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Impact of Interactive Media Utilization on Enhancing Learning Outcomes: Meta-Analysis

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Abstract: This study evaluates the impact of interactive media on students' learning outcomes through a meta-analysis approach. A total of 25 relevant studies published between 2019 and 2024 were analyzed using the Restricted Maximum Likelihood (ML) method in a random-effects model. The results show a moderate effect size (Cohen's d = 0.495) with substantial heterogenety (I^2 = 89.27%). Publication bias was tested using a funnel plot, Egger's test, and fail-safe N analysis, confirming the validity of the findings. The results indicate that interactive media significantly enhance student learning outcomes across various educational contexts. These findings suggest that teachers and policymakers should integrate interactive media into science education to foster student engagement and improve learning effectiveness. Future research should explore the long-term impact and optimal implementation strategies for interactive media in diverse learning environments.

Keywords: Interactive Media, Learning Outcomes, Meta-Analysis, Science Education

Introduction

One of the key indicators of educational effectiveness is student learning outcomes. In science education (IPA), developing students' conceptual understanding, critical thinking, and problem-solving skills is essential. However, numerous studies indicate that students still struggle to achieve optimal learning outcomes in science subjects at various educational levels. A major contributing factor to this issue is the limited use of innovative and engaging learning strategies that facilitate active participation in the learning process(Wiranata et al., 2021)

Interactive media have emerged as a potential solution to improve science learning by enhancing engagement and comprehension. These media include computer-based simulations, virtual laboratories, interactive videos, and augmented reality applications that enable students to explore scientific concepts dynamically (Lo & Hew, 2019). Unlike traditional teaching methods, interactive media allow students to visualize abstract scientific phenomena, conduct virtual experiments, and receve immediate feedback, which supports deeper learning and retention.

Several studies have demonstrated the benefits of interactive media in STEM education. (Wang et al., 2023) found that robotics-based interactive learning enhances computational thinking and problem-solving skills in science and technology subjects. Similarly, (Dias-Olivera et al., 2024) showed that interactive media promote not only conceptual understanding but also collaboration and critical thinking in scientific learning. These findings highlight the importance of incorporating interactive media in science education to create more effective and engaging learning environments.

Despite these promising results, there remains a gap in the literature regarding the overall impact of interactive media on science learning outcomes. Most

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previous studies have been conducted in isolated contexts, focusing on specific learning styles, student populations, or technology types. Additionally, prior meta-analyses in STEM education have primarily examined the effectiveness of technology-enhanced learning in engineering or mathematics but have not comprehensively analyzed its impact on science education (Arlinwibowo et al., 2022).

This study addresses this gap by conducting a meta-analysis specifically on the use of interactive media in science education. A total of 25 relevant studies published between 2019 and 2024 were analyzed using the Restricted Maximum Likelihood (ML) method within a random-effects model. The study evaluates the overall effect size of interactive media on science learning outcomes while assessing heterogenety and publication bias to ensure the reliability of the findings.

By synthesizing data from multiple studies, this research provides a broader perspective on how interactive media influence learning outcomes in science education. The findings contribute to existing literature by offering empirical evidence on the effectiveness of interactive media across different science learning contexts. Additionally, this study provides practical recommendations for educators and policymakers to optimize the integration of interactive media into science curricula.

Ultimately, the insights from this meta-analysis can help shape future research and educational policies that support interactive and technology-enhanced science learning. Understanding the broader impact of interactive media can guide curriculum development, teacher training programs, and resource allocation to improve student engagement and learning outcomes in science education.

Method

Data Collection and Study Selection

This study employed a meta-analysis approach to systematically analyze the impact of interactive media on students' learning outcomes in science education. A systematic search was conducted in reputable databases, including Scopus, Google Scholar, and SINTA, using keywords such as "interactive media," "learning outcomes," and "meta-analysis." The study selection process adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to ensure methodological rigor.

A total of 106 articles were identified in the initial search. After removing 6 duplicate studies, 100 unique articles remained. The selection process involved evaluating research design criteria, leading to the exclusion of 25 studies that did not meet the inclusion requirements. The final selection resulted in 25 studies that met the inclusion criteria and were included in the meta-analysis.

