

Learner Outcomes in Calculus-Based Physics Using Physics Education Technology Simulations: A Meta-Analysis

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ABSTRACT

PhET became a tool for learning Calculus-Based Physics (CBP) alongside inquiry-based teaching. A meta-analysis using a random-effects model was conducted following PRISMA guidelines to synthesize outcomes from eligible studies published from January 2006 to December 2025 in selected research databases. Of the 649 studies that were culled, 27 studies ($N = 10,062$) met the criteria, with a moderate inter-rater agreement ($\kappa = 0.674, p < .001$). A significant positive moderate random effect size (ES) ($g = 0.580, p < .001$) indicated positive improvement in CBP learning. Moderator analysis further detected a positive effect on the learning outcomes among high school learners ($g = 1.144, p < .001$), and when inquiry through exploration ($g = 0.898, p < .001$) was employed. The implications of its effectiveness depend on the sustainability, digital nativeness, mathematical preparation, curriculum integration of inquiry-teaching frameworks, and the appropriateness of the digital tools used.

Keywords: blended learning, calculus-based, inquiry, physics, PHET, simulation, teaching

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Introduction

Teaching has moved beyond reliance on traditional lectures to learner-enabled classes that foster inquiry. This drives educational planners to solve challenges on accessibility and world standards for education (UNICEF, 2023). The development of Physics Education Technology (PhET) simulations has provided digital laboratories that encourage discovery and address the lack of laboratories. Its core design focused on engaged exploration through multiple representations without compromising educational goals and extended what learners already understood (Kohl et al., 2008). An approach to achieve this state was to initiate exploration and variable manipulation, in which learners were involved in finding solutions (Moore et al., 2014a; Yunzal & Casinillo, 2020), leading to stimulated creativity, mathematical comprehension, and the connection of observed phenomena (Pospiech et al., 2019; Redish, 2021). It served as a valuable learning resource that enabled the breakdown of abstract concepts into concrete, controllable experiences at their own pace (Helm et al., 2020).

This digitalization transformed classes into technology-enhanced active learning environments (Tunggyshbay et al., 2023) that engaged learners and teachers as co-creators, enriching the representation of the Science behind it and serving as both creative and process thinkers through feedback (Ashraf et al., 2021; Tokarz et al., 2020). This type of teaching requires effective integration into the intended curriculum. It was emphasized that the involvement of teachers, learners, and parents in educational expectations and preparedness is key to the acceptance of this innovation (Pedaste et al., 2016). While the school provided instruction for learners, the post-instruction support from accompanying adults was equally important in

managing the extent of support, whether in terms of resources or guidance (Burghardt et al., 2020; Moore et al., 2014b).

Studies on Physics curriculum have focused on conceptual understanding and attitudes toward the subject (Brahmia et al., 2020; Madsen et al., 2015). It was regarded as a discipline that combines the observation of phenomena with rigorous proofs that demand advanced mathematical capability (Pospiech et al., 2019; Redish, 2021). Both learners and teachers alike were expected to discuss these using process thinking and metacognition (Astutik et al., 2019). Specifically, calculus-based physics was intended as a preparatory subject for interdisciplinary STEM applications such as robotics and infrastructure design, with increasing depth of calculus (Bohrnstedt et al., 2023; Kaldaras & Wieman, 2023). This notion, unfortunately, created the impression that it was for the intellectually capable, making it an impractical career choice and a hurdle to completing course requirements (Bruun et al., 2018). This resulted in a complacent attitude towards learning that led to fragmented understanding and misconceptions (Molina et al., 2025), which was reported by the inability to fully discuss the Physics process when individuals were pressed for explanations (Klassen et al., 2023; Kohn et al., 2018; Neidorf et al., 2019).

However, simulations were being misrepresented as a tool that encouraged conceptual understanding. The integration of simulations must be strictly moderated by the intended curricular outcomes. Without the deliberate provocation of higher-order cognitive engagement, there was a distinct risk that learners may develop a superficial sense of mastery. This overestimation of their conceptual grasp can lead to a haphazard approach to problem-solving, in which learners carelessly apply scientific

principles to complex situational tasks (Hurtado-Bermúdez & Romero-Abrio, 2020; Peters et al., 2023). It was argued that teachers needed to probe the depth of learners' understanding through inquiry by questioning the scientific grounding and not relying on what the simulations offered (Astutik et al., 2019; Thomas, 2016). This meta-analysis investigated whether this essential inquiry was practiced within CBP environments. Specifically, it contrasted comparative studies that utilized PHET as inquiry-based tools against those with traditional lecture-based formats.

following inquiries:

1. How effective was the use of PHET for learners' outcomes in CBP?
2. How effective was using PHET in teaching CBP when moderated according to the following:
 - a. educational level;
 - b. inquiry approach;
 - c. continent of study?

Research Questions/Objectives

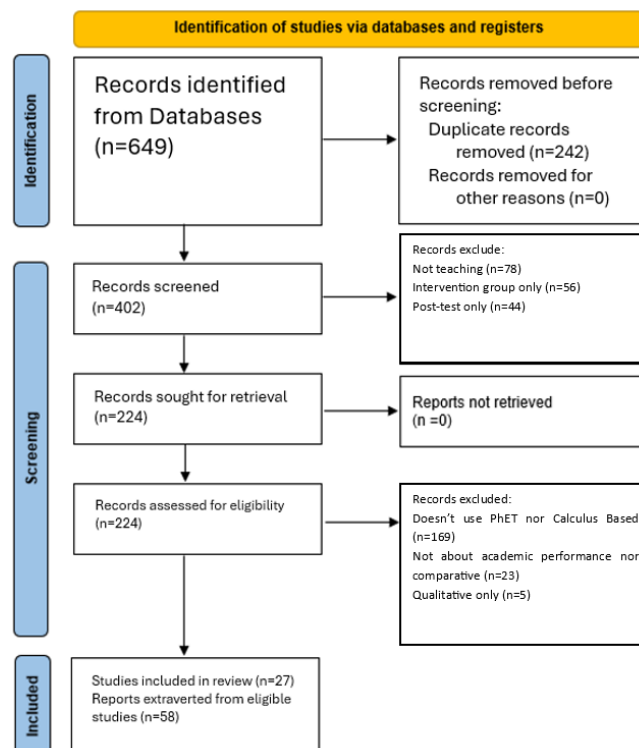
The researchers aimed to examine learners' academic outcomes in CBP using PHET. Additionally, the researchers pursued the

