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Does the Integrated Discovery Learning STEM Model Improve Students' Problem Solving Skills in Chemistry Learning? Meta-Analysis Study

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Abstract: The industrial revolution 4.0 has a significant impact on chemistry learning. Learning chemistry leads students to have problem-solving thinking skills in learning. There are many studies on STEM-integrated discovery learning models, but no overall effect size has been found from previous studies. This study aims to determine the effect of the size of the STEM-integrated discovery learning model on students' problem-solving skills. This type of research is quantitative research with a meta-analysis approach. The samples came from analyses of national and international journals. Inclusion criteria are publications derived from journals or proceedings indexed by SINTA and Scopus, experimental or quasi-experimental method research, research published in 2021-2024, research must be relevant, data search through google scholar, Springer, Hindawi, ScienceDirect and ERIC databases and Researchgate, research must have complete data to calculate effect size, and a sample size of ≥ 20 students. data analysis through JASP application. The results of the study concluded from the analysis of 19 heterogeneous and normally distributed journals explained the significant effect of the STEM-integrated discovery learning model on students' problem-solving skills ($p < 0.001$; rRE = 0.940) with high criteria.

Keywords: Discovery Learning; Effect Size; Problem Solving; STEM

Introduction

Problem-solving skills are a skill that students must have in the 21st century (Nasution et al., 2019). Problem-solving skills assist students in providing concrete solutions to specific problems (Çetİn et al., 2023; Özpinar & Arslan, 2023), but rather to teach students how to think critically, analyze situations, and identify the most appropriate solutions. Through problem-solving skills students can gain confidence in overcoming problems, both in educational contexts and in everyday life (Bal & Or, 2023). Problem-solving skills also help students become more independent learners and more creative thinkers. In addition, problem-solving skills also prepare students for a future full of challenges and rapid change (Widodo et al., 2023). In an increasingly complex and dynamic world, students have problem-solving skills to evaluate information, identify problems, and design effective solutions (Yapatang &; Polyiem, 2022; Ilwandri et al., 2023).

Furthermore, studentswho have good problem-solving skills will be better prepared to face various changes in the world of work and their lives, and have higher competitiveness in a growing society (Treepob et al., 2023; Mahanal et al., 2022). Therefore, problem-solving skills also require good communication skills to collaborate with others in finding the best solution (Ichsan et al., 2023; Ron et al., 2022; Özeren, 2023). By honing and developing problem-solving skills, students can become more effective in facing the various challenges they face in everyday life, as well as in achieving goals and success in chemistry learning (Rončević & Babić-kekez, 2021).

However, students' problem-solving skills in chemistry learning are still relatively low (Permatasari et al., 2022; Gunawan et al., 2020). In the chemistry

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learning process, teachers do not involve students to provide opinions or solutions in learning activities to solve a problem (Vula & Berisha, 2022; Sumiantari et al., 2019). In addition, in the learning process teachers do not involve students to be active so that interest and motivation to learn chemistry is low (Rahman et al., 2023; Zulkifli et al., 2022; Jayadiningrat & Ati, 2018; Susino et al., 2024). Not only that, the low problem-solving ability can be seen from the 2018 PISA research conducted by the OECD showing that the science literacy ability of Indonesian students is ranked 71 out of 78 countries in the world (Utomo et al., 2023; Suryono et al., 2023; Supriyadi et al., 2023; Elfira & Santosa, 2023). In addition, teachers use learning models that do not stimulate students to have problem-solving skills. So, there needs to be an effective model that encourages students' problem-solving abilities in learning chemistry.

Discovery learning is a learning model that can develop students' problem-solving skills (Bahtiar et al., 2022). Discovery learning, is a learning model that emphasizes the active role of students in exploring knowledge and understanding (Hariyanto et al., 2023; Yunus, 2021). In this model students are given the opportunity to independently discover certain concepts, facts, or principles through experimentation, investigation, or exploration (Rustam, 2018; Simanjuntak et al., 2018; Azis & Irvan, 2021). This approach rewards self-exploration and discovery, which can spur students' interest and motivation, while developing students' critical and analytical thinking skills in chemistry. Discovery learning provides many benefits in the context of education (Murtiyasa et al., 2020).

This model encourages students to actively engage in the learning process which can enhance their understanding of the subject matter. In addition, discovery learning mode can develop students' critical thinking and problem solving skills (Murtiyasa et al., 2020), because they have to find their own solutions or patterns. In addition, discovery learning can also increase students' confidence and independence in their learning (Utami, 2021). By designing learning experiences that allow students to explore and discover knowledge in their own way, education can become more engaging and meaningful for students, spurring students' creativity and helping them prepare for future challenges (Usman et al., 2022).

