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Meta-Analysis: The Effect of PhET Simulation Media on Enhancing Conceptual Understanding in Physics Learning

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Abstract

In the learning process, using interesting media can improve the quality of learning, especially in understanding concepts. PhET simulation media is one of the learning media that can be used. This research is one type of research to know how high the effect of learning by using PhET simulation media using meta-analysis to improve understanding of concepts in physics learning is. Meta-analysis, used as a research method, consists of formulating problems, collecting, coding, analyzing, and interpreting data. The population and sample were used as research material in scientific articles published nationally discussing the effect of PhET simulation media to improve understanding of concepts in physics learning in 2017–2022. Based on the research conducted, an effect size value of 1.48 was obtained, and the interpretation of the effect size value of the effect of PhET simulation media with the dependent variable, namely understanding of concepts in physics learning, was 92% so that the research conducted was classified in the high category. This means that the PhET simulation media have a strong effect on increasing the effectiveness of students' understanding of concepts in physics learning, especially at the SMA, SMK, or MA education level. Thus, PhET is one of the learning media in the form of interactive simulations that can be utilized in education because it presents complex data about processes and concepts so that students can more easily understand the subjects taught in detail.

Keywords: Conceptual understanding; Meta-analysis; PhET simulation

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INTRODUCTION

Physics is a subject in everyday life that delves into the realm of scientific knowledge under the category of science (Finkelstein et al., 2015; Maghfiroh et al., 2023; Saregar, 2016; Zamista & Kaniawati, 2015). Physics explains the occurrences of natural events, requiring a deep and comprehensive understanding of tangible forms (Nguyen et al., 2010; Sasmita, 2017). One of the subjects that students tend to struggle with is physics, despite teachers providing explanations and students reading

theories from textbooks and conventional teaching methods, such as memorizing formulas, which can hinder students from grasping the concepts accurately (Harjono, 2022; Hasni & Situmorang, 2018l; Nurdini et al., 2022).

In addition to teachers and teaching methods, instructional media also significantly affect the potential success of the learning and education process (Heo, 2009; Kurniawan et al., 2020). Instructional media play a crucial role in the learning process to help achieve the goals of ongoing education (Anitah, 2014; Kirkwood & Price, 2014). The choice of instructional media should align with the student's needs, so educators must consider various aspects such as the student's critical thinking abilities, level of comprehension, intellectual capabilities, and social conditions (Pujiyono et al., 2016).

Engaging media in the learning process can enhance the quality of education, especially concept understanding (Kurniawan et al., 2020; Puspitarini & Hanif, 2019). E-learning simulation media are widely employed nowadays (Kustyarini et al., 2020; Rohman, 2019). Simulation-based e-learning media is a design that presents a learning environment with real-life situations and events (Elazony et al., 2010; Prawiradilaga, 2016;). Several types of e-learning simulations, such as virtual laboratories, labs, and PhET simulations, are among the media that can be utilized in education (Suhardiman et al., 2022).

Research related to several previous studies about PhET simulations in education has been conducted in the teaching and learning process to determine the extent of their effect. The research by various scholars, including Mahtari et al. (2020), Nisa et al. (2022), Maulani et al. (2018), and Rizaldi et al. (2020) highlights the educational value of animation and simulations like PhET. PhET simulations are interactive computer software replicating lab equipment, offering a virtual real-life experience (Kusyanti, 2021; Muzana & Astuti, 2017; Sari et al., 2017).

As conducted by Ni'mah & Widodo (2022), it was found that the implementation of learning using the structured research model supporting the PhET Virtual Laboratory was rated very good in all sessions. Therefore, this instructional media significantly affected the improvement of students' understanding of concepts in electrodynamics (Ni'mah & Widodo, 2022). However, there was research with non-significant results, investigated by Jania et al. in 2022, which found that the PhET virtual simulation laboratory did not impact concept understanding in the Hooke's Law topic.