Participants

Eligible studies for analysis were required to explicitly demonstrate the use of PHET at any stage of CBP instruction. Further inclusion criteria were as follows: (1) academic outcomes

Figure 1

PRISMA Flowchart



evaluation conducted using a written objective-type test, i.e., multiple choice, true or false; and (2) establishment of multiple point comparisons, for instance, pre-test and post-test measurements, or comparison between control and experimental groups within the study. Studies were categorized by research continent, educational level, and the degree of manipulation, i.e., whether the teacher used PHET as a teaching tool or provided it to learners for direct manipulation. Presented in Figure 1 were the detailed results of the search.

Methodology

Research Design

The researchers adopted a meta-analytic design, following the PRISMA guidelines, to systematically analyze quantitative data from multiple evidence-based sources, enabling a comprehensive evaluation of CBP instruction (Borenstein et al., 2021).

Conceptual Framework

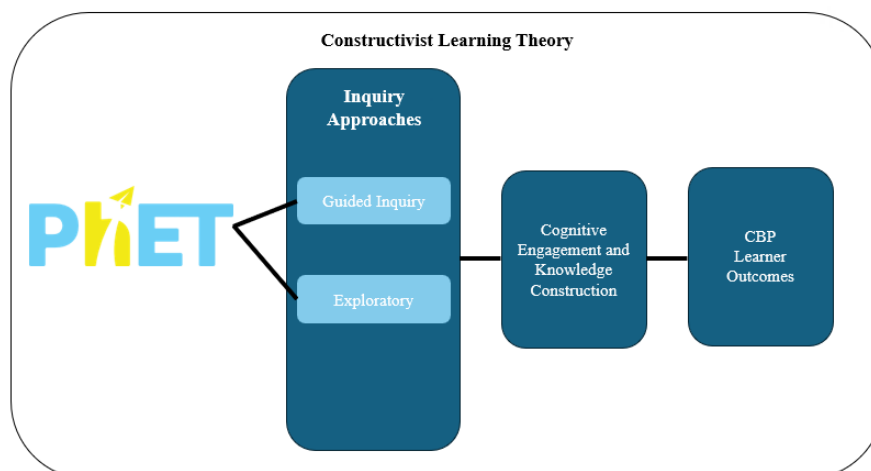
Constructivism believes that learning should be the basis of understanding the world. Based on this theory, PhET provided an experiential environment for testing concepts. In the inquiry approach, a branch of constructivist pedagogy, learning was classified as exploratory when learners solved general problems without structured procedures, and as guided when they followed structured procedures for investigation, with scaffolded questioning directed toward the desired learning outcome. These shaped learners' cognitive engagement and knowledge construction, thereby influencing CBP learning outcomes as measured by their conceptual understanding (Figure 2).

Study Search Procedure

Databases were searched using Harzing's Publish or Perish (POP) software, which compiled results from Google Scholar®, Scopus, and ERIC. The last search was performed on January 1, 2026. POP was

Figure 2

Conceptual Framework



configured to restrict the search to each year from January 2006 to December 2025. The search strategy involved the use of advanced Boolean commands. During the initial search, if up to 2000 listings were returned, the search was halted; if more than 2000 listings were returned, the search was halted, and the keywords were reviewed. The final keyword combinations used for the search were “PHET, worksheet, calculus-based, physics, high school.” Researchers also identified whether an inquiry teaching approach was used by either explicitly stating it in the study or by using an inquiry teaching checklist to classify it. Aside from journal publications, preprints and papers from university research repositories were an inclusive approach consistent with the meta-analytic approach to reduce the risk of bias arising from the preferential publication of significant results (Borenstein et al., 2021; Rothstein et al., 2006; Shi & Lin, 2019).

Risk of Selection Bias Quality Assessment

The risk of bias was evaluated using Cochrane’s ROBINS-I, which was appropriate for the non-randomized studies included in this analysis (Sterne et al., 2016). Each study was weighted from low (0) to critical (3) on bias due to confounding, participants, deviation from intended intervention, missing data, and measurement of outcomes, and reported results, and the overall risk of bias was calculated. Overall risk of bias above two was automatically rejected, while zero (low) was automatically accepted. Two (moderate), on the other hand, they were accepted with notes attached. Inter-rater reliability was calculated using Fleiss Kappa. The authors evaluated each article using a 3-point scale, where 3 = accept, 2 = modify, and 1 = reject, based on the predetermined inclusion criteria for the meta-analysis, which were applied during the identification and final

screening stages to improve the accuracy of the included studies. Studies that received at least 2 accept scores were included in the study roster for the analysis.

Coding Procedures

The researchers convened to discuss the included articles, examining the explicit characteristics as reported by the corresponding authors. Otherwise, a list of characteristics was used as identifiers to guide in identifying the group characteristics as follows: (a) inquiry was classified into two types: guided, which utilized scaffolded instruction and frequent teacher intervention, and exploratory, which emphasized learner-led discovery with minimal teacher intervention, (b) continent location: the location where the study was identified within the setting of the study, (c) education: the level of education was considered based on the context of the SEA educational structure such that i.e. middle school and pre-college was considered high school, and (d) publication type: the researchers identified studies that were published in journals and online university repositories. Additionally, if a paper involved multiple experimental setups during coding, each was treated as a sub-study and evaluated independently, in accordance with the recommendations of Forero et al. (2019).

