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THE IMPACT OF DISCOVERY LEARNING ON HIGHER-ORDER THINKING SKILLS IN CHEMISTRY: A META-ANALYSIS

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ABSTRACT

This research examines the effect of the discovery learning model on higher-order thinking skills in chemistry subjects at the high school level in Indonesia with a total sample of 230 students. The research method is a meta-analysis study with a range of research data from 2015-2024 based on Google Scholar indexed by Sinta. Heterogeneity test analysis using JASP version 0.8.5 shows a τ^2 value of 0.236 and a τ value of 0.485, with an I^2 value approaching 100% (CI: 74.015%–98.358%). The results indicate a high level of heterogeneity (98.358%). Therefore, a random effects model is used in the analysis. The meta-analysis results suggest that discovery learning significantly affects higher-order thinking skills ($z = 4.730$; $p < 0.001$; 95% CI). Funnel plot and Egger's tests did not show publication bias, supported by a fail-safe N value 488. The results of this study reinforce empirical evidence that discovery learning is a practical approach to chemistry learning.

Keywords: discovery learning, higher order thinking skills, chemistry learning, meta-analysis

INTRODUCTION

The 21st century skills include the ability to think, communicate, access information and technology to remain productive. Chemistry learning in the context of the 21st century must be directed at the capacity to reason creatively, critically, and logically to solve problems effectively (Ilmi, 2020; Redhana, 2019; Sarah et al., 2021). For this reason, chemistry learning must adopt a student-centered approach by encouraging collaboration, maintaining relevance to life contexts, and establishing direct links with the environment (Asri et al., 2023).

Chemistry learning requires understanding at three levels of representation: (1) macroscopic level (observable phenomena), (2) submicroscopic level (particle structure), and (3) symbolic level (equations and formulas) which is often a challenge for students (Mahfuzah et al., 2018; Fitria et al., 2024). This difficulty is increasingly seen in several chemistry topics such as redox reactions, electrochemistry, and electrolysis which require in-depth analytical skills for reactions at the anode and cathode and interpretation of chemical reaction results (Febriyanti & Widjajanti, 2023; Marlina et al., 2023; ’Ainillana & Louise, 2024). These difficulties generally arise from the abstract nature of the material and the demand to apply concepts through calculations that require in-depth understanding and the ability to relate theory to real-life contexts (Purwanti et al., 2022; Putri & Yerimadesi, 2022).

This is reinforced by research conducted by (Hasanah, 2021) which shows that only 50% of students meet the minimum score limit on Redox and Electrochemistry material, indicating difficulties in understanding some chemical concepts. One of the main causes lies in students' inability to link macro, submicro, and symbolic representations together, especially on electrochemical topics that require simultaneous understanding of reactions at the electrodes and ion movement. In line with this research showed that around 75% of students find it difficult to understand chemical concepts, especially in materials that require mastery of representations and interconnections between concepts (Rohayah, 2022). Therefore, a learning approach that is not only student-centered, but also able to integrate the three representations in learning and actively facilitate student involvement in the process of exploration and discovery of concepts is needed.

One approach that is in line with the characteristics of 21st century skills is the discovery learning model which plays a role in improving higher order thinking skills, such as problem solving, analysis, evaluation, and reflection. This approach encourages students to explore, analyze, and draw conclusions independently (Allo et al., 2024) This model is based on the theory of constructivism that focuses on directed learning, interaction with the environment, and reflection on experience.

The Discovery Learning model significantly improves students' higher-order thinking skills and strengthens their long-term memory, because they are encouraged to explore and investigate, and reflect on the learning process that has been obtained by strengthening collaboration during the learning process (Primahesa et al., 2023; Martaida et al., 2017). So in chemistry learning, this model is very suitable to be applied because it supports experimentation and observation of contextual scientific phenomena (Muntari et al., 2021;

Agustina et al., 2021) and actively involves students in improving the learning process (Agustian et al., 2022; Amanullah, 2020).

By applying the discovery learning model in chemistry learning, the teacher acts as a facilitator who helps students navigate the process of problem solving and concept discovery, which ultimately strengthens their understanding and high-level thinking skills to conduct experiments, observe scientific phenomena directly, and link various chemical representations (macroscopic, submicroscopic, and symbolic). This approach provides space for students to build knowledge contextually, strengthen learning motivation, and encourage active involvement in the learning process. This will certainly be a strategic step as an effort to prepare students to face the era of Industrial Revolution 4.0 and Society 5.0 (Sa'adah & Ikhsan, 2023; Chusni, 2022). This effort is also closely related to the development of higher-order thinking skills, which is a structured thinking process that encourages students to think critically, creatively, and innovatively in problem solving and decision making (Sarah et al., 2021).