Exclusion and criterion for inclusion were utilized within this study to remove low-quality and relevant articles were analyzed. The inclusion criteria included: (1) articles with experimental designs involving control and experimental groups, (2) including information gathered from the posttest, such as average scores, number of participants, and standard deviation, (3) articles published in nationally accredited journals (SINTA 1-3) or Scopus indexed international journals, (4) research relevant to the topic of interactive media utilization in learning, and (5) publishing period between 2019 and 2024. Exclusion criteria included articles that did not provide complete data, only used descriptive designs, or were published in non-peer-reviewed journals. This selection process followed the PRISMA systematic method to increase validity and avoid bias ((Arlinwibowo et al., 2022); (Wahono et al., 2020) By ensuring that each article met the inclusion criteria, this study produced a credible and useful analysis to support the generalizability of the findings.

Table 1. Inclusion Criteria for Meta-analysis Articles

Criteria	Inclusion
Scientific Domain	Publications that address the topic of how the use of interactive technology might enhance educational result
Publication Year of the Journal	The publication year of the articles is 2019–2024.
Article Type	Piece published in esteemed periodicals on a national and worldwide scale
Research Design	Articles that use experimental research methods using control classes and experimental classes about the effect of utilization of interactive media to enhance educational outcomes, as well as an experimental class investigating the impact of using interactive technology to enhance learning results.
Research Data	Experimental and control classes' posttest results are included in this article. The standard deviation (SD), sample size (N), and mean value (M) should all be included.

Among the 25 selected studies, 18 (72%) explicitly focused on science education (IPA), covering subjects such as physics, chemistry, and biology. The remaining 7 studies (28%) were broader STEM-based studies, including engineering and computational sciences (Lo & Hew, 2019) The distribution of studies across educational levels was as follows: Primary Education: 5 studies (20%); Secondary Education: 12 studies (48%; Higher Education: 8 studies (32%). These findings highlight that most studies targeted secondary education, renforcing the significance of interactive media in science learning at this level.

Data Analysis Technique

This meta-analysis used ML (Maximum Likelihood) as its data analysis technique random effect restricted model. This approach was chosen to accommodate heterogenety among the studies processed, resulting in more generalized estimates. Before conducting the main analysis, the first step is to test the heterogenety of the data through the residual heterogeneity test using Q-statistics. If the p-value is less than 0.05, which indicates that the data is diverse, then the random effect model is appropriate for usage. Using the post-test data from both the experimental and control groups, the standard formula for meta-analysis was used to calculate the effect size. For this purpose, we calculated the effect size using the following formula:

$$d = \frac{M_2 - M_1}{\sqrt{\frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}}} \quad (1)$$

The means (M1) and standard deviations (S2) of the two groups, as well as the control group's (S1) and experimental group's (S2) scores. The formula for determining the standard error is as follows: $SE_g =$

$$\sqrt{J \times V_d} \quad (2)$$

$$J = 1 - \frac{3}{4(n_1+n_2-2)-1} \quad (3)$$

$$V_d = \frac{n_1+n_2}{n_1.n_2} + \frac{d^2}{2(n_1+n_2)} \quad (4)$$

To check for publication bias, we employed a funnel plot; next, we used Egger's Test and Fail-safe N to evaluate the results. Data symmetry was verified using the funnel plot results, and the presence of significant bias in the included papers was assessed using Egger's test. The purpose of calculating fail-safe N values was to determine if the results remained significant after including some studies that did not meet the significance level. The results of the bias analysis, effect size calculations, and 95% confidence intervals were presented graphically and in tables (forest plot). For effect size values, Cohen's criterion states that they are minor for $0.2 \leq d < 0.5$, medium for $0.5 \leq d < 0.8$, and big for $d \geq 0.8$.

The two sets of averages used in the previous equations are the experimental group's (M2) and the control group's (M1), along with the coefficient of determination (d). We can see that there were n1 and n2 samples in the control and experimental groups, respectively. S22 represents the variance in the experimental group and S12 represents the control group. The standard error of the effect size is denoted by Seg, and the correction factor used to minimize bias in the effect size computation is J. With the help of equation 4, we can find the value of the impact size variance, or Vd, the last variable. (According to (Arlinwibowo et al., 2022) and (Goulet-Pelletier & Cousineau, 2018)).