Effect Size Calculations

The data extracted from the studies included sample sizes, means, and standard deviations; results from t-tests or F-tests with their respective p-values; effect sizes (ES) reported as Cohen’s *d* or Hedge’s *g*; and odds ratios, which were processed using CMA© version 4 software (Borenstein, 2022). The software calculated the ES that was used to produce the effect-size models, tests of heterogeneity *I*² and *Q*, publication bias, and the

pooled true effect size (Borenstein et al., 2017). Hedge's g was selected as the calculated ES due to its correction factor J used to mitigate extreme ES, coupled with confirmatory statistical tests for publication bias, such as Egger's and Begg's test. Furthermore, the primary model used in this study was a random-effects model, given that factors such as teaching conditions, learner differences, and culture were not controlled for and to avoid overestimation (Borenstein et al., 2009).

Findings and Discussion

Table 1

Frequency distribution of qualified studies

Categories	Frequency	%
Education Level		
High School (G7-G12)	10	37
College	17	63
Inquiry Approach		
Exploratory	16	59
Guided Inquiry	11	41
Publication Type		
Journal	17	63
University Paper	10	37
Location		
North America	17	63
Europe	5	19
Africa	3	11
Asia	2	7

$\alpha=0.05$, significant at $p<0.05$

The analysis included twenty-seven eligible studies with fifty-eight reports, as shown in Table 1. The calculated inter-rater agreement among a three-person panel showed a significantly moderate substantial κ value

of .674 ($Z=11.91, p<.001$). Publication bias analysis showed that the Begg and Mazumdar Correlation $\tau=0.098$ ($p>.05$) and Egger's regression ($t(58)=2.388, p=.02$) proved that no significant publication bias was detected in the pooled reports. Furthermore, Rosenthal's Classic Fail-safe N indicated that 3,315 null-effect studies would be required to reduce the overall effect to non-significance, which mitigated this risk. These showed that the overall findings of the meta-analysis remained robust and with no potential publication bias.

A total of 10,062 participants were included, with 5,388 in the control group and 4,674 in the experimental group. The prevalence of CBP classes was expected to be higher in college-level STEM courses than in high school courses, given that curricula differ across countries (Madsen et al., 2015; Yadak, 2020). Exploratory and guided inquiry methods were employed to teach CBP using PHET at both educational levels, a ligning with the importance of an investigative learning environment (Agustina & Putra, 2022). Furthermore, most studies originated from North America, which was attributed to PHET being developed on the same continent. The ES of 58 individual reports were extracted (Table 2) and linked for moderator analysis (Forero et al., 2019).

Calculated ES in Table 2 presented both a significant, small, fixed model ES and a moderately random model ES (Brydges, 2019; Taylor & Alanazi, 2023). However, the report suggested significant heterogeneity ($Q(57) = 1400.968, p < .0001$ with $I = 98.76$ that indicated the possible variations in teaching of inquiry in CBP had contributed to this result. This evidence reinforced the need for a moderator analysis and a random-effects model a suitable

Table 2

Effect Sizes arranged in increasing order

Study Name	Statistics for each Study					
	Hedges g	SE	z	p	95% Upper CI	95% Lower CI
Massey-Allard (2021) 1	-3.575	0.204	-17.516	.000	-3.175	-3.974
Massey-Allard (2021) 2	-2.304	0.163	-14.113	.000	-1.984	-2.624
Fadaei (2021) 1	-1.501	0.337	-4.459	.000	-0.841	-2.160
Fadaei (2021) 2	-1.228	0.324	-3.794	.000	-0.594	-1.863
Doherty (2010) 3	-1.009	0.272	-3.714	.000	-0.476	-1.541
Doherty (2010) 5	-0.481	0.213	-2.258	.024	-0.063	-0.898
Caballero (2011)	-0.175	0.045	-3.926	.000	-0.088	-0.263
Couch (2014) 1†	-0.117	0.372	-0.314	.754	0.613	-0.847
Shemwell, Chase, and Schwartz (2015) 3†	0.004	0.223	0.020	.984	0.442	-0.433
Carli (2025) 1†	0.014	0.090	0.158	.875	0.191	-0.162
Sima (2019)†	0.028	0.374	0.075	.940	0.760	-0.704
Hwang (2021) 1†	0.030	0.142	0.211	.833	0.308	-0.248
Shemwell, Chase, and Schwartz (2015) 4†	0.038	0.223	0.170	.865	0.475	-0.400
Peters, Doetinchem, and Rande (2023) 4†	0.066	0.496	0.133	.894	1.038	-0.907
Couch (2014) 4†	0.112	0.372	0.302	.763	0.842	-0.617
Carli (2025) 2	0.181	0.091	2.000	.046	0.359	0.004
Doherty (2010) 2†	0.209	0.121	1.732	.083	0.446	-0.028
Milner-Bolotin et al (2011)†	0.223	0.114	1.962	.050	0.446	0.000
Doherty (2010) 6†	0.267	0.211	1.267	.205	0.680	-0.146
Peters, Doetinchem, and Rande (2023) 1†	0.269	0.156	1.719	.086	0.575	-0.038
Peters, Doetinchem, and Rande (2023) 5†	0.293	0.328	0.895	.371	0.936	-0.349
Peters, Doetinchem, and Rande (2023) 6†	0.300	0.504	0.595	.552	1.287	-0.687
Carli (2025) 3	0.303	0.092	3.297	.001	0.484	0.123
Peters, Doetinchem, and Rande (2023) 3†	0.384	0.276	1.393	.164	0.925	-0.156
Hwang (2021) 5†	0.426	0.293	1.452	.146	1.000	-0.149
Tarekegn (2009) 3†	0.464	0.304	1.528	.127	1.059	-0.131
Pineda (2015) 2†	0.475	0.331	1.435	.151	1.123	-0.173
Carli (2024)	0.505	0.153	3.295	.001	0.806	0.205
Peters, Doetinchem, and Rande (2023) 2†	0.507	0.368	1.376	.169	1.229	-0.215
Doherty (2010) 1	0.544	0.123	4.431	.000	0.784	0.303
Miller (2023)	0.573	0.142	4.044	.000	0.851	0.295
Pineda (2015) 1†	0.588	0.342	1.718	.086	1.260	-0.083
Tarekegn (2009) 2	0.609	0.307	1.988	.047	1.210	0.009
Nsengamungu (2024) 2†	0.658	0.381	1.726	.084	1.404	-0.089
Shemwell, Chase, and Schwartz (2015) 1	0.723	0.230	3.138	.002	1.175	0.271
Shemwell, Chase, and Schwartz (2015) 2	0.731	0.229	3.193	.001	1.179	0.282
Massey-Allard, Roll, and Ives (2019) 1	0.765	0.153	4.989	.000	1.066	0.465
Velazquez (2020)	0.858	0.169	5.088	.000	1.189	0.528