Furthermore, discovery learning models can be integrated with STEM decoding. STEM stands for Science, Technology, Engineering, and Mathematics, which is an interdisciplinary educational approach that blends the four fields (Akoz et al., 2022; Yang & Baldwin, 2020). The STEM approach aims to integrate concepts and skills from these four disciplines in learning (Eroğlu, 2021), so that students can develop a more comprehensive understanding of the real world and face a variety of complex technological and scientific challenges (Fadlelmula et al., 2022).

Previous research on the application of discovery learning models has a significant influence on problem-solving skills in students (Lubis et al., 2019; Herdiana & Sispiyati, 2017; Nur et al., 2020). Furthermore, the research of Hariyanto et al. (2023) the discovery learning model has a positive influence on problem-solving skills in students in the learning process. Many studies on the application of discovery learning models in learning have not found effect sizes of the application of STEM-integrated discovery learning learning models in chemistry learning. Therefore, it is necessary to conduct a meta-analysis to determine the effect size of the entire STEM integrated discovery learning model in chemistry learning. Therefore, this study aims to determine the effect of the size of the STEM-integrated discovery learning model on students' problem-solving skills.

Method

This research is a type of quantitative research with a meta-analysis approach. Meta-analysis is a research approach that collects and analyzes primary research quantitatively (Suparman et al., 2021; Chamdani et al., 2022; Razak et al., 2021; Balemen & Keskin, 2018). Meta-analysis was conducted to determine the effect of STEM-integrated discovery learning model on students' problem-solving skills. According to Borenstein et al. (2009), the meta-analysis research procedure consists of determining research inclusion criteria, collecting and coding data from primary studies, and analyzing statistically.

Data Collection

Data collection in this meta-analysis through searching the databases of Google Scholar, Springer, Hindawi, ScienceDirect and ERIC as well as Researchgate. Data search keywords: discovery learning model; the influence of discovery learning in chemistry learning, and the influence of STEM-integrated discovery learning models on students' problem-solving abilities in chemistry learning. The amount of data obtained from the data database is seen in Table 1.

Table 1. Data obtained from Journal Database

Database	Sum	Percentage (%)
Google scholar	501	70.16
ScienceDirect	42	5.89
Hindawi	11	1.54
ERIC	112	15.68
Springer	19	2.67
Researchgate	29	4.06
Total	714	100

Inclusion Criteria

In meta-analysis research to obtain valid data must pay attention to inclusion criteria. The inclusion criteria for this meta-analysis are research must be experimental methods or quasi-experiments, research comes from international journals or proceedings indexed by SINTA, Scopus and Web of Science, research related to the effect of STEM-integrated discovery learning models on students' problem-solving skills, research that must report complete data for effect size calculations, research published from 2021 to 2024 and sample size must be ≥ 20 Participants. In a database search, 714 studies were obtained. The results were selected with the specified inclusion criteria obtained by 19 relevant journals. Selection of research data through the PRISMA method can be seen (Figure 1).

Data Coding

In the research, 19 studies that met the inclusion criteria were given data codes. The data code is created to reflect the characteristics of the meta-analysis study. The results of data coding can be seen in Table 2.

Table 2. Data coding

Group	Code
Study	Research (Journal/Proceedings)
Learning outcomes	Troubleshooting
Content Area	Chemistry
Grade level	High School and College
Location	Indonesian
Meta-analysis quality	Low, Moderate and High
Publication bias	Low, trivial, no and unknow

Data Analysis

In the meta-analysis of the data analysis process by calculating the effect size value of relevant primary data (Puspita & Irfandi, 2022; Juandi et al., 2021; Putra et al., 2023). According to Borenstein et al. (2009) the statistical analysis procedure in meta-analysis consists of calculating the effect size value of the study; test the heterogeneity of the data; calculate the summary effect size and determine the estimation model, check publication bias and calculate the p-value to test the research hypothesis. Statistical analysis with the help of JASP application. Furthermore, the value of the effect size criterion is guided by the criteria Cohen et al. (2007) can be seen in Table 3.