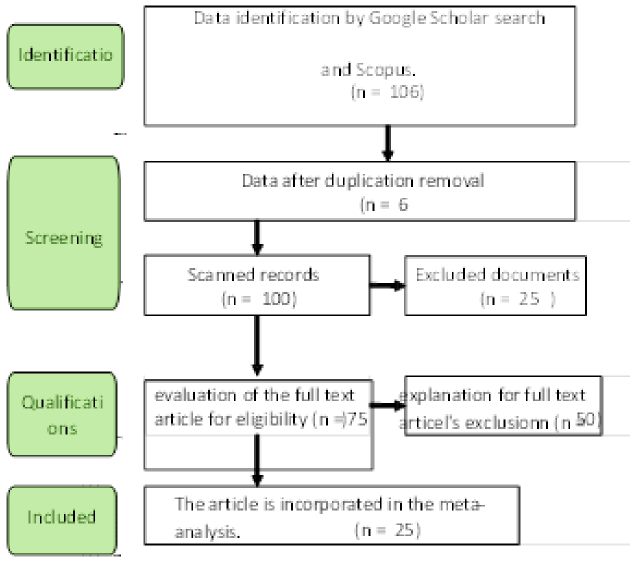

Figure 1. Selection of Articles Based on the PRISMA Method

Based on the journal search method, namely the PRISMA method and the inclusion and exclusion criteria, the total number of articles receved is 106. Based on the titles, all these articles fit into the same category: they explain how using interactive media might improve learning outcomes in vocational education. The data obtained came from the Google Scholar database, Scopus. The first analysis carried out is to analyze whether the articles have the same title as each other even though they are from different databases. The results of this analysis showed 6 articles were declared the same or duplication of the same article from different data bases, so there were 100 articles that were analyzed further. Further selection by applying research design inclusion criteria, namely selecting articles that only use experimental research methods by applying control classes and experimental classes. In this search, 25 articles were eliminated, and 75 articles met these criteria.

Result and Discussion

Results

The last selection made in the selection of articles is by looking at the research data presented to see whether it meets the inclusion criteria or not. There were 25 publications deemed to fulfill the criteria for data presentation inclusion derived from the analytical findings. From sample sizes, average scores, and standard deviations for both the experimental and control groups, all data required for this meta-analysis is present in these 25 studies.

Based on data sources from various databases, the most articles analyzed came from Scopus. Scopus now includes additional research on the topic of how vocational high schools might improve ther students' learning results through the use of interactive media, as well as indicating that this topic is currently trending. In order to gather the necessary data for the meta-analysis, which included control and experimental class sample sizes, means, and standard deviations, the 25 publications that were chosen were subsequently summarized. Following data collection, in order to calculate the effect size and standard error, we followed the steps in the previous analytical technique and used equations 1-4. Table 2 displays the research data obtained from these 25 articles in detail. Table 2. Summary of Article Data Utilized for Meta-Analysis. Table 3 displays the research data obtained from these 25 articles in detail.