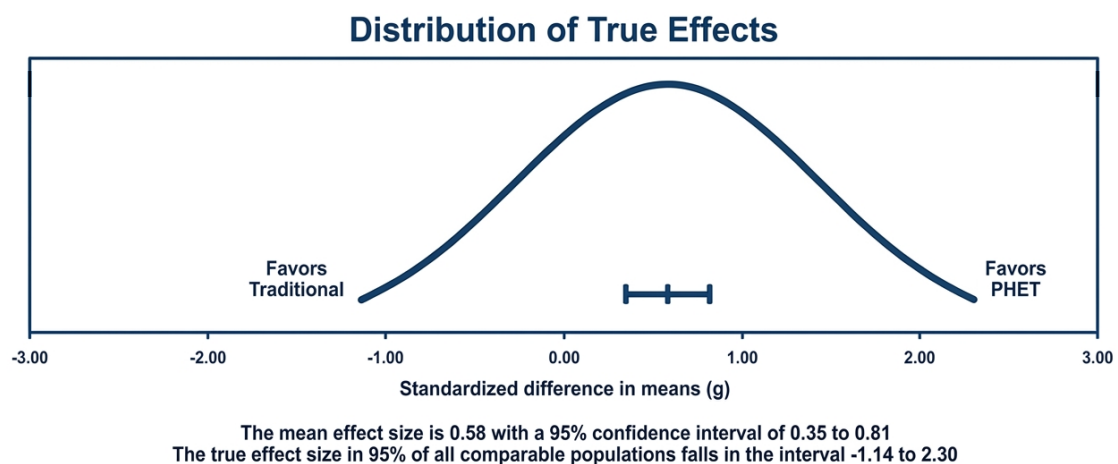
Study Name	Statistics for each Study					
	Hedges g	SE	z	p	95% Upper CI	95% Lower CI
Kotoka (2021)	0.881	0.258	3.417	.001	1.386	0.376
Tarekegn (2009) 1	0.902	0.315	2.866	.004	1.520	0.285
Hwang (2021) 3	0.906	0.213	4.259	.000	1.323	0.489
Crogman et al. (2015)	0.934	0.098	9.501	.000	1.127	0.741
Nsengamungu (2024) 1	0.960	0.345	2.779	.005	1.637	0.283
Lindberg (2022)	1.032	0.458	2.251	.024	1.930	0.133
Ramachandran (2025)	1.034	0.276	3.741	.000	1.575	0.492
Couch (2014) 3	1.052	0.397	2.651	.008	1.830	0.274
Hwang (2021) 2	1.105	0.345	3.202	.001	1.782	0.429
Ihekoronye (2021) 1	1.116	0.197	5.679	.000	1.501	0.731
Couch (2014) 2	1.150	0.401	2.864	.004	1.937	0.363
Massey-Allard, Roll, and Ives (2019) 2	1.215	0.161	7.538	.000	1.531	0.899
Richards (2010)	1.406	0.462	3.044	.002	2.311	0.501
Hwang (2021) 4	1.416	0.156	9.102	.000	1.720	1.111
Ihekoronye (2021) 2	1.484	0.199	7.464	.000	1.873	1.094
Doherty (2010) 4	1.811	0.279	6.491	.000	2.358	1.264
Sobhanzadeh (2015)	2.073	0.636	3.262	.001	3.319	0.828
Couch (2014) 5	3.837	0.626	6.127	.000	5.064	2.609
Cunnings (2019)	6.336	0.692	9.155	.000	7.692	4.979
Almadrones and Tadifa (2024)	7.865	0.596	13.196	.000	9.033	6.697
Fixed Effects	0.228	0.022	10.246	.000	0.271	0.184
Random Effects	0.580	0.118	4.899	.000	0.812	0.348