By integrating effective models and innovative approaches, students can more easily connect theoretical concepts and develop higher order thinking skills in the process of problem solving in chemistry (Jayanti, 2024; Alsaleh, 2020). As a result, the ability to think analytically, evaluatively, and creatively, which are important skills needed in 21st century education will improve. The discovery learning approach goes beyond acquiring theoretical knowledge, but also allows students to explore new concepts, make connections with existing knowledge, and improve their understanding through rigorous scientific methodology (Rizki et al., 2021).

Several studies applying the discovery learning method have shown that the application of the discovery learning model has a positive impact on the development of higher order thinking skills. For example, research by (Chusni et al., 2020; Syamsuri et al., 2023) reported that this approach was able to improve students' ability in problem solving and higher order thinking. Similar findings were expressed by (Ardila et al., 2022) (Simanjuntak & Silalahi, 2022; Ispani & Laili, 2023) It also revealed that through this approach, students not only improve their higher-order thinking skills but also significantly improve their conceptual understanding and learning outcomes (Said & Aminah, 2021; Ristanto et al., 2022) It also showed that students who were taught using the Discovery Learning model obtained higher HOTS scores compared to the conventional model, especially in the analysis and evaluation aspects. However, these results are not entirely consistent. This inconsistency raises the need for a more comprehensive synthesis of findings.

In response to this, this research was conducted in the form of a meta-analysis to comprehensively investigate the impact of the application of the Discoverry learning model on higher order thinking skills in chemistry education. The meta-analysis research was conducted by analyzing and combining the results of various studies that aim to provide a more complete, objective, and evidence-based picture of the application of the Discovery Learning model in improving students' higher-order thinking skills that can be used as a strong basis for the development of chemistry learning practices that are more innovative and responsive to the demands of the 21st century education era.

RESEARCH METHOD

This research is a meta-analysis study conducted to examine the implementation of discovery learning in chemistry education by synthesizing various secondary data from empirical studies, focusing on improvements in outcomes and statistical strength, and providing a more comprehensive conclusion from previous research data (Israel & Richter, 2011; Field & Gillett, 2010)).

By integrating diverse secondary data from various research findings, the meta-analysis technique offers more substantial evidence than individual studies (Cohen, 1988). In this study, the researcher conducted data analysis using JASP software version 0.8.5 to facilitate the calculation of effect size and standard error.

The calculation of effect size and standard error in a meta-analysis begins with a heterogeneity test, which aims to determine differences in the studies' results. The heterogeneity test includes Fixed and Random Effects models and is supported by the Residual Heterogeneity Estimate test.

The next stage is the summary effects test, which aims to obtain an overall conclusion regarding the effect size being analyzed using a random effects model. The effect size test is also supported by the Forest Plot, which is used to assess the consistency of the effect sizes and to determine the magnitude of the discovery learning model's influence on higher-order thinking skills in chemistry learning.

Once the effect size of the reviewed articles has been identified, a moderator variable analysis is conducted. The following step is the Funnel Plot test, which aims to identify potential bias in the reviewed articles. If the plot appears symmetrical, it indicates no bias;

whereas an asymmetrical shape may suggest the presence of bias, such as publication bias. Finally, an Egger's test is conducted to support the results of the Funnel Plot test (Sterne et al., 2011).

The researchers conducted this meta-analysis study by following the international PRISMA guidelines (Page et al., 2021; Moher et al., 2015), which were modified to align with the specific objectives and characteristics of the study. The inclusion criteria used in this research included: (1) Selecting scholarly articles from Google Scholar, a widely used platform among researchers due to its accessibility to academic literature across disciplines; (2) Selecting publications indexed in SINTA (Science and Technology Index), which serves as a ranking system for academic journals published in Indonesia; (3) Focusing on studies that examine the use of the discovery learning model in chemistry education, particularly those evaluating its impact on higher-order thinking skills; (4) Ensuring that publications include r, t, or f values as prerequisites for quantitative analysis; (5) Including studies with a sample size of $n \geq 20$ to maintain the validity and reliability of the results; and (6) Analyzing studies conducted at the senior high school level to ensure the relevance of the findings to the characteristics of the student population being studied.