Table 2. Summary of Article Data Utilized for Meta-Analysis

The name of the researcher	Annual period	Class in Control			Class for Experimenting		
		N	M	SD	N	M	SD
Liliana et al., 2020.,	2020	108	71.55	7.529	108	76.01	4.923
Sahronih et al., 2019	2019	16	66.75	6.36	16	70.25	1.,98
Faisal et al., 2023	2023	22	61.22	10.42	22	82.27	4.82
Saepuloh et al., 2022	2022	16	42.44	10.973	16	78.65	6.164
Gever et al., 2021	2021	235	3.50	0.34	235	3.4	0.66
Gever et al., 2021	2021	235	2.20	0.45	235	2.4	0.67
Lehikko et al., 2024	2024	44	5.25	0.89	22	5.08	0.87
Lehikko et al., 2024	2024	44	5.74	0.94	22	5.93	0.84
Petersen et al., 2022	2021	76	3.34	0.66	76	3.37	0.77
Petersen et al., 2022	2021	76	3.08	0.9	76	3.01	0.83
Song & Cai, 2024.	2024	14	75	10.35	14	80	81.87
Nasseri et al., 2024	2023	77	3.93	1.17	88	4.03	1.33
Agustiana & Irfan, 2023	2023	29	69.31	10.33	32	80.41	8.51
Sukariasih et al., 2019	2019	33	64.90	14.73	33	84.78	13.01
Untari et al., 2020	2020	34	83,76	5.52	32	87.29	3.88
Ramadhona et al., 2024	2024	20	46	20.9	20	44.6	19.7
Saengduenchay & Noenthaisong, 2023	2023	40	9.80	2.82	40	21.25	2.84
Mewengkang & Liando, 2021	2021	20	76.70	11.367	20	89.2	5.27
Susanti et al., 2022	2022	40	62.32	26.07	40	62.78	26.16
Hakiki et al., 2024	2024	43	50.51	9.5	43	81.48	11.04
Fortuna et al., 2024	2024	64	50.67	9.15	64	83	6.8
Uiphanit et al., 2023	2023	25	21.36	2.11	25	25.04	2.76
Mallya & Srinivasan, 2019	2019	40	12.15	3.02	40	13.85	3.12
Werdiningsih et al., 2019	2019	36	47.25	14.167	36	47.42	15.047
(Sumarlin et al., 2024)	2024	10	70	9.53	10	83.12	6.99

Description: Sample size (N), mean (M), and standard deviation (SD)

Heterogenety testing results

Heterogenety testing is carried out with the aim of knowing whether the random effect model restricted ml method can be used as a meta-analysis technique for this article. According to (Arlinwibowo et al., 2022)), the heterogenety test must be passed when random effect approaches are used in meta-analysis. The results of heterogenety testing using the jasp application as shown in table 4. The residual heterogenety test results obtained are (156.552) and the p-value obtained (p = < .001). From these facts, we can deduce that the observed A significant value (α) of p-value (0.001 < 0.05) is less than the conventional significance level of 0.05. The 25 articles that made up this meta-analysis are, therefore, diverse. These outcomes indicate that the random effect model restricted ml method can be used to conduct meta-analysis of this article. After the data passed this test, the second data test carried out was testing the publication bias of the article.

Table 3. Heterogenety Test Results

	Q	df	p
Omnibus test of Model Coefficients	15.430	1	< .001
Test of Residual Heterogenety	156.552	24	< .001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method.

Bias Testing Outcomes

In order to ensure that researchers do not make any mistakes when publishing ther results, bias testing is conducted. In order to conduct high-quality research with trustworthy data, the articles included in this study should not exhibit any bias towards publishing. Research bias testing aims to uncover data distortion in studies utilized in meta-analyses, which is important because of the enormous number of studies included in these types of analyses. Fluent plot testing, Statistical tests developed by Egger and the Fail-safe N statistical test were the three methods of bias analysis employed in this research (Labata-Lezaun et al., 2023; Tavares Olivera et al., 2023). While both bias and JASP testing make use of the same application, the Fail-safe N test differs in that it declares the article to be unbiased if the value of Fail-safe N acquired from is larger than the value obtained from the formula (5K + 10). The number of articles used in the meta-analysis is indicated by the variable K (Lo & Hew, 2019).

While both bias and JASP testing make use of the same application, the Fail-safe N test differs in that it declares the article to be unbiased if the value of Fail-safe N acquired from is larger than the value obtained from the formula (5K + 10). The number of articles utilized in the meta-analysis is indicated by the variable K. Figure 2 shows the results of a bias test that was interpreted using a funnel plot. The data distribution, as shown by the points in the funnel plot, is symmetrical and evenly distributed on both the left and right sides of the plot.

There is no article publication bias in the data used, as shown in Figure 2. There is no statistical way to explain the funnel plot's results; they are merely a visual representation of the data. So, to make the funnel plot results more solid, we used Egger's test to check for funnel plot symmetry. The regression value that emerged from Egger's test is 3.523, and the p-value that was obtained is 0.001. Our results show that the obtained significance alpha value (3.523>0.001) is higher than the significance criterion (0.05). From this, we can deduce that the data-generated funnel plot and the funnel flot are symmetrical. Therefore, it is clear that there was no bias in the selection of publications for the meta-analysis.

