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The Effect of Guided Inquiry Learning by Virtual Laboratory Assistance in Physics Learning in Indonesian Senior High Schools: A Meta-Analysis

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There are hundreds of studies on the effect of Guided Inquiry Learning by Virtual Laboratory Assistance (GILVLA) in Physics learning in Senior High School on students' learning outcomes in science. The studies have some contradictory results. In order to determine the impact of GILVLA on students' science learning outcomes and to gauge the degree of inter-study variation, a meta-analysis research was done. To find pertinent research that falls under the research's purview, the ERIC, Scopus, and Google Scholar databases were investigated. By entering predefined keywords into the databases, it was found that there are 128 articles published in the last decade related to research purposes. Based on the results of the inclusion criteria, there were 24 articles that met the eligible for analysis. The data analysis used Comprehensive Meta-Analysis (CMA) software, and the effect size (ES) index of the Hedges-g metric is obtained based on the estimated random-effects model. The research findings reveal that the total ES of GILVLA on student outcomes in science learning is 0.94, with a standard error of 0.15. This finding suggests that GILVLA's deployment in Indonesia is effective since it significantly improves students' scientific learning outcomes. Four moderator variables were taken into account while analyzing the degree of variation in the study, and the results revealed significant differences in the sample size ($Q=11.45$; p0.05) and treatment duration ($Q=125.07$; p0.05). It was found that the year of study variable ($Q=3.71$; $p>0.05$) and a class of study ($Q=0.028$; $p>0.05$) did not change the effect size of using GILVLA on students' science learning outcomes. The findings show that the GILVLA model will achieve a high level of effectiveness by considering the sample size and duration of treatment.

Keywords: guided inquiry, virtual laboratory, students' science learning outcomes, meta-analysis, effect size

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INTRODUCTION

Currently, the purpose of education is for students to acquire knowledge and competencies that are in accordance with the needs of modern society (Bolstad, 2020). The ability to adapt in the 21st century is needed to maintain individual and national existence. The new educational standards emphasise higher skills, including reasoning, creativity, and open-ended problem solving (Bao, 2019). In line with that, science lessons like physics train students in critical thinking, solving complex problems, modelling real-world situations, and communicating technical information so they can answer 21st-century challenges (Foote, 2020). In particular, the task force of the American Association of Physics Teachers has compiled a comprehensive report on preparing science students for 21st-century careers. Science learning competencies or outcomes have broad implications for students.

Students' science learning outcomes can be improved by using appropriate learning models (Freeman-Green, O'Brien, Wood, & Hitt, 2015). Haagen-Schützenhöfer & Joham (2018) suggested that learning that organises students to work within groups, conducts discovery simulations, and an experiment will effectively develop students' science learning outcomes. One learning model that fulfils these suggestions is Guided Inquiry Learning by Virtual Laboratory Assistance (GILVLA). Learning through guided inquiry gives students independence by encouraging them to have a more active and responsible role in various stages of investigation (Hardianti & Kuswanto, 2017). In general, a guided inquiry learning approach for science learning creates a favorable environment for the growth of student-active learning (Margunayasa et al., 2019). A virtual laboratory is one of the interactive media that can help students conduct experiments and discoveries. This provides convenience for students in the learning process. The ability to access learning at a higher level is part of this convenience. By engaging in continual, independent simulation and evaluation activities, students can increase their understanding (Arista & Kuswanto, 2018). Another element that has to be introduced in the scientific education curriculum is the usage of interactive simulations. Additionally, interactive simulations can be used to meet a variety of learning goals, implementation environments, instructional techniques, grade levels, and student populations (Ouahi et al., 2022). GILVLA encourages students to think critically, solve problems, communicate effectively, work in groups, receive criticism, and use and share information with others (Haagen-Schützenhöfer & Joham, 2018).

Primary research related to the effect of GILVLA on student science learning outcomes has been conducted by different research teams and places, as well as on different students. Different studies on the same topic sometimes provide varied and even contradictory results and result in subjective conclusions about research questions (Franzen, 2020; Juandi, Kusumah, Tamur, Perbowo, & Wijaya, 2021; Juandi & Tamur, 2021; Tamur, Juandi, & Kusumah, 2020). Failure to recognize the majority of research findings in the literature will produce arbitrary conclusions and even outcomes manipulation. (Franzen, 2020; Tamur, Juandi, & Kusumah, 2020).