The exclusion criteria included research articles published in national journals not indexed in SINTA, studies that did not use the discovery learning model, and studies on lower-order thinking skills. The research data used is presented in Figure 1.

Based on the flowchart, the initial search stage using Google Scholar with the keywords *Discovery Learning* and *higher-order thinking skills* yielded 10.400 articles. A duplicate check was then conducted, resulting in 2.600 articles. A classification process was carried out from these, yielding 500 articles that met the criteria of focusing on discovery learning and higher-order thinking skills. In comparison, 2.100 articles were excluded because they did not focus on applying discovery learning to higher-order thinking skills.

From the 500 articles, 9 were identified that specifically focused on using discovery learning to enhance higher-order thinking skills in chemistry education and were indexed in SINTA. However, 3 of these articles were excluded because they did not meet the requirement of including one of the statistical values: r, t, or F.

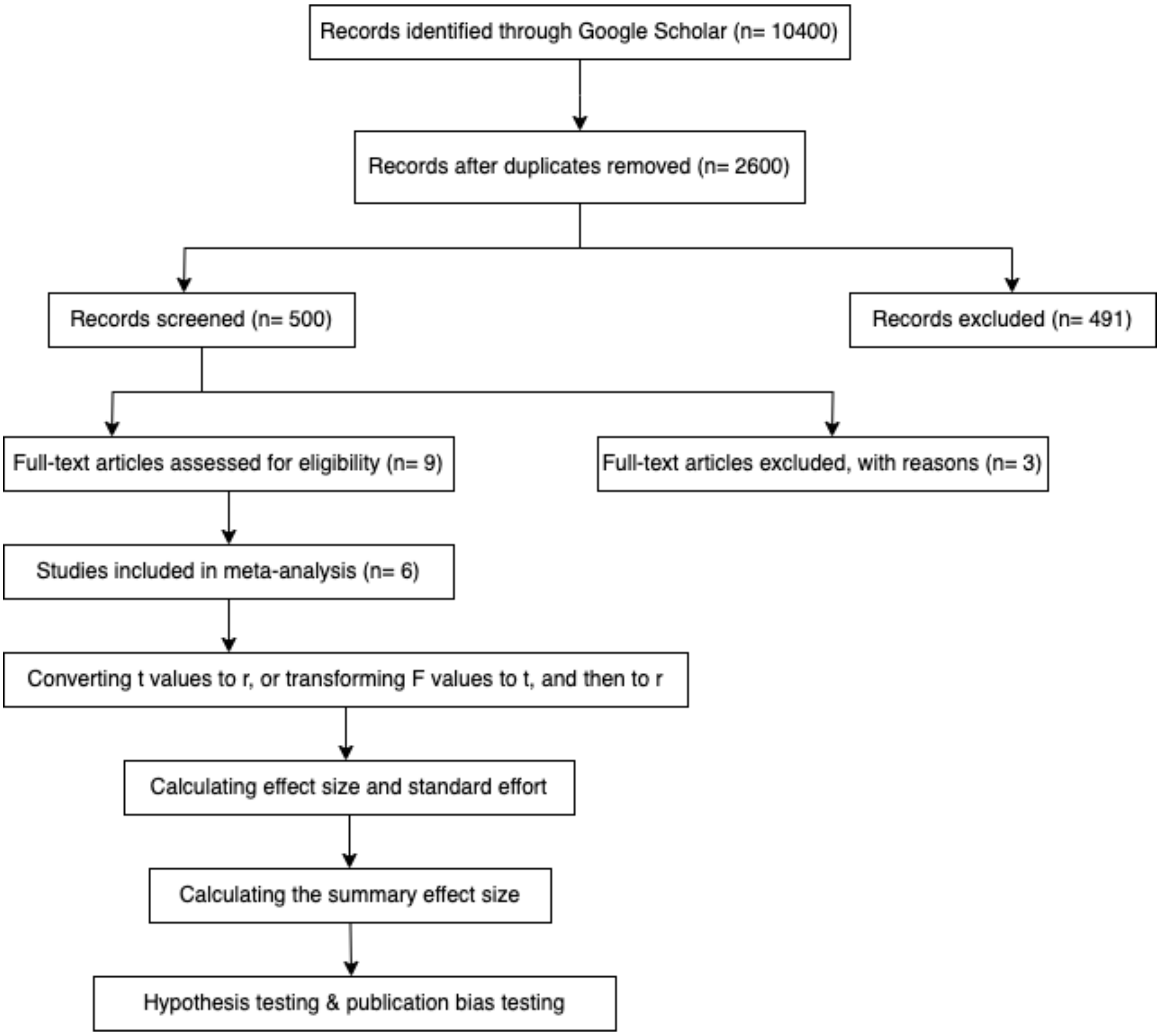

Figure 1. Flowchart of The Data Analysis Procedure

Thus, six articles were selected for inclusion in the meta-analysis, each playing an important role in the overall analysis. The articles were selected based on their relevance and quality, in alignment with the research focus. Table 1 presents the data coding results from these studies, including each study that reported an r, t, or F value.

Table 1. Data Encoding Summary

No.	Year	Author	Index	R	t	F
1	2015	Utami, M.P., Fadiawati N., & Rudibyani, R.B	Sinta 4	0.952	15.16	
2	2018	Mahfuzah, B.,A, Munzil., & Utomo, Y	Sinta 3	0.000		1.2
3	2023	Yerimadesi Et Al	Sinta 1	0.884	14.43	
4	2024	Sutiani, A & Bela, C	Sinta 4	0.258	2	
5	2024	Sara, , S & Suyanti, D. S	Sinta 4	0.184	1	
6	2021	Tania, L., & Saputra, A	Sinta 2	0.780	6.831	

In this meta-analysis, d-Cohen's was used as the effect size metric to measure the magnitude of the influence of the discovery learning model on higher-order thinking skills. One of the advantages of d-Cohen's is its standardized interpretation thresholds for small, medium, and large effects (Cohen, 1988), which facilitate understanding of the findings. This study chose d-Cohen's as the effect size measure. It included a heterogeneity analysis using the Q, I^2, and τ^2 statistics to identify the extent of variation among studies that is not due to random error.