Table 3. Effect Size Value

Effect Size	Category
0.00 ≤ ES ≤ 0.20	Low
0.20 ≤ ES ≤ 0.80	Medium
ES ≥ 0.80	High

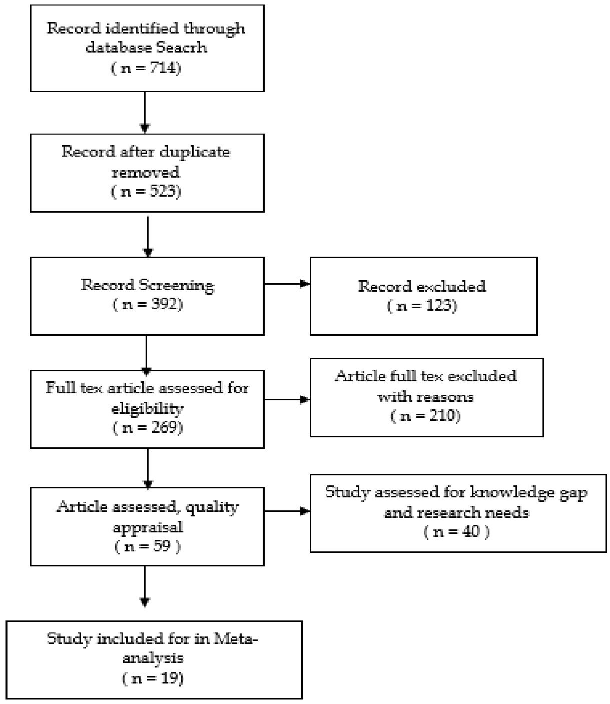

Figure 1. Selecte Data with PRISMA

Result and Discussion

From the results of data search through the database of google scholar, Springer, Hindawi, ScienceDirect and ERIC and Researchgate related to keyword search data obtained 714 research journals. Furthermore, the results were selected based on the specified inclusion criteria, then 19 research journals were included in the meta-analysis data. Data that meet the inclusion criteria are calculated effect size values which can be seen in Table 4.

Table 4. Effect Size 19 Research Journal

Study Code	Year	Effect Size	Standard Error
Study 1	2022	1.13	0.34
Study 2	2021	0.91	0.20
Study 3	2021	1.33	0.38
Study 4	2023	1.47	0.41
Study 5	2021	0.97	0.30
Study 6	2022	0.62	0.21
Study 7	2023	1.11	0.30
Study 8	2023	0.69	0.18
Study 9	2022	0.83	0.29
Study 10	2023	0.81	0.33
Study 11	2021	2.41	0.52
Study 12	2022	2.07	0.47
Study 13	2024	1.27	0.46
Study 14	2023	0.77	0.32
Study 15	2023	1.05	0.41
Study 16	2022	0.92	0.36
Study 17	2021	0.75	0.26
Study 18	2023	0.59	0.26
Study 19	2023	1.16	0.35

Based on Table 4, the results of effect size analysis from 19 research journals have the highest effect size value of 2.41 with a standard error of 0.52 and the lowest effect size value of 0.59 with a standard error of 0.26. Furthermore, according to the effect size criteria Cohen et al. (2007) from 19 research journals analyzed obtained 14 effect sizes with high criteria and 5 medium chiteria effect sizes. Next, conduct heterogeneity tests and determine estimation models for the 19 studies analyzed. The results of heterogeneity tests using random and fixed effect models can be seen in Table 5.

Table 5. Fixed and Random Effect

	Q	Df	P
Omnibus test of Coefficients Model	163.874	1	< 0.001
Test of Residual Heterogeneity	25.261	18	< 0.001

Note: *p -values are approximate*
Note: *The model was estimated using Restristed ML Methods*

Table 5, the results of the analysis obtained a Q-value value of 163,874. The value is greater than the value of 25.261 and the p value < 0.001. These results imply an analysis of 19 heterogeneously distributed effect sizes. The meta-analysis model used to analyze the average value of 19 effect sizes is the random effect model. Furthermore, checking publication bias on 19 research journals analyzed. To analyze publication bias used is funnel plot analysis and Egger's test (Tamur et al., 2020; Martin & Carolina, 2022; Aybirdi et al., 2023; Diah et al., 2022). The results of checking publication bias can be seen in Figure 2.