The conclusion which affects future GILVLA implementation is driving the momentum towards "evidence-based research". This theoretical response integrated quantitative findings to provide accurate and valuable conclusions for future policy setting and learning practices (Higgins & Katsipataki, 2015; Juandi, Kusumah, Tamur, Perbowo, Siagian, et al., 2021; Siddaway, Wood, & Hedges, 2019). As a result, meta-analytical studies are required to combine and analyze the findings in order to arrive at comprehensive and compelling conclusions (Schmidt & Hunter, 2015; Khan, 2020). To summarize the population's existing evidence, meta-analyses were conducted (Lee, 2019; Suparman, Juandi, & Tamur, 2021; Tamur et al., 2021). Thus, a meta-analysis of the total impact of GILVLA is required in order to produce more objective data and serve as the foundation for decisions.

The meta-analysis calculates effect sizes (ES) and combines them in an objective formula, increasing the likelihood that different readers will come to the same conclusion (Schmidt & Hunter, 2015). However, no specific meta-analysis study has questioned the effect of GILVLA on students' science learning outcomes. However, the educators need accurate information to decide in which condition the implementation of GILVLA will achieve higher effectiveness on students' science learning outcomes.

Several meta-analyses on the effect of guided inquiry learning on students' science learning outcomes have been carried out (e.g., Usman, Cahyati, Putri, & Asrizal, 2019; Sari, Siari, Darvina, & Asrizal, 2020; Mardianti, Yulkifli, & Asrizal, 2020). However, they did not question the effect of moderator variables on the overall ES of the study. The previous meta-analysis also did not analyse treatment duration as a potential variable that might explain the variation of ES of the study. Moreover, they only showed the overall ES without specifying the estimation method as essential in the meta-analysis. As a result, reported results may be exaggerated and indicate publication bias. Estimating models and publication bias analysis have been carried out in recent meta-analyses (e.g., Fadhli, Brick, Setyosari, Ulfa, & Kuswandi, 2020; Kul, Çelik, & Aksu, 2018; Turgut & Turgut, 2018). However, these studies have not questioned GILVLA on students' science learning outcomes as an object of analysis.

This current study extends and complements previous research that focuses on determining the overall effect of GILVLA on students' science learning outcomes. It also examines the reasons for the variation in ES between primary studies by analysing the relationship between the identified moderator variables, such as the year of study, research class, sample size, and duration of treatment. The findings of this study provide accurate information to educators in implementing GILVLA in the future. This explanation justifies the importance of conducting a meta-analysis study on the effect of GILVLA on students' science learning outcomes in Indonesia in the last decade.

METHOD

This study used a meta-analysis method, by reviewing several articles related to this research topic published in national and international journals. The analysed primary studies were related to the effect of the application of GILVLA on students' science learning outcomes. Selecting inclusion criteria is one of the processes that Borenstein et al. (2009) explain in general. Second, explain the procedures utilized to code the variables for the research and gather the empirical data. Third, explain statistical techniques. The following procedures were used in the research.

Inclusion Criteria

All research articles in the search engines were examined and assessed to meet the inclusion criteria of the meta-analysis, namely; (a) publication in recognized national and international journals; (b) publication through a peer-review process; c) presentation of research findings on the effects of GILVLA on Indonesian students; (d) published in the last decade, and (e) the presence of statistical data for ES transformation.

Data collection

Empirical data obtained from the ERIC (Education Resources Information Centre), the Scopus, and Google Scholar databases were examined to achieve relevant research within the research scope with the keywords, "Physics and guided inquiry learning by virtual laboratory assistance". In addition, manual searches were carried out by visiting the library and contacting the main authors. The literature search was conducted for six months and resulted in 128 articles published between 2011 and 2021 being examined for research purposes. The data selection process was based on Pigott & Polanin (2020) suggestions regarding a transparent and quality process. As a result, the data was filtered using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) procedure. This protocol was started by identifying 128 articles collected from related databases. Then screening was carried out and obtained 43 removed articles because of the double. The eligibility stage, which involved choosing articles based on the inclusion criteria, was then implemented. Finally, 24 research were suggested for inclusion in our analysis whereas 61 articles were discarded.