These steps were taken to ensure that the level of analysis remained consistent and aligned with methodological guidelines recommended by (Clephas & Heesen, 2022) who emphasize the importance of consistency in reporting and interpreting effect sizes in cross-study meta-analyses. In this analysis, the criteria for effect size refer to Cohen's classification, ranging from weak to very strong. These criteria are presented in Table 2.

Table 2. Cohen's Effect Size Criteria

Values	Criteria
< 0 + / -.1	Weak effect
< 0 + / -.3	Modest effect
< 0 + / -.5	Moderate effect
< 0 + / -.8	Strong effect
≥ + / -.0	Very strong effect

RESULTS AND DISCUSSION

This meta-analysis study used six research studies that met the inclusion criteria. Based on the 6 study articles, the effect measurements were then carried out to determine how strong the influence of the discovery learning model is on high-order thinking skills in chemistry learning. The effect size of each study provides information on how influential the application of the discovery learning model is on high-level thinking skills. The following is presented in Table 3. The analysis results of the effect size and category of each effect in each study studied, along with the standard error.

Table 3. List of Effect Sizes and Standard Errors of Studies

Authors	Year	G	Category	SE
Utami, M.P., Fadiawati N., & Rudibyani, R.B	2015	1.533	Very Strong	0.209
Mahfuzah, B.,A, Munzil., & Utomo, Y	2018	1.256	Very Strong	0.192
Tania, L., & Saputra, A	2021	0.678	Strong	0.186
Yerimadesi et al.	2023	1.533	Very Strong	0.132

Sutiani, A & Bela, C	2024	0.678	Strong	0.120
Sara, S & Suyanti, D. S	2024	0.304	Medium	0.174

The results of the study size show that three different categories were obtained from each study, ranging from 0.304 to 1.533, with very strong, strong, and moderate categories. The results show that 50% of the studies analyzed are in a strong category with a G value (Hedges' g) above 1.2, with two studies showing the highest G value of 1.533, which indicates that discovery learning is very effective in improving high-order thinking skills. In the other two studies, although not in the very strong category like the other three studies, the G value = 0.678 is also still in the strong category, indicating that the discovery learning model is still effective in improving high-level thinking skills. At the same time, one study has a value in the moderate category with a G value of 0.304. The G value in the range of 0.3 to 0.5 can already show an influence (Borenstein et al., 2009; Mikolajewicz & Komarova, 2019). Thus, the discovery learning model is effective in improving high-order thinking skills.