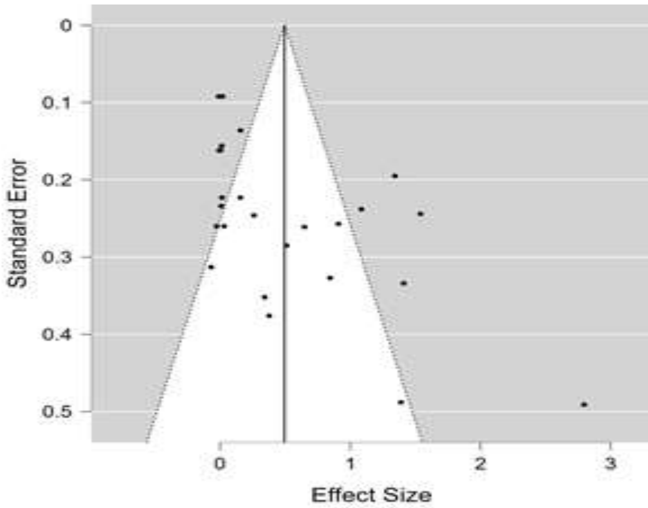

Figure 2. Funnel Plot

Table 4. Egger's test

	z	p
se	3.523	< .001

Additional bias testing was conducted using Rosenthal's Fail-safe N test to bolster the thesis that was concluded. In Table 5, we can see that the findings yielded a Fail-safe N value of 751. The obtained Fail-safe N value is larger than the Fail-safe N value computed using the Fail-safe N formula, as shown in the result (135). Additionally, the findings from the Fail-safe N test demonstrate that the articles utilized are devoid of publication bias. Further evidence that the articles used did not exhibit publication bias is provided by this outcome. The findings of the funnel plot analysis and the Rosenthal N fail-safe test provide evidence that the 25 articles included in the meta-analysis are not influenced by publication bias.

Table 5. Bias Testing Outcomes Utilizing the Fail-safe Technique N

	Fail-safe N	Target Significance	Observed Significance
Rosenthal	751.000	0.050	< .001

Mean Effect Size Testing Results

The data obtained in this study are valid and free from article publication errors. This is shown in the results of heterogeneity testing and bias testing that has been done. The subsequent step in the meta-analysis involves examining the average effect size derived from the 25 publications utilized in this investigation. This test will delineate the total effect size of employing interactive media to enhance learning results. This test was performed with the Wald test data analysis method, also referred to as the Wald chi-square test. The Wald test is a statistical method employed to evaluate the significant impact of the therapy administered to the research subject (Labata-Lezaun et al., 2023); (Wahono et al., 2020) The outcomes of evaluating the mean impact size derived from the Wald test methodology are presented in Table 6.

Table 6. Effect Size Test Summary

	Estimate	Standard Error	z	p
Intercept	0.495	0.126	3.928	< .001

Note. Wald test.

