grade level, competency, test type, and study materials were evaluated using a moderator analysis, as indicated in Table 3. This displays the findings from the subgroup analysis used to identify variations in the effect sizes among the learning achievements of the students according to the subgroups.

Table 3a: POGIL Subgroup Analysis - Academic Discipline

Subgroup Name	Hedges' g	CI Lower Limit	CI Upper Limit	Weight	Heterogeneity		
					Q	df	p
Academic Discipline	0.94	-1.17	3.05		0.27	1	0.602
Science	0.96	0.75	1.16	87.35%			
Mathematics	0.80	0.26	1.34	12.65%			

The subgroup analysis based on academic discipline showed that POGIL had a positive effect in both Science and Mathematics. The wide confidence interval in the moderator row reflects the low degrees of freedom and statistical uncertainty when estimating differences between only two subgroups. This result in Table 3a addressed RQ 2a by showing that POGIL is similarly effective for both, with no significant difference between the two disciplines. For Science, the pooled effect size was Hedges' g = 0.96 (95% CI: 0.75–1.16), indicating a large and statistically meaningful effect. Science studies contributed the majority of the weight in the analysis (87.35%), reflecting the larger number of available studies in this area. For Mathematics, the effect size was Hedges' g = 0.80 (95% CI: 0.26–1.34), also reflecting a positive and substantial effect, though with a wider confidence interval due to fewer studies (12.65% weight). The test of heterogeneity across the two subgroups indicates that there is no significant difference between Science and Mathematics which suggests that POGIL is comparably effective across these academic disciplines.

Table 3b: POGIL Subgroup Analysis - Students' Grade Level

Subgroup Name	Hedges' g	CI Lower Limit	CI Upper Limit	Weight	Heterogeneity		
					Q	df	p
Level	0.83	-1.35	3.01		0.10	1	0.753
Junior High School	0.80	0.49	1.11	61.83%			
Senior High School	0.88	0.49	1.28	38.17%			

The subgroup analysis based on the students' grade level showed that POGIL had positive effects for both Junior High School (JHS) and Senior High School (SHS) learners. For JHS students, the pooled effect size was Hedges' g = 0.80 (95% CI: 0.49–1.11), indicating a moderate to large effect. JHS studies contributed the majority of the weight (61.83%) in this subgroup. For SHS students, the effect size was Hedges' g = 0.88 (95% CI: 0.49–1.28), also reflecting a substantial positive effect. SHS studies accounted for 38.17% of the weight. The heterogeneity test across grade levels indicates no significant difference between JHS and SHS subgroups. This suggests that POGIL is similarly effective across these grade levels which addressed RQ 2b, indicating that POGIL benefits both junior and senior high school students.

Table 3c: POGIL Subgroup Analysis - Competency

Subgroup Name	Hedges' g	CI Lower Limit	CI Upper Limit	Weight	Heterogeneity		
					Q	df	p
Competency	0.77	-0.77	2.31		0.72	2	0.697

Conceptual Understanding	0.74	0.54	0.94	84.86%
Science Process Skills	0.77	0.00	1.55	5.64%
Critical Thinking	1.01	0.41	1.60	9.50%

The results in Table 3c address RQ 2c by demonstrating that POGIL improves conceptual understanding, science process skills, and critical thinking, with no significant variation among these competencies. The subgroup analysis showed that POGIL had positive effects across all measured learning competencies. For Conceptual Understanding, the pooled effect size was Hedges' g = 0.74 (95% CI: 0.54–0.94), representing a moderate to large effect, contributing the majority of the weight (84.86%) in this subgroup. For Science Process Skills, the effect size was Hedges' g = 0.77 (95% CI: 0.00–1.55), indicating a positive effect but with a wider confidence interval due to fewer studies (5.64% weight). In Critical Thinking, the effect size was Hedges' g = 1.01 (95% CI: 0.41–1.60), reflecting a large effect, although this subgroup accounted for only 9.50% of the total weight. The heterogeneity test across competencies indicates no significant difference among the three competency subgroups. This suggests that POGIL is similarly effective across different types of learning outcome.