The results of the measurement of the effects on six articles that examine the application of the discovery learning model and its influence on high-order thinking skills in chemistry learning in high schools in Indonesia are used as a reference for further application of the heterogeneity test and at the final stage the summary effect test. The heterogeneity test analysis was conducted using JASP software version 0.8.5, which showed variations in the study results. The analysis stage begins with a heterogeneity test to determine the extent of data variation.

Table 4. Heterogeneity Test Results

Fixed And Random Effects	Q	Df	P
Omnibus Test Of Model Coefficients	22.373	1	< .001
Test Of Residual Heterogeneity	50.682	5	< .001

The heterogeneity test was conducted through the Fixed and Random Effects model, providing a more comprehensive picture of the consistency in applying the discovery learning model to improve students' high-order thinking skills in chemistry learning. Based on the results of the analysis of the studies, the statistical value of heterogeneity (Q) was obtained at 50.682, with a p-value of less than 0.001 at a significance level of 0.05 (95% confidence level, $\alpha = 0.05$). These statistical data indicate high variability or heterogeneity in the study results, indicating significant differences between the studies analyzed. This finding is reinforced by the residual heterogeneity estimate, which confirms the variation in the data from the studies (Petitti, 2001; Villanueva & Zavarsek, 2004).

Table 5. Heterogeneity Measures

Residual Heterogeneity Estimates	95% Confidence Interval		
	Estimate	Lower	Upper
τ^2	0.236	0.074	1.565
T	0.485	0.273	1.251
I^2 (%)	90.025	74.015	98.358
H^2	10.025	3.848	60.919

The results of the residual heterogeneity analysis showed that the variance effect sizes (τ^2) were 0.236, while the standard deviation between studies (τ) was 0.485. These figures indicate that the studies used are heterogeneous because τ^2 is greater than zero and τ is not zero, with the acquisition of confidence interval values ranging from 74.015% to 98.358%. This wide confidence interval indicates significant heterogeneity between studies (Borenstein et al., 2009; Higgins, 2003). Significant variability among the six studies analyzed indicates that the effect of the discovery learning model on higher-order thinking skills differs significantly among the studies that have been analyzed. The next stage is further analysis using a random effects model to calculate the summary effect size.

Table 6. Effect Size Summary

Coefficients						
					95% Confidence Interval	
	Estimate	Standard Error	Z	P	Lower	Upper
Intercept	0.994	0.210	4.730	< .001	0.582	1.405

Note. Wald Test.

Analysis using the random effects model and summary effect size test shows that implementing the discovery learning model has a positive influence, indicating a positive correlation between the discovery learning model and high-order thinking skills with a Z value of 4.730 and a p-value <0.001, indicates a very strong effect statistically, with a 95% confidence interval between 0.582 and 1.405. Based on Cohen's criteria, the calculation of the summary effect shows that the application of the discovery learning model has a positive relationship with high-order thinking skills, as indicated by the value of 0.994 and a standard error of 0.210, which is a strong effect (L. V. , & O. I. Hedges, 2014; Clephas & Heesen, 2022).

The results of the random effect analysis with summary effect calculations are illustrated through the results of the forest plot test. The forest plot test provides a clear visualization of the variation in effect sizes across the studies analyzed and identifies the lowest and highest effect values reported in the articles used as data sources for this meta-analysis (Hedges, 1982; Ahn & Kang, 2018). In addition, a forest plot analysis was conducted to illustrate the impact of the discovery learning model on improving students' high-level thinking skills. The plot (Figure 2) shows that most effect size points are to the right of the reference line, indicating a positive effect (Dettori et al., 2021; Shanmugam et al., 2024).