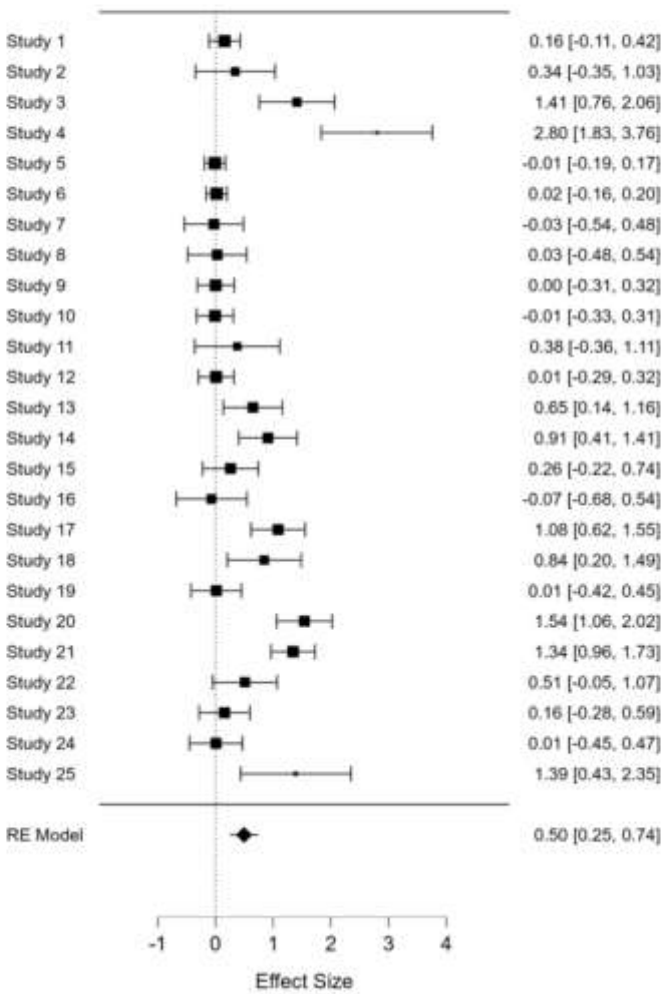

Figure 2. Forest Plot

It is evident from the wald test data analysis results in Table 4 that the p-value obtained (α = 0.005) is statistically significant, and the wald test value (Z = 3.523) is also presented. It is evident from this outcome that the p-value significance value (α = 0.001 <0.05) is less than the usual significance value (0.05). If the results of the wald test are to be believed, the model of interactive media utilization significantly improves course outcomes. Results from the overall effect size computation corroborate these findings. Using a 95% confidence interval, the 25 papers yielded an average effect size value of 0.495, the estimated upper value of the effect size obtained is 0.443 and the lower limit value is 0.002. Based on these two results, it renforces that the use of interactive media with moderate categories improves learning outcomes. This category is determined based on the category of effect size values put forward by Cohen's d where the value (0.8 ≤ d ≤ 2.0) is categorized as large, the value (0.5 ≤ d < 0.8) is a medium category, and the value (0.2 ≤ d < 0.5) is a small category.

It is clear from Figure 2 that the effect size value generated is different so that the criteria for the effect of interactive media utilization are also different. The lowest effect size value obtained was 0.002 with a confidence interval of 95%, so the estimated lower limit and upper limit of the effect size produced were -0.07 and 0.51. While the highest effect size value obtained is 0.443 with confidence intervals of 95%, the estimated lower limit and upper limit of the resulting effect size are 0.85 and 1.50. In general, the use of interactive media improves students' academic performance.

Discussion

The results of this meta-analysis confirm that interactive media have a moderate impact on students' learning outcomes in science education, with an effect size of d = 0.495. This finding aligns with previous research, such as (Lo & Hew, 2019) and (Faisal et al., 2023), which highlighted the potential of interactive learning tools to enhance conceptual understanding and engagement in STEM education. However, the moderate effect size suggests that while interactive media contribute significantly to student learning, ther effectiveness may depend on several contextual factors, including instructional design, student characteristics, and the specific science topics beng taught.

The substantial heterogenety (I^2 = 89.27%) found in this study indicates that the impact of interactive media varies considerably across different research settings. Several key factors may explain this variability. First, the level of interactivity and engagement plays a crucial role in determining learning gains. Interactive media encompass a wide range of tools, from basic animations to fully immersive virtual simulations. Studies using highly interactive simulations (e.g., virtual laboratories and augmented reality) tend to report higher effect sizes than those using simpler multimedia presentations ((Dias-Olivera et al., 2024) This suggests that the depth of student engagement significantly influences the effectiveness of interactive learning.

Second, the complexity of science topics may also affect the outcomes. Subjects that require conceptual visualization, such as physics (e.g., motion and forces) and chemistry (e.g., molecular interactions), may benefit more from interactive simulations than topics that rely heavily on memorization (Wang et al., 2023). However, if the interactive elements are too complex or cognitively demanding, they may overload students' working memory, leading to diminished learning outcomes ((Goulet-Pelletier & Cousineau, 2018)). Therefore, careful instructional design is needed to balance interactivity with cognitive load.