Table 3d: POGIL Subgroup Analysis - Type of Test

Subgroup Name	Hedges' g	CI Lower Limit	CI Upper Limit	Weight	Heterogeneity		
					Q	df	p
Type of Test	0.76	-1.42	2.94		7.99	1	0.005
Researcher-made test	1.04	0.71	1.37	45.62%			
Standardized Test	0.52	0.39	0.64	54.38%			

The type of test is the only subgroup with statistically significant heterogeneity (p = 0.005). This suggests that the type of test used moderates the effect of POGIL. Researcher-made tests yielded a substantially higher effect size than standardized tests, possibly due to better alignment with inquiry-based learning outcomes. This indicates that assessment format plays a critical role in capturing the impact of POGIL, with researcher-made tests more sensitively reflecting its instructional benefits. This addressed RQ 2d by showing that the type of test significantly moderates the effect of POGIL, with larger effects observed for researcher-made tests than for standardized tests. The subgroup analysis based on the type of test revealed notable differences in the magnitude of POGIL's effects. Studies using researcher-made tests produced a pooled effect size of Hedges' g = 1.04 (95% CI: 0.71–1.37), indicating a large and substantial effect. These studies accounted for 45.62% of the total weight. In contrast, studies using standardized tests yielded a smaller but still positive effect size of Hedges' g = 0.52 (95% CI: 0.39–0.64), representing a moderate effect, and contributed 54.38% of the weight. The heterogeneity test of test type was statistically significant (Q (1) = 7.99, p = 0.005), indicating that the type of assessment meaningfully influences the observed effect sizes.

Table 4: Classic Fail-Safe N

The Resistance of the Meta-analysis vs Publication Bias	
Over-all Z-score	12.04
p-value	0.000
Alpha-value	0.050

N	13
No. of missing studies that would bring the p-value to >alpha	684

To assess the robustness of the meta-analytic results and ascertain the probability of publication bias, the Classic Fail-Safe N approach was utilized. With a p-value of 0.000 and a significant overall Z-score of 12.04, the meta-analysis in this study synthesized 13 effect sizes from 10 independent investigations, which was below the traditional alpha criterion of 0.050. This demonstrates that Process-Oriented Guided Inquiry Learning has a statistically significant impact on student achievement that is unlikely to be the result of chance. The result indicates that 684 additional studies would be required to nullify the statistical significance of the meta-analysis to raise the p-value above 0.05 and render the overall effect statistically insignificant. This number far exceeds typical benchmarks used to assess publication bias vulnerability, suggesting that the meta-analytical result is highly resistant to publication bias. This also shows that even if a large number of unpublished or unreported studies existed, their inclusion would be insufficient to overturn the conclusion that POGIL has a meaningful and positive impact on student learning. The confidence interval associated with the combined effect size indicates statistical significance ($p < .05$). Since the primary aim of the meta-analysis is to test the hypothesis that POGIL improves academic achievement, these results provide strong evidence to reject the null hypothesis and affirm the presence of a substantial and reliable educational benefit due to POGIL. This supports the practical application of POGIL in diverse educational settings and underscores the importance of inquiry-based learning models in fostering student achievement and process skill development.