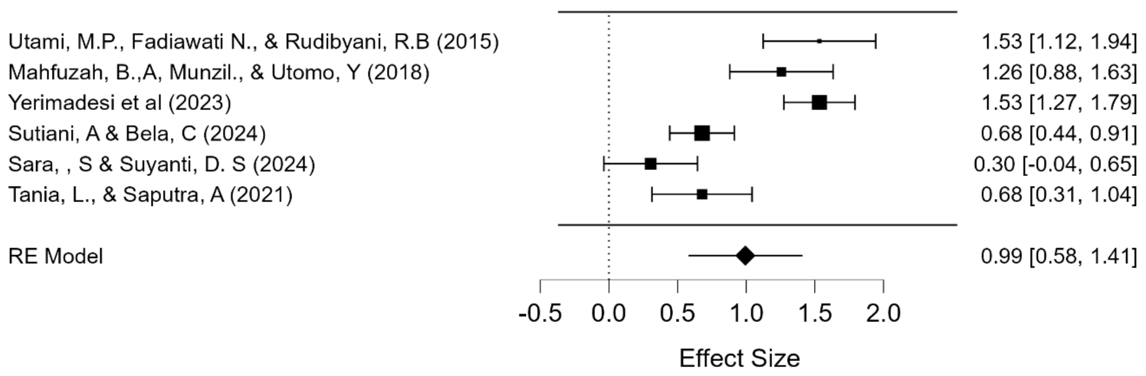

Figure 2. Forest Plot Results

Forest plot analysis revealed variations in effect sizes across the studies examined(Fisher, 2015; Chang et al., 2022). The results of the forest plot analysis showed that the effect sizes of the various studies analyzed ranged from 0.30 to 1.53. The points shown in the forest plot correspond to the correlation values of each study, with a wide spread of points, primarily located on the right side of the reference line, indicating that all studies provided positive results in improving students' higher-order thinking skills. The distribution of points on the right side indicates that all studies analyzed showed significant effect sizes (Ghajarzadeh, 2025; Patole, 2021).

Thus, based on the heterogeneity test of the six articles reviewed, there was a gain (Q) of 50.682, with a p-value of less than 0.001. Based on these results, the Q value <0.05 indicates that the studies show significant effect size results. Based on the effect size results, an investigation was carried out on the moderator variables based on the year of publication of the six studies reviewed.

Table 7. Moderator Variable Analysis

No.	Variable	K	Q	Df	Qw	Qb	*P*
1	2015-2019	2	0,953	1	40,386	10,296	0,00133
2	2020-2024	4	39,433				

The analysis of moderator variables during the publication period with a significance level of 0.05, the statistical value of Qb = 10.296 with a P value of 0.00133. The statistical value of P 0.00133 < 0.05 indicates differences in research results based on the year of publication. This is due to differences in technological developments that are increasingly advanced and can increase learning effectiveness (Fajaruddin et al., 2024; Öztop, 2023). The next stage is a funnel plot test to ensure that publication bias does not influence the research findings (Sterne et al., 2011). Conducting a publication bias test using a funnel plot to ensure these findings are valid and not influenced by publication bias is essential. The funnel plot helps assess the reliability of the results based on the effect size test obtained from the six research articles used in this analysis. This is evidenced by looking at the symmetry or asymmetry of the funnel plot against the summary effect value, which functions as an indicator of whether the research results experience publication bias or not (Doleman et al., 2020). The funnel plot (Figure 3) helps assess the reliability of the results based on the effect size tests derived from the six research articles used in this analysis.

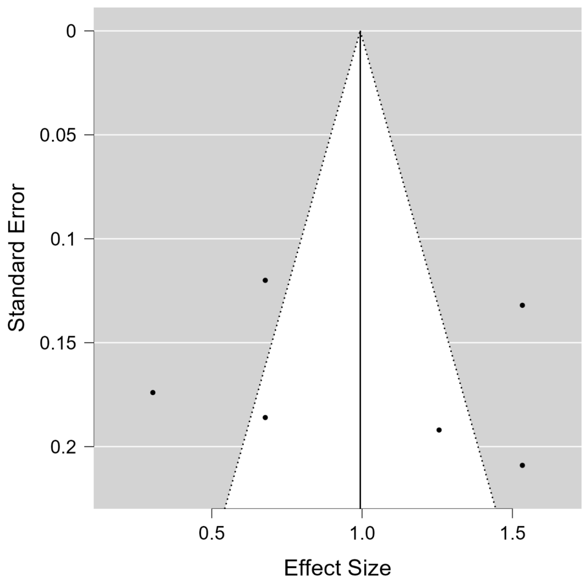

Figure 3. Funnel Plot Test

Based on the results of the funnel plot test, there are no black or white dots in the distribution. The distribution of dots from the studies analyzed in this study indicates that this meta-analysis is symmetrical, indicating no publication bias.