Given the wealth of research on using PhET simulations to improve students' grasp of physics concepts, combining the varied past results is necessary. This calls for a method like meta-analysis to merge and reach conclusions. This involves merging outcomes from earlier studies to arrive at conclusions. Hence, an appropriate method and structure are required to reach these conclusions. The meta-analytic research method is one such suitable approach applied in this study.

METHOD

This research was a quantitative study that utilized the meta-analysis method. The research process included exploring literature, defining inclusion criteria, coding data, determining years, and using metrics to express effect size (Cooper et al., 2019). The procedure of this meta-analysis method was as follows:

Literature Review Exploration

The study utilized various approaches. The search used electronic databases with the keywords "PhET Physics

Simulation, Students' Physics Conceptual Understanding with PhET Simulation, Learning Media". The initial search was carried out using electronic databases, specifically Publish or Perish 8, in the form of national and international articles or journals. Generally, the literature databases originated in high schools in Indonesia.

Inclusion criteria

The inclusion criteria were applied to high schools in Indonesia through synthesizing exploratory research on the impact of PhET simulation media on enhancing conceptual understanding in physics education. Research and Development (R&D), experimental research, and quasi-experimental learning with various meta-analysis methods were used to compare the learning processes using PhET simulation media and students taught through traditional methods. The scope of the study was limited to research conducted in Indonesia. Studies without control groups were not included in the analysis. Research lacking effect sizes and the required statistics for transformation was excluded. The data needed for this study included mean scores, standard deviation values, and several parametric statistics like t-test scores.

Data Coding

A coding sheet was utilized to translate data information, including variables such as physical subject, coding timeframe (within a range of less or more than four weeks), school level (high school equivalent), publication year (2017-2022), publication source (journal articles), sample size (maximum of 30 individuals), and measurement tool (test), into code format, by applying this data coding sheet, effect sizes and variables used as research materials were marked for each study.

Metric for Expressing Effect Size

The effect size measure of the standardized difference (d-index) is used to assess and depict the applied effect size for each group (Cohen, 2013). In the analysis of two samples, the effect size is computed by subtracting the mean of the control group from the experimental group's mean and then dividing it by the pooled standard deviation. The within-sample calculation is determined by subtracting the pretest's mean from the posttest's mean and dividing it by the pooled standard deviation of the mean difference. The formulas that can be used are presented in Table 1.

Table 1 Effect size formula

No	Statistic Data	Formula
1	One class that calculated the mean and standard deviation	$ES = \frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}}$
2	Two classes involved in the research conducted only posttests, where the mean and standard deviation were calculated	$ES = \frac{\bar{X}_{Eksperimen} - \bar{X}_{kontrol}}{SD_{kontrol}}$

No	Statistic Data	Formula
3	Two classes involved in the research conducted were posttests and pretests, where the mean and standard deviation were calculated.	$ES = \frac{(\bar{X}_{post} - \bar{X}_{pre})_{Eksperimen} - (\bar{X}_{post} - \bar{X}_{pre})_{kontrol}}{\frac{SD_{pre\ kontrol} + SD_{pre\ Ekspermien} + SD_{post\ kontrol}}{3}}$
4	Comparative test	$ES = \frac{2r}{\sqrt{1-r^2}}; r = \sqrt{\frac{x^2}{n}}$
5	T-test	$ES = t\sqrt{\frac{1}{n_{Eksperimen}} + \frac{1}{n_{kontrol}}}$

Once the effect size values were obtained, the results were interpreted into high, moderate, and small categories, with the criteria outlined in Table 2.

Table 2 Categories of scores in effect size

Effect Size (ES)	Cohen's Standard Categories
$0 \leq ES \leq 0.2$	Low
$0 \leq ES \leq 0.8$	Moderate
$2ES \geq 0.8$	High

After obtaining the ES score, researchers interpreted it to determine the extent of the effect exerted by the independent variable on the dependent variable under the conditions outlined in Table 3.