Significant at $p < 0.05$

Not significant $p > 0.05$

Figure 3

Distribution of True Effect

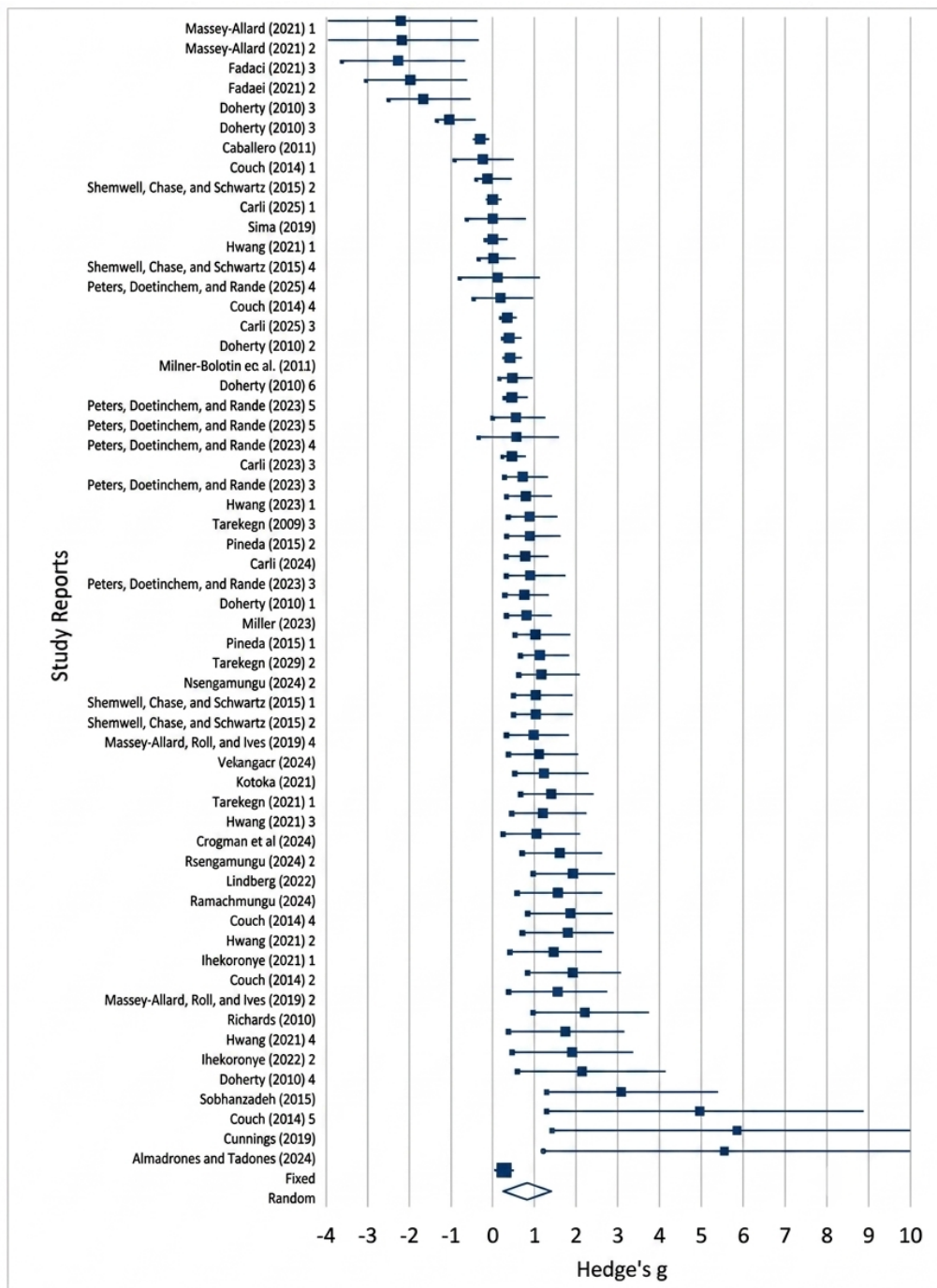


ES estimate. Additionally, the measure of true effect (Figure 3) showed a tendency toward preferring lecture-type classes without PHET interventions, with the 95% CI [-1.14, 2.30].

The forest plot of individual ES reports, shown in Figure 4, reported insignificant small ES ($0.2 \leq g \leq 0.49, N = 10$), negligible ES ($g < 0.2, N = 7$), and preferring lecture-only (g

Figure 4

Forest Plot



$< 0, N = 8$) approach in teaching CBP (Couch, 2014; Doherty, 2010; Massey-Allard, 2021) shared common characteristics: (1) indicated inadequate pre-laboratory orientation on the use of the simulation, leading to more misconceptions compared to their preconception. (2) Activities structured as group labor made individual members refrain from active participation and delegated their tasks to those who could complete the activities. (3) Limited testing setups; otherwise, the initial testing reported lower performance due to performance lag (Soderstrom & Bjork, 2015). Lastly, (4) inefficient facilitation by teachers. Facilitation was constrained by teachers' capabilities, integration into teaching, and teaching efficacy, as evident by the learner's outcomes (Budnyk, 2019; Do & Zsolnai, 2022). This accounted for the caution about the risks of using technology in classes, and the need for proper planning of its integration and supervision in instruction. Furthermore, positive ES studies emphasized the importance of Mathematical preparedness as a language for arguing one's inquiry into observed phenomena, a common theme across these studies. However, the presence

of this result does not negate the effectiveness of PHET in learning CBP, considering that the random effects model has a significant moderate effect on learning, which was achieved when it was adequately instructed regarding its purpose, their preparations, and how it was integrated in the instruction, together with the availability of the needed resources in implementing this approach.