A research instrument is a coding form designed to turn the information from 24 investigations into numerical data. The numerical data consist of the author's name, statistical information (mean, standard deviation, and sample size of both groups from each primary study), year of study, research class, and duration of treatment. Two independent investigators were used to code the 24 studies, this was done to ensure the reliability of the coding process. To assess the level of agreement among coders in the reliability test, the Cohen's Kappa coefficient (κ (7)) statistical test was used (McHugh, 2012). Cohen's Kappa formula is; (7)=(Pr(a)-Pr(e))/(1-Pr(e)) where Pr(a) represents a completely observable agreement, and Pr(e) represents a coincidental agreement. A value of 0.85 or greater is predefined to be considered high. The level of agreement in the study is 0.89, which means a substantial match between the coders. The level of agreement between coders is at a high level. Thus, this data reflects that the research instrument is reliable.

Statistical Analysis

The data in the meta-analysis is an ES (Glass, 2015). The ES in this study was an index that describes the effect of GILVLA on students' science learning outcomes. The statistical procedure in this study was based on the description of Borenstein et al. (2009), namely (a) calculating the ES of each primary study; (b) performing heterogeneity test and selection of estimation model; (c) checking for publication bias; and (d) calculating the p-value to test the research hypothesis. Analysis of the reasons for the variation in ES was conducted by examining the mediator variables relationship carried out after it was known that the estimated model was random-effect (Haidich, 2010). The data were analyzed using a tool called Comprehensive Meta-Analysis (CMA). Cohen's equation estimates the population but is biased towards studies with small samples. However, the Hedge's g metric was used to determine the ES index by considering the small sample in this study. Furthermore, the interpretation of ES used Cohen, Manion, & Morrison (2018) as follow: ES is less than 0.2 (small effect), ES is between 0.2 and 0.5 (medium effect), ES is between 0.8 and 1.3 (significant effect), and the ES is above 1.3 (very significant effect).

The Q statistic and p-value were examined in the heterogeneity test. The null hypothesis, which claims that the ES of each study is homogeneous, is rejected if the p-value is less than 0.05. The estimate technique chosen was the random-effect model. If the fixed-effect model is examined and the p value is greater than 0.05, the null hypothesis is accepted. The study's level of variation was analysed by examining moderator variables after determining that the estimate chosen was a random-effect model.

An examination of publication bias was carried out to prevent misrepresentation of the findings (Cooper, Hedges, & Valente, 2019; Çiftçi & Yıldız, 2019). Published studies are more likely to be included in the meta-analysis than unpublished ones, and this fact has led to concerns that meta-analyses may overestimate the actual ES (Borenstein, Hedges, Higgins, et al., 2009). Furthermore, funnel plots were examined to assess the possible amount of bias, and Rosenthal's FSN statistics (Tamur, Juandi, & Adem, 2020) were utilised to assess the impact of bias. This study was resistant to bias if the spread of ES showed a symmetrical distribution around the vertical line (Borenstein, Hedges, & Rothstein, 2009). If the ES were not entirely distributed symmetrically, then the Trim and Fill's test was used to reveal the influence of research publication bias (Tamur, Mandur, & Pereira, 2021).

FINDINGS

Overall Analysis Result

First, this research is expected to reveal the magnitude of the overall effect of GILVLA on students' science learning outcomes. The forest plots of ES for each study are shown in Figure 1 based on the data processing findings obtained using CMA.