Table 3 Interpretation of ES's effect on the independent variable

ES	Effect (%)
0.0	50
0.1	54
0.2	58
0.3	62
0.4	66
0.5	69
0.5	73
0.7	76
0.8	79
0.9	82
1.0	84
1.2	88
1.4	92
1.6	95
1.8	96
2.0	98
2.5	99
3.0	99,9

The researchers accompanied the method used with research sources, significant modifications, research steps, and data collection methods and highlighted the research flow in the literature review article (Nisa et al., 2021).

RESULT AND DISCUSSION

This study had 30 (n = 30) eligible journals for investigation. Among them, ten articles (n = 10) were selected as relevant after being screened for suitability based on the standard inclusion and exclusion criteria. Exclusion criteria that were not met included the dependent variable being mathematical, conceptual understanding, the availability of statistical data allowing the calculation of the effect size values by the formula table, and the research data being sourced from articles or journals discussing physics topics at the high school level (SMA, SMK, or MA) within the range of 2017–2022. The respective article or journal was not

utilized if any of these criteria were not met. These ten articles collectively focused on enhancing students' conceptual understanding of physics topics through the impact of implementing PhET simulation media. The abstraction of data processing is depicted in Figure 1.

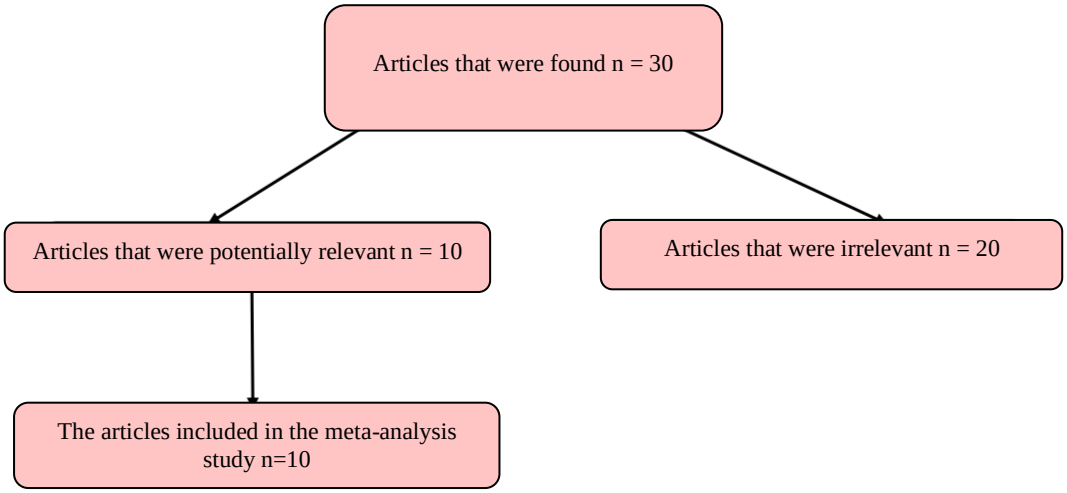

Figure 1 The flowchart of study selection was used

The details obtained can be seen in Table 4. The effect size calculations showing the impact of PhET simulation media on improving conceptual understanding in physics education are displayed in Table 4.

Table 4 Categories of effect size: Impact of PhET simulation media on conceptual understanding in physics education