The moderator analysis (Table 3) provided an in-depth view of the outcomes. High school learners showed a higher ES with a large effect on CBP when using PHET, as the simulation's original design was intended for such learners, whereas its use in college showed no significant effect. A similar investigation by Sukarelawan et al. (2024) observed similar outcomes and found that college learners viewed PHET as didactic visualizations of phenomena rather than analytic tools, especially for some Calculus applications. Both inquiry approaches had a significant positive ES; however, they were not significantly different when compared ($Q(1) = 1.46, p = .228$). Specifically, it showed

Table 3

Moderator Analysis of the Random Effects Model

Moderator	Sub-moderator	Statistics for each Study						
		n (Reports)	Hedges g	SE	z	p	95% Upper CI	95% Lower CI
Education Level	High School	10	1.144	0.204	5.611	.000	1.544	0.745
	College	17	0.255	0.143	1.785	.074	0.535	-0.025
Implementation	Guided	11	0.445	0.043	10.401	.000	0.529	0.361
	Exploratory	16	0.899	0.296	3.038	.002	1.478	0.319
Continent	Africa	3	0.959	0.156	6.132	.000	1.265	0.652
	Asia	2	4.429	3.416	1.297	.195	11.123	-2.266
	Europe	5	0.397	0.151	2.633	.008	0.693	0.102
	North America	17	0.431	0.149	2.881	.004	0.724	0.138

*Significant at $p < 0.05$

that exploration had a large effect size, indicating its contribution to deeper cognitive engagement that led to authentic knowledge construction, while guided inquiry was equally relevant, given its small ES and appropriateness for beginners. Continent-level moderation showed that Africa had a significantly larger ES, while Europe and North America showed small but significant ES towards improving CBP outcomes.

Implications

Teaching CBP posed challenges in balancing knowledge acquisition, curriculum design, and maintaining learner interest. The integration of simulations and similar digital tools with clear outlines of when and how these tools were incorporated into lessons. The challenge did not stem solely from its inherent complexity, but from the need for teachers to help learners bridge prior knowledge and confirm it through physical phenomena. PHET served as a tool for bridging this knowledge, with the critical role of inquiry as a taught scientific attitude in effectively differentiating facts from misconceptions. PHET should be viewed as a tool for breaking down applied calculus in Physics concepts into an observable learning experience.

Inquiry approaches showed a significant effect on learning CBP. As PHET was an important tool for arousing HOTS, the inclusion of inquiry in teaching benefits the learner's ability to confront their intuitive and flawed understanding of the world against what science actually dictates. This process forces learners not only to observe phenomena but also to actively evaluate and reconcile outcomes, transforming simulations from simple demonstrations into rigorous environments for scientific validation.

North America reflected the widespread integration of simulation in instruction. The acceptance of technology as a learning tool and the emphasis on discovery through inquiry. Their preparedness in infrastructure and pedagogical principles in curriculum development was evident, as they explicitly provided opportunities to optimize teaching with similar tools. In contrast to Africa and Asia, which, despite their positive outcomes, had slower adoption due to these deficiencies, this led to a smaller footprint. Overall, the positive outcomes were novelty effects and instead reflected sustainability in instructional development and the normalization of simulations as part of an evolving teaching approach.

Conclusion

CBP outcomes improved significantly with PHET, and PHET was taught using inquiry. This was achieved through effective planning among stakeholders, resource management, and integration, as well as the depth of the proposed CBP curriculum. There was a need to consider the learners' academic preparedness and the appropriateness of any digital resource to optimize learning outcomes. Inquiry, as a framework for teaching and learning resource design, was observed to be beneficial for both teaching and learning. This also emphasizes the need for future designers of PHET to integrate inquiry principles into interface updates to their collections, whether by adding scaffolding and directed exploration.

An investigation may be warranted into the effects of similar digital tools on Physics learning. Furthermore, the significant gap in published studies from Asia suggests that the digitalization

of teaching, particularly in policy development and implementation, remains a critical area for future research.

■ ■ ■

Statements and Declarations

1. **Disclosure statement:** The authors report that there are no competing interests to declare.
2. **Acknowledgment:** The researchers would like to thank the DOST-Science Education Institute for the support provided in this meta-analysis. Furthermore, the lead researcher extends his sincere gratitude to Dr. Socorro E. Aguja, for the critical insights that enabled the completion of this research.
3. **Ethical Approval:** The present study employed a meta-analytic design utilizing secondary data from previously published sources and ProQuest research repositories. As the research did not involve direct interaction with human participants or animals, nor the collection of identifiable private information, ethics committee approval was not required.
4. **Declaration of Generative AI in Scientific Writing:** The author(s) used AI-assisted tools, i.e., Grammarly®, solely for grammar checking, spelling correction, and verb tense refinement during the manuscript preparation. No

generative AI was used to create, rewrite, or substantively modify the content, arguments, analysis, or interpretations presented in this work. All scientific content, structure, and conclusions were developed by the author(s), who take full responsibility for the accuracy and integrity of the manuscript.

References

- Agustina, R. D., & Putra, R. P. (2022). Sophisticated thinking blended laboratory (STB-LAB) learning model: Implications on virtual and real laboratory for increasing undergraduate student's argumentation skills. *Jurnal Pendidikan IPA Indonesia*, 11(4), 657–671. <https://doi.org/10.15294/jpii.v11i4.38772>.
- Almadrones, R. D., & Tadifa, F. G. (2024). Physics educational technology (PHET) simulations in teaching general physics 1. *International Journal of Instruction*, 17(3), 635–650. <https://doi.org/10.29333/iji.2024.17335a>
- Ashraf, M. A., Yang, M., Zhang, Y., Denden, M., Tlili, A., Liu, J., Huang, R., & Burgos, D. (2021). A systematic review of systematic reviews on blended learning: Trends, gaps and future directions. *Psychology Research and Behavior Management*, 14, 1525–1541. <https://doi.org/10.2147/PRBM.S331741>
- Astutik, S., Mahdiannur, M. A., Suliyanah, L., & Prahani, B. K. (2019). Improving