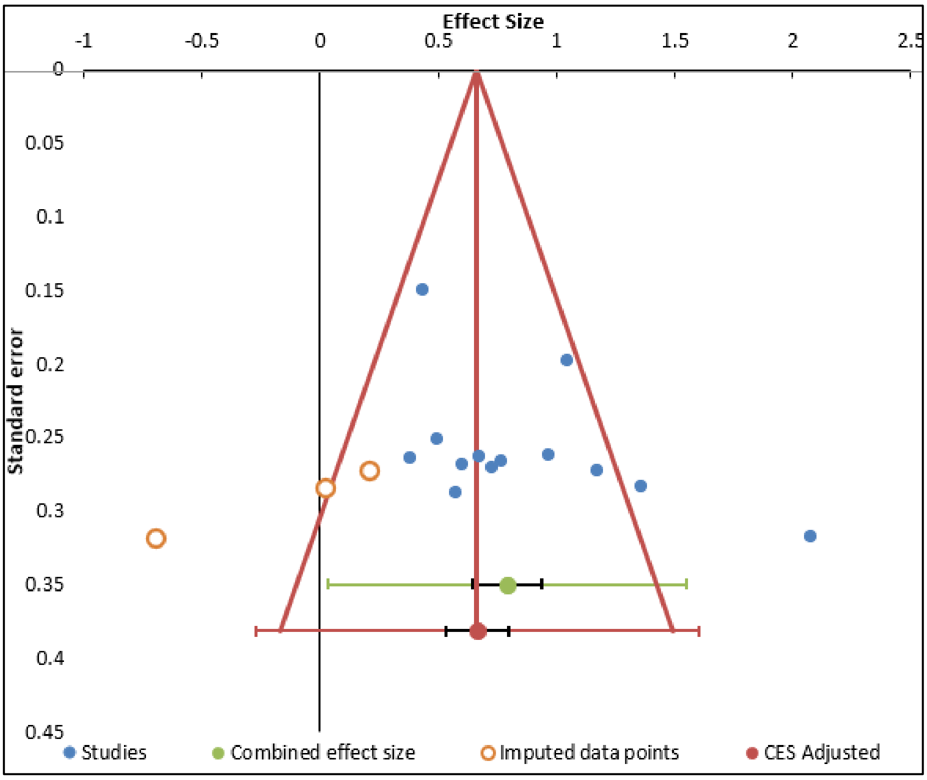

Figure 3: Funnel plot showing the publication bias status of the obtained studies.

Figure 3 presents the funnel plot used to visually assess the presence of publication bias in the meta-analysis. In this plot, the distribution of studies appears relatively symmetrical, with data points spread evenly on both sides of the combined effect size. This symmetry suggests a low risk of publication bias as studies with smaller or less favorable results are not systematically missing. The presence of imputed data points and CES-adjusted values further supports the robustness of the analysis, indicating that even when accounting for potential missing studies, the overall effect remains stable.

The confidence interval for the combined effect size lies entirely on the positive side of zero. This confirms that the meta-analytic effect is statistically significant and favors the experimental group exposed to POGIL. The overall pattern reinforces the conclusion drawn from the Classic Fail-Safe N analysis: the meta-analysis is resistant to publication bias, and the observed positive effect of POGIL on student achievement is both statistically and practically meaningful. Its asymmetry can be explained by the fact that the funnel plot, as seen in Figure 3, only identified one outlier among the papers that were part of this meta-analysis. The Begg-Mazumdar test yielded a p-value of 0.088 ($p>.05$), indicating that there is no publication bias in the studies that were retrieved.

Table 5: *Publication Bias*

Publication Bias	
$\Delta_{x\text{-}y}$	28.00
Kendall's Tau	0.36
Tau for z-value	1.71
P	0.088

This meta-analysis included statistical indicators to further validate the absence of publication bias. Kendall's Tau, a non-parametric measure of rank correlation, was calculated at 0.36, indicating a moderate positive association between effect size and standard error. The Tau for z-value was 1.71, and the corresponding p-value of 0.088 exceeds the conventional alpha level of 0.05. This result suggests that the correlation is not statistically significant, reinforcing the conclusion that the distribution of effect sizes is not systematically skewed by selective reporting or publication bias. The $\Delta x–y$ value of 28.00 reflects the difference in rank between the observed and expected values which, while informative, is secondary to the p-value for determining bias. Taken together with the funnel plot and Classic Fail-Safe N results, these indicators provide converging evidence that the studies included in this meta-analysis are free from significant publication bias and that the observed positive effect of POGIL on student achievement is both statistically robust and credible.

Discussion

The overall effect size of 0.79 demonstrates that POGIL has a meaningful and consistent positive impact on student learning. This aligns with the findings that guided inquiry approaches enhance conceptual understanding, engagement, and higher-order thinking (Antonio & Prudente, 2024; Musa et al., 2025). The effect size reported in this meta-analysis ($g = 0.79$) is substantially larger than the effect identified in the earlier meta-analysis by Walker and Warfa (2017), who reported a pooled effect of $g = 0.29$. Several contextual differences between the two evidence bases help explain this discrepancy. The present study draws predominantly from non-Western secondary-level classrooms—especially Indonesia—where POGIL may be relatively new and implemented with high fidelity, whereas Walker and Warfa's dataset was composed largely of Western, tertiary-level STEM courses. Differences in educational systems, learner characteristics, subject areas, and implementation contexts likely contribute to the stronger effects observed in the current sample. Taken together, these contrasts suggest that the findings of the present meta-analysis should be interpreted within the specific geographic and educational contexts represented, rather than as a direct global counterpart to earlier Western-based syntheses.