No	Article's Title	Author(s)	Dependent Variable	Research Design	X_{Eks}	$X_{Control}$	SD Control	ES	Category
1	The Effect of Conceptual Change Learning Model Assisted by PhET Simulation on Improving Students' Understanding of Physics Concepts	(Juniartini et al., 2017)	Students Understanding of Physics Concepts	Quasi-experiment	t_{count} = 11.461 n_E = 25 n_K = 25			3.2	High
2	The Effect of PhET Simulations Media on the Conceptual Understanding of Molecular Models among Students of SMA Negeri 1	(Ismaun, 2019)	Conceptual Understanding of Molecular Models among Students of SMA Negeri 1 Mawasang	Quasi-Experiment (Pretest and Posttest Control Group Desain)	$X_{post(experiment)}$ = 77.29 $X_{pre(experiment)}$ = 47.95 $X_{post(control)}$ = 67.36 $X_{pre(control)}$ = 44.52 $SD_{pre(control)}$ = 15.41 $SD_{pre(experiment)}$ = 15.36 $SD_{post(control)}$ = 8.54			0.5	Moderate

No	Article's Title	Author(s)	Dependent Variable	Research Design	X_{Eks} $X_{Control}$ SD Control	ES	Category
	Mawasangka		ka				
3	The Effect of PhET Media in the Discovery Learning Model on Students' Conceptual Understanding in Physics	(Maulida et al., 2022)	Students' Conceptual Understanding in Physics	Quasi-Experiment (Nonequivalent Control Group Design)	$X_{post(experiment)}$ = 86.84 $X_{pre(experiment)}$ = 32.19 $X_{post(control)}$ = 75.87 $X_{pre(control)}$ = 26.59 $SD_{pre(control)}$ = 4.17 $SD_{pre(experiment)}$ = 2.99 $SD_{post(control)}$ = 7.56	1.1	High
4	Implementation of STEM Approach Based on PhET Simulations to Enhance Students' Conceptual Understanding in Physics	(Abdi et al., 2021)	Students' Conceptual Understanding in Physics	Quasi-Experiment (Nonequivalent Control Group Design)	t_{count} = 3.71 n_E = 60 n_K = 60	0.7	Moderate
5	Implementation of PhET Simulation-Based Learning to Enhance Core Physics Conceptual Understanding in High School Students	(Muzana & Astuti, 2017)	Conceptual Understanding of Core Physics Concepts in High School Students	Quasi-Experiment (The Randomized Pretest - Posttest Control Group Design)	t_{count} = 15.15 n_E = 28 n_K = 28	4.0	High
6	Application of TGT Model Through PhET Simulations to Improve Students' Understanding of Optical Instruments	(Ginting et al., 2020)	Students Understanding of Optical Instruments	Quasi-Experimental Design	t_{count} = 1.972 n_E = 20 n_K = 20	0.6	Moderate
7	Implementation of Discovery Learning Model Using Virtual Lab Media PhET on Understanding Physics Concepts	(Kalsum et al., 2019)	Understanding of Physics Concepts	pre-eksperimen (one-group-pretest-posttest design)	X_{post} = 8.96 X_{pre} = 6.l9 SD_{pre} = 2.58	1.1	High
8	Implementation of PhET Simulation	(Fathurohman et al., 2018)	Student Understanding of	Quasi-experiment	t_{count} = 6.90 n_E = 27 n_K = 27	1.9	High

No	Article's Title	Author(s)	Dependent Variable	Research Design	X_{Eks}	$X_{Control}$	SD Control	ES	Category
	Media to Enhance Students' Understanding of Fluid Concepts		Fluid Concepts	(control non-equivalent)					
9	Implementation of Virtual Laboratories to Enhance Students' Conceptual Understanding	(Hikmah et al., 2017)	Students' Conceptual Understanding	Quasi-Experimental design (pretest – posttest control group design)	$X_{post(experiment)}$ = 77.53 $X_{pre(experiment)}$ = 22.1	$X_{post(control)}$ = 71.10 $X_{pre(control)}$ = 23.10	$SD_{pre(control)}$ = 5.018 $SD_{pre(experiment)}$ = 5.870 $SD_{post(control)}$ = 6.132	0.1	Low
10	Implementation of Project-Based Learning Model Using PhET Simulation Media to Enhance Students' Conceptual Understanding	(Setiawan et al., 2018)	Students' Conceptual Understanding	Quasi-Eksperiment (Non-equivalent Control Group Design)	t_{count} = 6.1 n_E = 30 n_K = 30			1.6	High
			Average					1,48	High