Meta Analysis

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Izzati et al (2021)	0.73	0.29	0.08	0.17	1.29	2.54	0.01
Amalina et al (2018)	0.37	0.24	0.06	-0.10	0.83	1.54	0.12
Haerani et al (2020)	1.09	0.35	0.12	0.40	1.78	3.08	0.00
Rusliati et al (2019)	1.12	0.25	0.06	0.63	1.61	4.47	0.00
Herlina et al (2019)	0.33	0.30	0.09	-0.25	0.91	1.12	0.26
Saputri et al (2016)	2.23	0.36	0.13	1.51	2.94	6.11	0.00
Kusdiastuti et al (2016)	1.43	0.29	0.08	0.86	2.00	4.93	0.00
Hayati et al (2017)	1.11	0.30	0.09	0.51	1.70	3.64	0.00
Yulianci (2017)	0.54	0.27	0.07	0.01	1.07	2.00	0.05
Tampubolon (2017)	1.99	0.35	0.12	1.31	2.68	5.70	0.00
Hermansyah (et al (2017)	2.22	0.34	0.12	1.56	2.89	6.54	0.00
Husnaini et al (2019)	-0.44	0.26	0.07	-0.95	0.06	-1.73	0.08
Wen et al (2020	0.14	0.25	0.06	-0.36	0.64	0.54	0.59
Graaf et al (2020)	-0.07	0.24	0.06	-0.55	0.40	-0.30	0.76
Fan et al (2020)	2.06	0.33	0.11	1.41	2.72	6.18	0.00
Graaf (2020)	1.02	0.27	0.07	0.49	1.54	3.80	0.00
Hairani (2016)	0.48	0.24	0.06	0.01	0.96	1.99	0.05
Rizki et al (2021)	1.30	0.30	0.09	0.72	1.88	4.37	0.00
Suprianti et al (2021)	2.14	0.32	0.10	1.50	2.77	6.61	0.00
Magdalena et al (2014)	-0.05	0.25	0.06	-0.54	0.44	-0.20	0.84
Ngertini et al (2013)	1.05	0.28	0.08	0.50	1.59	3.78	0.00
Wastiti et al (2019)	1.52	0.32	0.10	0.90	2.14	4.78	0.00
Hartati et al (2015)	0.09	0.25	0.06	-0.39	0.57	0.37	0.71
Kurniawan (2014)	0.77	0.29	0.08	0.20	1.33	2.67	0.01
	0.94	0.15	0.02	0.64	1.24	6.06	0.00

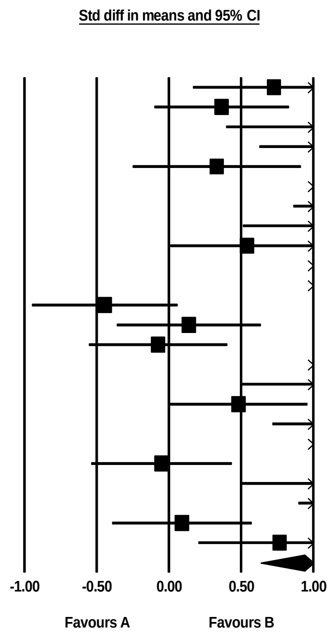

Figure 1

Forest plot of the research

The research's forest plot, shown in Figure 1, shows the research's general confidence levels and inconsistent response rates. It indicates the heterogeneity or variation in results among the primary studies. It also shows the overall ES and confidence intervals of these studies according to the meta-analysis method. Research findings from Tamur et al. (2020) indicate that several moderating variables moderates the ES study. Thus, further analysis needs to be carried out to see how far the influence of the related moderator affects the study ES (Arik & Yilmaz, 2020). However, before that step, the estimation model needs to be tested whether it fits the random effects model or not. As shown in Figure 1, the combined ES is 0.94, with an ES range for each study being 0.63-1.24. Table 1 shows a comparison of research results based on the estimation method.

Table 1

Results of the Research Using the Estimation Method

Model	N	ES	SE	95% Confidence Interval		Q	P	Decision
				Lower	Upper			
Fixed-effect	24	0.81	0.05	0.68	0.92	165.18	0.00	Reject h_0
Random-effect	24	0.94	0.15	0.63	1.24			

The ES distribution is heterogeneous, as shown by the p-value is < 0.05 in Table 1, which indicates that the estimation model matches the random-effects model. So the ES studies use the random-effect model, which is 0.94. Furthermore, the study funnel plot in Figure 2 was looked at to look for publication bias. When the distribution of the ES study is symmetrical, it is resistant to publication bias (Borenstein et al., 2009). In cases where the 24 ES experiments were not entirely symmetrical, the Trim and Fill tests were applied. If k is the number of studies, then the Fail-Safe Number (FSN) / (5k + 10) < 1 is considered resistant to publication bias (Mullen, Muellerleile, & Bryant, 2001).