- science process skills of junior high school students through the implementation of collaborative creativity learning (CCL) model in physics learning. *Journal of Physics: Conference Series*, 1171(1), 012006. <https://doi.org/10.1088/1742-6596/1171/1/012006>
- Bohrnstedt, G. W., Ogut, B., Yee, D., & Bai, Y. (2023). AP Calculus and Science coursetaking: Their relationships with choosing a STEM major and expecting to be in a STEM occupation. *AERA Open*, 9, 23328584231184426.
- Borenstein, M. (2022). Comprehensive meta-analysis software. In M. Egger, J. P. T. Higgins, & G. D. Smith (Eds.), *Systematic reviews in health research: Meta-analysis in context* (3rd ed., pp. 535–548). John Wiley & Sons. <https://doi.org/10.1002/9781119099369.ch27>
- Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2009). Fixed-effect versus random-effects models. *Introduction to Meta-analysis*, 77, 85.
- Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2021). *Introduction to meta-analysis*. John Wiley & Sons.
- Borenstein, M., Higgins, J. P. T., Hedges, L. V., & Rothstein, H. R. (2017). Basics of meta-analysis: I^2 is not an absolute measure of heterogeneity. *Research Synthesis Methods*, 8(1), 5–18. <https://doi.org/10.1002/jrsm.1230>
- Brahmia, S. W., Olsho, A., Smith, T. I., & Boudreaux, A. (2020). Framework for the natures of negativity in introductory physics. *Physical Review Physics Education Research*, 16(1). <https://doi.org/http://dx.doi.org/10.1103/PhysRevPhysEducRes.16.010120>
- Bruun, M., Willoughby, S., & Smith, J. L. (2018). Identifying the stereotypical who, what, and why of physics and biology. *Physical Review Physics Education Research*, 14(2), Article 020125. <https://doi.org/10.1103/PhysRevPhysEducRes.14.020125>
- Brydges, C. R. (2019). Effect size guidelines, sample size calculations, and statistical power in gerontology. *Innovation in Aging*, 3(4), Article igz036. <https://doi.org/10.1093/geroni/igz036>
- Budnyk, O. (2019). Innovative competence of a teacher: Best European practices. *Journal of Vasyl Stefanyk Precarpathian National University*, 6(1), 76–89. <https://doi.org/10.15330/jpnu.6.1.76-89>
- Burghardt, M., Ferdinand, P., Pfeiffer, A., & Romagnoli, G. (2020). Integration of new technologies and alternative methods in laboratory-based scenarios. *International Conference on Remote Engineering and Virtual Instrumentation*. https://doi.org/10.1007/978-3-030-52575-0_40
- Couch, A. S. (2014). *The impact of virtual simulations on student comprehension of mechanics* (Publication No. 151) [Master's thesis, Louisiana State University]. LSU Scholarly Repository. https://repository.lsu.edu/gradschool_theses/151

- Doherty, M. (2010). *The effect of daily graded reflective journaling on gains in conceptual understanding and the scientific attitude toward conceptual understanding for high school students studying Newtonian mechanics* (Publication No. 3424167) [Doctoral dissertation, University of Massachusetts Lowell]. ProQuest Dissertations and Theses Global.
- Do, T. D., & Zsolnai, A. (2022). Teachers' social and emotional competence: A new approach of teacher education in Vietnam. *Hungarian Educational Research Journal*, 12(2), 131–144. <https://doi.org/10.1556/063.2021.00050>
- Forero, D. A., Lopez-Leon, S., Gonzalez-Giraldo, Y., & Bagos, P. G. (2019). Ten simple rules for carrying out and writing meta-analyses. *PLoS Comput Biol*, 15(5), e1006922. <https://doi.org/10.1371/journal.pcbi.1006922>
- Helm, F., & Beaven, A. (Eds.). (2020). *Designing and implementing virtual exchange – A collection of case studies*. Research-publishing.net. <https://doi.org/10.14705/rp-net.2020.45.9782490057726>
- Hurtado-Bermúdez, S., & Romero-Abrio, A. (2020). The effects of combining virtual laboratory and advanced technology research laboratory on university learners' conceptual understanding of electron microscopy. *Interactive Learning Environments*, 1–16. <https://doi.org/10.1080/10494820.2020.1821716>
- Kaldaras, L., & Wieman, C. (2023). Introducing an instructional model for teaching blended math-science sensemaking in undergraduate STEM courses using computer simulations. *arXiv*. <https://doi.org/10.48550/arXiv.2305.13451>
- Klassen, M., Jesiek, B. K., Zheng, L., & Case, J. M. (2022). Institutionalizing engineering education research: Comparing Australia, China, and the United States. In S. Christensen, C. Baillie, & G. Östlund (Eds.), *Philosophy of engineering and technology: Engineering, social sciences, and the humanities: Have their conversations come of age?* (pp. 33–63). Springer. https://doi.org/10.1007/978-3-031-11601-8_3
- Kohl, P., Kuo, V., & Ruskell, T. (2008). Documenting the conversion from traditional to studio physics formats at the Colorado School of Mines: Process and early results. *AIP Conference Proceedings*, 1064, 135–138. <https://doi.org/10.1063/1.3021247>
- Kohn, P. K., Underwood, S. M., & Cooper, M. M. (2018). Energy connections and misconceptions across chemistry and biology. *CBE—Life Sciences Education*, 17(1), ar3. <https://doi.org/10.1187/cbe.17-08-0169>
- Madsen, A., McKagan, S. B., & Sayre, E. C. (2015). How physics instruction impacts learners' beliefs about learning physics: A meta-analysis of 24 studies. *Physical Review Special Topics-Physics Education Research*, 11(1), Article 010115. <https://doi.org/10.1103/PhysRevSTPER.11.010115>