The substantial heterogeneity ($I^2 = 74.86\%$) indicates that POGIL does not produce identical effects across all contexts. Instead, its impact varies depending on factors such as subject area, grade level, type of competency measured and the type of assessment, which supports the need for moderator analyses. The subgroup analyses reveal that this variability is not explained by academic discipline, grade level, or competency type, as POGIL produced comparable benefits across science and mathematics, junior and senior high school students, and multiple learning outcomes. The only significant moderator was assessment type, with researcher-made tests yielding larger effects than standardized tests, likely due to the closer alignment with inquiry-based learning processes. This was supported by Hansford and Schechter (2023), emphasizing that variability is inevitable in education research and that moderator analyses are essential for interpreting heterogeneous effects.

These results confirm that although POGIL research is moderate in number, the evidence consistently favors POGIL over traditional instruction (Moog & Spencer, 2008; Walker & Warfa, 2017. By quantifying the overall effect and identifying variability, the meta-analysis fills a gap left by narrative reviews and single-context studies (Hansford & Schechter, 2023). The strong pooled effect suggests that POGIL can be recommended as an effective instructional strategy for improving achievement aligning with broader evidence, thus supporting inquiry-based learning approaches (Antonio & Prudente, 2024; Lazonder & Harmsen, 2016; Musa et al., 2025). Schools and curriculum designers may consider integrating POGIL to support inquiry-based learning goals. These results reinforce the value of POGIL as an instructional approach that counters passive learning environments by requiring students to actively construct knowledge through guided inquiry and teamwork. Despite contextual differences, publication-bias analyses including the Fail-Safe N, funnel plot, and Kendall's Tau confirm that the findings are stable and not meaningfully influenced by selective reporting. Overall, the evidence supports POGIL as a robust, versatile, and pedagogically sound instructional approach.

Limitation

Although this meta-analysis provides strong evidence for the effectiveness of POGIL, several limitations should be acknowledged. First, the number of eligible studies remains limited, which constrains the breadth of generalization. Second, a large proportion of the included studies were conducted in Indonesia, resulting in geographic clustering that may influence the cultural or curricular applicability of the findings. Third, most studies employed quasi-experimental pretest–posttest designs rather than randomized controlled trials, which may introduce selection bias despite the presence of control groups. Finally, the variability in implementation fidelity reporting made it difficult to determine the extent to which POGIL was delivered consistently across the studies. These limitations highlight the need for more rigorous and geographically diverse research to further validate and extend the present findings.

Conclusion

This meta-analysis synthesized 13 effect sizes from 10 studies to evaluate the impact of Process-Oriented Guided Inquiry Learning (POGIL) compared to traditional instructional methods. The results revealed that POGIL has a significantly greater effect on students' conceptual understanding, science process skills, and critical thinking competencies. The large overall effect size (Hedge's g = 0.79), statistically significant confidence intervals, and strong resistance to publication bias, as evidenced by the Classic Fail-Safe N and Begg-Mazumdar tests, affirm the robustness and practical relevance of these findings. The consistent positive outcomes across academic disciplines and grade levels suggest that POGIL is effective and adaptable, making it a promising model for curriculum reform and instructional innovation.

Across all analyses, publication-bias tests—including the Fail-Safe N, funnel plot, and Kendall's Tau - showed no meaningful evidence of bias, reinforcing the robustness and credibility of the findings. The findings confirm that POGIL fosters active engagement, inquiry, and meaningful learning, supporting its continued integration into science and mathematics education at multiple levels. Overall, this study contributes a comprehensive and quantitative synthesis of

POGIL's impact, addressing the previously fragmented nature of the literature. The results affirm that POGIL is a versatile and powerful instructional strategy that can be effectively implemented across subjects, grade levels, and learning competencies. To deepen the understanding of POGIL's impact, future meta-analytic research should explore additional moderators such as the duration of implementation, topic coverage, and its specific effects on college-level learners. Expanding the scope to include affective outcomes such as student motivation, attitudes, and self-efficacy, and metacognitive dimensions like self-regulation and strategic thinking could provide a more holistic view of POGIL's influence on learning. These directions will not only enhance the theoretical framework surrounding inquiry-based instruction but also inform more targeted and equitable applications in diverse educational contexts.

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