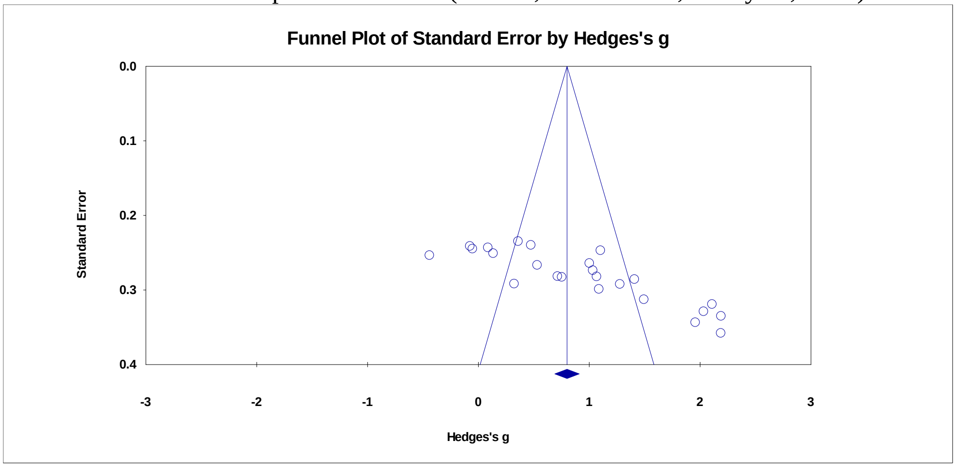

Figure 2
Funnel plot of the research

Figure 2 shows that the vertical lines in the ES distribution of each study are not perfectly symmetrical. To assess the magnitude of the effects associated with publication bias, Trim and Fill tests have to be used. The results are shown in Table 2.

Table 2
Trim and fill test results

	Studies Trimmed	ES	Confidence Interval		Q Value
			Lower Limit	Upper Limit	
Observed values		0. 94	0.63	1.22	165.18
Adjusted values	0	0. 94	0.63	1.22	165.18

The trim and fill test results, as illustrated in Table 2, show no difference between the observed ES and the virtual effect based on the random-effects model. This result means no publication bias in this study, or no studies were trimmed or added due to publication bias.

Moderator Variable Analysis Results

The analysis results show that the distribution of ES is heterogeneous, so the mediator variables (the year of study, research class, sample size, and duration of treatment) need to be further analysed to investigate whether these four variables play a role in influencing variations in the study ES. Table 3 is a summary of the analysis results.

Table 3
Summary of the results of mediator variable analysis

Mediator Variable	Group	N	Hedge's g	Heterogeneity (Q$_b$)	df(Q)	P	Decision
Year of Study	2011-2013	2	0,90	3.71	3	0.29	Accept H_0
	2014-2016	5	0.61				
	2017-2019	9	0.80				
	2020-2021	8	0.89				
Research Class	X	12	0.79	0.028	1	0.88	Accept H_0
	XI	12	0.80				
Sample Size	≤ 30	8	1.08	11.45	1	0.00	Reject H_0
	≥ 31	16	0.67				
Treatment Duration	Less than five meetings	9	1.59	125.07	2	0.00	Reject H_0
	Five to seven meetings	8	0.95				
	More than seven meetings	7	0.10				

When Table 3 was examined, it appears that the year of study and the research class is not significant from the four potential moderator variables. In comparison, the other two variables are statistically significant. A detail of the overall analysis and the moderator's analysis results is presented in the discussion section.

DISCUSSION

The analysis results of the study, as illustrated in Figure 1 and Table 1, reveal that the ES of the GILVLA impact is estimated at 0.94 (significant effect), which means that GILVLA has a significant impact on students' science learning outcomes. This finding differs from the results of previous meta-analyses. For example, Sari et al. (2020) reported that the magnitude of the application effect of the guided inquiry learning model on students' science learning outcomes was 0.44 (medium effect). At the same time, Mardianti et al. (2020) reported ES 1.43 when they analysed nine individual studies on the influence of the guided inquiry learning models implementation on students' science learning outcomes. This distinction serves as the foundational concept for subsequent study.

Figure 2 is a funnel plot with a fixed-effect model. If you look closely, the 24 studies that were sampled in the meta-analysis were not symmetrically distributed. This shows that there is an indication of bias. The funnel plot method itself has come under some criticism. These criticisms are related to the interpretation of the funnel plot which is only based on visual assessment and seems very subjective. In situations when protocols or trial register records are not available for the majority of research, Pages et al. (2020) suggest that the funnel plot method can assist review authors in finding indications of non-reporting bias. However, they have well-documented limitations. Therefore, a trim and fill test was applied to measure the impact of the bias. Trim and Fill use an iterative process to eliminate the most extreme small studies from the funnel plot's positive side. With each iteration, the effect size is recalculated until the funnel plot is symmetrical. Theoretically, this would produce a unbiased estimate of the effect size (Duval & Tweedie, 2000a, 2000b). The results of the trim and fill test in Table 2 show no difference between the observed ES and virtual effects based on the random-effects model. This means that there was no publication bias in this study, or that no studies were trimmed or added due to publication bias. Therefore, our conclusion that GILVLA has a significant effect on students' science learning outcomes is free from the potential for publication bias.