Third, student characteristics and prior knowledge are critical factors that influence the effectiveness of interactive media. Research suggests that students with high intrinsic motivation and strong background knowledge tend to benefit more from interactive learning than those with lower motivation or weaker foundational skills ((Hakiki et al., 2024)). This implies that scaffolding strategies, such as guided instructions or adaptive feedback, are essential to maximize learning outcomes for all students. Educators should consider providing structured support for learners with lower prior knowledge while allowing more exploratory learning experiences for advanced students.

Fourth, the integration of interactive media with pedagogical strategies significantly impacts learning effectiveness. The findings suggest that interactive media alone do not guarantee improved learning outcomes unless they are embedded within effective teaching frameworks. Approaches such as inquiry-based learning, problem-based learning (PBL), and flipped classrooms have been shown to enhance the benefits of interactive media in science education ((Saengduenchay & Noenthaisong, 2023)). When interactive media are used in isolation without proper instructional scaffolding, ther impact tends to be weaker. Therefore, teachers play a crucial role in designing structured learning activities that encourage students to actively engage with interactive content.

The findings of this study provide several key implications for science education (IPA) and the integration of technology-enhanced learning in schools. Given that interactive media are particularly beneficial for subjects requiring visualization and conceptual understanding, ther use should be prioritized in physics, chemistry, and biology topics involving abstract concepts (e.g., energy transformations, molecular structures, and ecological systems). Educators should also consider differentiated instruction when implementing interactive media. For students with low prior knowledge, structured guidance (e.g., step-by-step tutorials, adaptive learning pathways) should be provided, while advanced students can benefit from open-ended simulations and exploratory learning environments.

The moderate effect size found in this study suggests that technology alone is not sufficient to guarantee improved learning outcomes. Teachers should integrate interactive media within inquiry-based approaches, where students actively explore and apply scientific principles rather than passively receving information. Furthermore, the effectiveness of interactive media depends on how well teachers can design and facilitate technology-enhanced learning. Professional development programs should focus on training science teachers to effectively incorporate interactive tools into ther lesson plans ((Labata-Lezaun et al., 2023). Without adequate teacher training, even the most advanced interactive media may fail to produce meaningful learning gains.

While this meta-analysis provides valuable insights, several areas warrant further investigation. Future research should explore the long-term impact of interactive media on students' retention and understanding of scientific concepts. Additionally, studies should investigate the role of metacognitive strategies in enhancing the effectiveness of interactive learning. Given the growing development of digital education tools, future research should also examine how different types of interactive media (e.g., AR, VR, AI-based learning) influence specific science disciplines.

Overall, this study confirms that interactive media significantly improve science learning outcomes, but ther effectiveness varies depending on several contextual factors. To maximize ther impact, educators must strategically integrate interactive media with inquiry-based pedagogy and provide scaffolding to accommodate diverse learners. These findings underscore the importance of evidence-based technology adoption in science education, ensuring that digital tools enhance—not replace—effective teaching and learning practices.

Conclusion

The results of the meta-analysis show that students' learning outcomes are much enhanced when interactive media are used. With an average effect size of 0.495, the results demonstrated that the interactive medium had a moderate level of effectiveness. This suggests that incorporating interactive media into the classroom can help students learn more effectively by according to ther own preferences and needs. These results are also renforced by heterogenety testing and publication bias analysis which show the validity of the data, so the research findings can be trusted as a basis in the development of interactive learning methods.

Study's goals—to assess how interactive media affects learning outcomes and to suggest solutions to enhance learning quality—are bolstered by this conclusion. To get the most out of interactive media, it's important to think about the study's setting and methodology, according to the research. Thus, interactive media not only improves student learning outcomes but also provides a more in-depth and relevant learning experience.

Next, we need studies that look at how interactive media affects students' social and emotional development in addition to ther academic performance. To further guarantee future implementation success, it is suggested that interactive media be created with a focus on innovation and adaptability to meet the demands of students at all educational levels. Educational policies that are more conducive to the In the classroom, the utilization of technology can be built upon the findings of this study.

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Author Contributions

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Conflicts of Interest

The authors declare no competing interests.

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