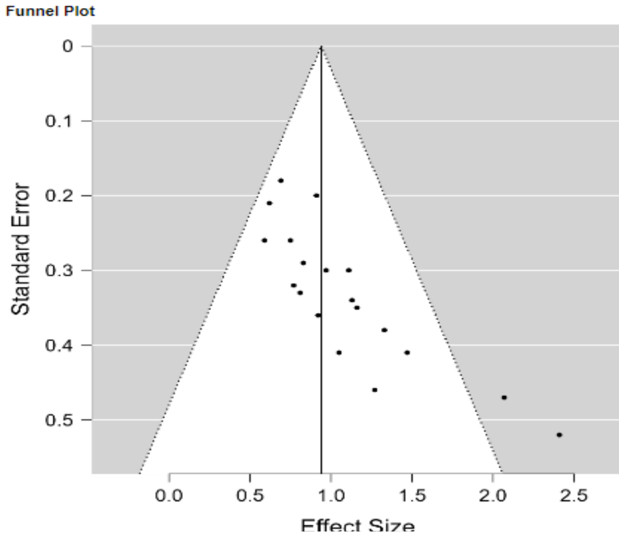

Figure 2. Funnel Plot Random Effect Model

Figure 2, showing the results of the bias analysis of the publication of 19 effect sizes with funnel plots, it is difficult to know the shape of the curve of symmetric or asymmetric funnel plots, so further tests need to be carried out, namely the Egger's test. Egger's test results can be seen in Table 6.

Table 6. Regression Test for Funnel Plot Asymetry (Egger's)

	z	p
Sei	3.966	< 0.001

Table 6 Egger's test results obtained a value of Z 0.966 > 1 and p < 0.001. These results conclude that the funnel plot curve is symmetrical, meaning that the analysis of 19 effect sizes found no publication bias. The last step, perform a p-value calculation to test the hypothesis. The results of the p – value analysis with summary effect size can be seen in Table 7.

Table 7. Summary/Mean Effect Size

	Estimate	Standard Error	z	P
Intercept	0.940	0.073	9.923	< 0.01

Based on Table 7, the summary effect size value is obtained r_{RE} = 0.940 and standard error 0.073. This result shows the value of the effect size of the high category, Furthermore, from the results of the Z test shows a significant influence with a value of 9.923 and p < 0.001. These findings explain that STEM-based discovery learning models have a significant effect on students' problem-solving skills.

This research is Ananda & Atmojo (2022) the discovery learning model has a significant influence on students' problem-solving skills. This finding is in accordance with Arisujati & Suweken (2019) said the discovery learning model can improve problem-solving skills in the learning process. This discovery learning model combines the principles of discovery learning with a STEM approach, which combines science, technology, engineering, and mathematics so as to develop students' thinking skills (Zulyusri et al., 2023; Elsayary et al., 2015). Thosewho learn with the STEM-integrated discovery learning model have significant improvements in problem-solving skills (Purwaningsih et al., 2020; Rustam, 2018).

In the discovery learning model, students are invited to actively engage in experimentation, investigation, or exploration to find their own solutions or answers (Azriyanti, 2023). This helps them develop critical thinking, analytical, and problem-solving skills as they have to design experiments, collect data, and formulate conclusions. In addition, the integration of STEM provides a more tangible context for learning, allowing students to see how science, technology, engineering, and mathematics can be used in real-world problem solving (Debora & Pramono, 2022; Chen et al., 2019). The results of the study by Syahmel & Jumadi (2019) show that the STEM-integrated Discovery Learning model can help students develop problem-solving skills that are indispensable in developing students' 21st century skills (Priemer et al., 2020).

Furthermore, Shieh (2016) research on the STEM integrated learning model shows that this learning method can increase students' confidence in facing problem-solving challenges (Miterianifa et al., 2019; Supriyadi et al., 2023). When students have the opportunity to actively participate in the learning process and successfully solve problems, their confidence in problem-solving skills increases. This is important because self-confidence can be a powerful motivator for students to continue learning and develop their higher-order thinking skills.(Usman et al., 2022; Thibaut et al., 2018). STEM can provide a solid foundation for students in the development of in-depth problem-solving skills. Students who have become accustomed to this approach tend to be better equipped to deal with complex and unexpected problems in real life. That way, this approach can help students to better prepare for their future.

Conclusion

From this meta-analysis study, it can be concluded that there is a significant influence of the STEM integrated discovery learning model on students' problem-solving skills ($p < 0.001$; rRE = 0.940) with high criteria. These findings explain that STEM-based discovery learning models can develop problem-solving skills and students are more active in learning. Not only that, the discovery learning model can increase students' confidence in learning. This model has a positive impact on teachers to implement the STEM integrated discovery learning model in schools.

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Author Contributions

The research consisted of two contributing authors. Erni Jojan contributed to collecting data, selecting and analyzing data statistically. Eli Rohaeti contributed input and suggestions in completing this research.

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Conflicts of Interest

The authors declare no conflict of interest.

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