The results of the moderator analysis in Table 3 shows that GILVLA was moderated by differences, sample size and treatment duration. Meanwhile, the research year and the research class did not play a statistical role in moderating the study ES. The four study groups did not differ significantly (P-value = 0.29 > 0.05). However, there is a tendency that the average ES of the four study groups based on the year of study has decreased from year to year. Theoretically, the latest technological developments should impact the magnitude of the GILVLA implementation impact from year to year. These results suggest that GILVLA implementation may be affected by the Hawthorne effect. In comparison, Tamur, Kusumah, et al. (2021) has reported the effect of Hawthorne on the use of software in learning. Although the use of software has a major effect on students' learning outcomes, if it is given continuously, the effect will decrease.

When Table 3 was examined, it was revealed that the effectiveness of GILVLA was not affected by differences in study class (P-value = 0.88 > 0.05). This data indicates that there are no specific recommendations regarding the implementation of GILVLA to class. This result means that learning using GILVLA can be applied in all classes. It is possible to occur because the subject of the analysis in this study is the result of primary research on the effect of ITVBL in high school. This finding is also supported by a previous meta-analysis related to the use of technology that there was no significant difference between the classes or categories analysed (Tamur, Juandi, & Kusumah, 2020).

In terms of research sample size, Table 3 shows differences in ES between categories (P-value = 0.00 < 0.05). This result indicates that the implementation of GILVLA must consider the sample size. In this case, the analysis results recommend that GILVLA achieve a higher effectiveness level when students are organised into small groups. These results are supported by previous meta-analyses that GILVLA is more effective when administered in small groups (e.g., Tamur et al., 2020; Yunita et al., 2020). These results show that the trend of students' activity-based learning such as discovery simulations and experiments considers the sample size in its implementation.

Finally, Table 3 presents that the duration variable of treatment is related to the study ES. The analysis results showed that the three categories of these variables were significantly different (P-value = 0.00 < 0.05). In detail, it can be seen that the category with less duration of the treatment gives a larger average of ES. The longer the duration of GILVLA implementation, the more negligible effect it will have. This fact shows that GILVLA is associated with the Hawthorne effect. Theoretically, the Hawthorne effect exists when high results are obtained as an impact of the new treatment (Bayraktar, 2001; Juandi et al., 2021). These results are consistent with the results of previous studies that the Hawthorne effect significantly affects the study effect (Cheung & Slavin, 2013; Tamur & Juandi, 2020; Tamur, Juandi, & Kusumah, 2020; Yunita, Juandi, Tamur, Adem, & Pereira, 2020). They are considered objective conclusions to contribute to policies regarding the learning curriculum, primarily related to variations in the use of learning models or methods. No matter how good a learning model is, the effect will decrease if it is used continuously.

The moderator analysis's findings showed that the factors sample size and treatment time influenced the use of GILVLA. On the other hand, the heterogeneity of the studies implies variations in results between studies that reflect the magnitude of the variance between studies. This finding implies that there are additional moderating factors that affect GILVLA's efficacy. As a fundamental concept for the application of future research, this constraint creates a new gap.

CONCLUSION

This study was conducted to summarize the evidence on the magnitude of the effect of GILVLA on student science learning outcomes, and to examine whether the relationship was moderated by year of study, class of study, sample size, and duration of treatment. The results showed that GILVLA had a big impact on students' science learning outcomes. GILVLA implementation is most effective when applied through small groups, with GILVLA implementation helping students make observations and discoveries effectively. The application of GILVLA is also recommended suitable for use in junior high and high school students. However, these findings were only supported by individual studies that were eligible for analysis. There are still many other individual studies that are weak in terms of descriptive statistics for ES calculations. Due to a lack of statistical data, several relevant studies could not be examined. In addition, this study was only able to analyze 24 studies because it was purely an online-based study search technique. This study also only analyzed four mediator variables. Further studies are needed to verify these findings by involving more individual studies and covering more mediators such as duration of treatment, comparison of effectiveness between countries, combinations of GILVLA used, and learning resources.

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