Table 8. Egger Test

Regression Test For Funnel Plot Asymmetry ("Egger's Test")		
	Z	P
Sei	0.295	0.768

In addition to the funnel plot test, an Egger test was also conducted to confirm the absence of publication bias. Based on the results of the Egger test, a P-value of > 0.05 was obtained, indicating that the distribution of studies on the funnel plot curve was symmetrical, indicating the absence of publication bias. This finding is further supported by the results of the file drawer analysis, especially the file-safe N test, which is presented in Table 9.

Table 9. Fail Safe N Test

File Drawer Analysis			
	Fail-Safe N	Target Significance	Observed Significance
Rosenthal	488.000	-	< .001

The analysis drawer file shows a K value of 6, which is used to calculate the fail-safe N value. Using the formula 5K + 10, the result is 5(6) + 10 = 40, which indicates the number of studies needed to balance the effects found in this meta-analysis. The calculated fail-safe N value is 488, with a significance level of 0.05 and a p-value < 0.001. This value, which far exceeds the minimum threshold of 40 (Rosenthal, 1979), confirms that the findings are statistically significant, robust, and systematically bias-free.

Theoretically, the analysis results align with Bloom's updated taxonomy framework by (Anderson, 2001) which states that higher-order thinking skills are developed through hierarchical and interrelated processes. In this context, the Discovery learning model prioritizes the process of exploration, elaboration, and reflection, naturally involving students in complex thinking activities. This process includes important aspects of higher-order thinking skills, such as critical, evaluative, and creative thinking that can significantly improve higher-order thinking skills.

Although this analysis has not separated the impact of discovery learning on each type of high-order thinking skill, such as analytical skills, evaluation, and creation, the results are still relevant because most of the studies analyzed in this meta-analysis treat high-order thinking skills as an integrated construct, not as a stand-alone domain, so that it can be used not only to strengthen the theory of discovery learning but also to highlight its relevance in chemistry education, especially for teaching complex and abstract concepts where its application supports broader educational goals by developing 21st-century skills by encouraging an inductive reasoning approach to conclude concrete data collected by students themselves. This helps students understand the material concept better (Putri Utami, 2022; Siregar et al., 2022; Loka et al., 2022; Wilda et al., 2024).

The results of this analysis are also supported by several other studies that found a relationship between discovery learning and high-order thinking skills with statistical value acquisition with a 95% confidence interval. This high interval shows that the application of discovery learning has a strong and positive effect, especially in the development of high-order thinking skills (Pristiana et al., 2024; Izzatul N & Endang Widjajanti Laksono, 2021; Delismar et al., 2024; Suryanti & Mufit, 2021; Sa'diyah et al., 2024). Studies involving discovery learning stimulation activities, problem identification, data collection, processing, and generalization allow students to be directly involved in the learning process (Thamrin & Darmawan, 2024; Wulandari Diah et al., 2018).

The results of this analysis also provide evidence that the application of the discovery learning model allows educators to provide opportunities for students to be actively involved in constructing knowledge through exploration and problem-solving, which also contributes to improving students' higher-order thinking skills (Ott et al., 2018; Yuniawati & Purba, 2021; Arwaty & Lullulangi, 2022; Koten & Rohaeti, 2024).

Thus, the high heterogeneity in the studies analyzed indicates that various contextual factors, such as educational level, student characteristics, and learning environment, can influence the implementation of discovery learning. Therefore, it is recommended that further researchers consider the context of implementation in interpreting the effectiveness of this model by exploring the specific effects of discovery learning on each component of students' higher-order thinking skills in more detail and involving a more diverse population in terms of region, language, and education level. In addition, applying a combined approach between quantitative and qualitative data can strengthen the findings' validity.

CONCLUSION

Based on the results of the meta-analysis conducted on six research articles showing a high level of heterogeneity and the validity of the funnel diagram analysis supported by the N test, which showed no publication bias in the meta-analysis, it can be concluded that the application of the discovery learning model has a significant impact on improving students' high-order thinking skills in chemistry education at the Senior High School level. Overall, the analysis results are supported by several other studies that found a positive effect of discovery learning on developing students' high-order thinking skills, making it a very relevant and practical approach, especially in chemistry learning. However, this study has limitations in the scope of the research area and level of education because this study only focuses on the senior high school level in Indonesia. Therefore, it is recommended for further researchers to cover a broader population in terms of education level, research location, and language, using qualitative and quantitative approaches or by comparing it to other methods to gain a deeper understanding of the effectiveness of the discovery learning.

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