The effect size results yielded a total ES of 1.48. This signifies that the PhET simulation media had a 92% impact (Coe, 2021) on enhancing students' conceptual understanding of physics. The effect size criteria fell within the high category (Cohen, 2013). This indicated that using PhET simulation media as an instructional tool significantly influenced the success of physics education, particularly in improving students' conceptual understanding. In the current era of digital technology, PhET contributed as an interactive simulation-based learning media that presents complex data on processes and concepts (Nasir et al., 2021), thereby supporting the enhancement of concept mastery (Fan et al., 2018).

PhET simulation was one of the learning media in multimedia-based software that mimicked laboratory equipment arrangements, accessible online with a flexible design (Moore et al., 2014). As a result, it replicated laboratory experiments, making users feel like they were using real equipment. This ease of use enhanced students' comprehension and conceptual understanding of the subject matter in detail (F. Nisa et al., 2018).

This is evidenced by the results of the meta-analysis and based on calculations of effect size values from several relevant articles. It was clear that instructional media employing PhET simulations significantly impacted physics education at the high school level, enhancing students' conceptual

understanding. This aligned with research conducted by Oktamuliani et al. (2021), which found that engagement in such activities improved students' understanding of physics concepts in high school. Additionally, according to the investigation by Prastiwi (2016), PhET simulation-assisted learning yielded significantly higher results in enhancing conceptual understanding.

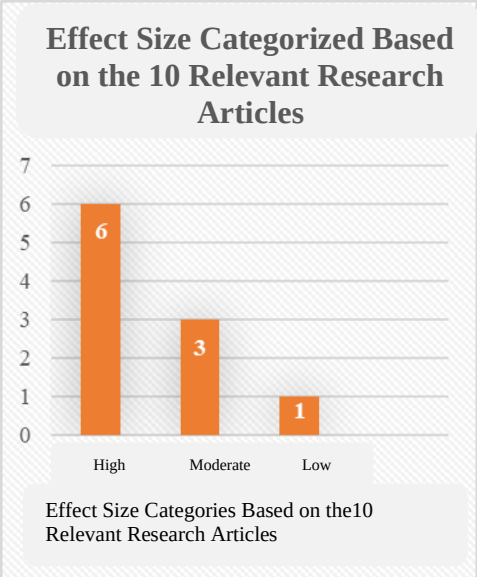

Figure 2 Effect size categories based on the 10 relevant research articles

In Figure 2, each relevant research article's effect size value categories were presented based on the high, moderate, and low categories. From the graph, it was observed that six research articles fell under the high category, three under the moderate category, and one under the low category. This indicated that PhET simulation media could enhance conceptual understanding, with more articles having effect size values in the high category. This finding aligned with several studies, including Nefrita (2019), which suggested that using PhET simulation media was a way to engage students and improve their conceptual understanding without becoming bored. Additionally, PhET simulations were interactive and easily accessible, allowing students to access them online anytime and anywhere. This corresponded with the research by Setiadi & Muflika (2012), which highlighted the advantages of PhET simulations due to their accessibility and lack of physical equipment requirements.

CONCLUSION

Analyzing ten relevant articles in high school physics, I found an effect size of 1.48, showing PhET simulation's strong effect on enhancing conceptual understanding in physics education. This substantial effect highlights PhET's strong impact on enhancing students' comprehension in physics education, especially at the high school level. This effect size falls within the high category. Therefore, the interpretation of the effect size value for the influence of PhET simulation media on the dependent variable, conceptual understanding in physics education, is 92%. This underscores that PhET simulation media substantially influence the effectiveness of students' conceptual understanding in physics education, particularly at the high school level (SMA, SMK, or MA).

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