- Massey-Allard, J. (2021). *Learning physics with interactive simulations: Inductive inquiry learning activities for an introductory electromagnetism course* [Doctoral dissertation, University of British Columbia]. UBC Theses and Dissertations. <https://open.library.ubc.ca/cIRcle/collections/ubctheses/24/items/1.0402206>
- Molina, V. C., Guzman, D. S., Montalvo, T. R., & Garcia-Salcedo, R. (2025). Teaching competencies in physics for engineering education: A qualitative analysis from teaching practice. *arXiv*. <https://doi.org/10.48550/arXiv.2510.27674>
- Moore, E., & Perkins, K. (2014a). Assessing the implicit scaffolding design framework: Effectiveness of the build a molecule simulation. In *Proceedings of the National Association for Research in Science Teaching (NARST) Annual International Conference*. ComPADRE. <https://www.per-central.org/items/detail.cfm?ID=16318>
- Moore, E. B., Chamberlain, J. M., Parson, R., & Perkins, K. K. (2014b). PhET interactive simulations: Transformative tools for teaching chemistry. *Journal of Chemical Education*, 91(8), 1191–1197. <https://doi.org/10.1021/ed4006497>
- Neidorf, T., Arora, A., Erberber, E., Tsokodayi, Y., & Mai, T. (2019). Review of research into misconceptions and misunderstandings in physics and mathematics. In T. Neidorf, A. Arora, E. Erberber, Y. Tsokodayi, & T. Mai (Eds.), *Learner misconceptions and errors in physics and mathematics: Exploring data from TIMSS and TIMSS Advanced* (pp. 11–20). Springer. https://doi.org/10.1007/978-3-030-30188-0_2
- Pedaste, M., Lazonder, A., Raes, A., Wajeman, C., Moore, E., & Girault, I. (2016). Grand Challenge Problem 3: Empowering science teachers using technology-enhanced scaffolding to improve inquiry learning. In T. de Jong, M. Specht, & F. Wild (Eds.), *Grand challenge problems in technology-enhanced learning II: MOOCs and beyond* (pp. 17–20). Springer. https://doi.org/10.1007/978-3-319-12562-6_5
- Peters, M., von Doetinchem, P., & von Doetinchem de Rande, S. (2023). Virtual physics laboratory courses: An evaluation of students' self-efficacy and intelligence mindset. *arXiv*. <https://doi.org/10.48550/arXiv.2301.02699>
- Pospiech, G., Michelini, M., & Eylon, B.-S. (Eds.). (2019). *Mathematics in physics education*. Springer. <https://doi.org/10.1007/978-3-030-04627-9>
- Redish, E. F. (2021). Using math in physics: Overview. *The Physics Teacher*, 59(5), 314–318. <https://doi.org/10.1119/10.0004880>
- Rothstein, H. R., Sutton, A. J., & Borenstein, M. (2006). *Publication bias in meta-analysis: Prevention, assessment and adjustments*. John Wiley & Sons. <https://doi.org/10.1002/0470870161>

- Shi, L., & Lin, L. (2019). The trim-and-fill method for publication bias: Practical guidelines and recommendations based on a large database of meta-analyses. *Medicine*, 98(23), e15987–e15987. <https://doi.org/10.1097/MD.00000000000015987>
- Soderstrom, N. C., & Bjork, R. A. (2015). Learning versus performance: An integrative review. *Perspectives on Psychological Science*, 10(2), 176–199. <https://doi.org/10.1177/1745691615569582>
- Sukarelawan, R. M., Pranata, R., & Putri, A. (2024). The effectiveness of PhET simulations in physics education: A comprehensive meta-analysis of secondary vs. tertiary outcomes (2018–2023). *Indonesian Science Education Journal*, 17(3), 632–648.
- Sterne, J. A., Hernán, M. A., Reeves, B. C., Savović, J., Berkman, N. D., Viswanathan, M., Henry, D., Altman, D. G., Ansari, M. T., & Boutron, I. (2016). ROBINS-I: A tool for assessing risk of bias in non-randomised studies of interventions. *BMJ*, 355, i4919. <https://doi.org/10.1136/bmj.i4919>
- Taylor, J. M., & Alanazi, S. (2023). Cohen's and Hedges'g. *Journal of Nursing Education*, 62(5), 316–317.
- Thomas, G. (2016). Metacognition in science education: considering cultural and contextual orientations. *Alberta Science Education Journal*, 44(2), 4–15.
- Tokarz, K., Czekalski, P., Drabik, G., Paduch, J., Distefano, S., Di Pietro, R., Merlino, G., Scaffidi, C., Sell, R., Kuaban, G. S., Gansch, R., Grocholewicz, M., Harasymiv, S., Kocur, D., Orłowski, M., Pławiak-Mowna, A., Podaza, J., Robert, J., Schillinger, A., . . . Žagar, M. (2020). Internet of things network infrastructure for the educational purpose. *2020 IEEE Frontiers in Education Conference (FIE)*, 1–8. <https://doi.org/10.1103/FIE44824.2020.9274040>
- Tunggyshbay, M., Balta, N., & Admiraal, W. (2023). Flipped classroom strategies and innovative teaching approaches in physics education: A systematic review. *Eurasia Journal of Mathematics, Science and Technology Education*, 19(6), Article em2283. <https://doi.org/10.29333/ejmste/13258>
- UNICEF. (2023). *SDG 4 Quality Education: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all*. UNICEF. Retrieved June 12, 2023 from <https://www.unicef.org/unicef-and-sustainable-development-goals#sdg4>
- Yadak, P. (2020). *A meta-analysis of gender gap on the FCI in high school and college introductory physics courses in the US and international countries* (Publication No. 552) [Doctoral dissertation, University of San Francisco]. USF Scholarship: a digital repository @ Gleeson Library | Geschke Center. <https://repository.usfca.edu/diss/552>
- Yunzal, A. N., Jr., & Casinillo, L. F. (2020). Effect of Physics Education Technology (PhET) simulations: Evidence from STEM students' performance. *Journal of Education Research and Evaluation*, 4(3), 221–226. <https://doi.org/10.23887/jere.v4i3.27450>

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