Meta-Analysis of the Effect of Discovery Learning Model Assisted by PhET Simulation on Students' Learning Outcomes

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Abstract *- This study aims to see the effectiveness of the application of discovery learning model assisted by PhET simulation on student learning outcomes. The research method used is meta-analysis by calculating the effect size (ES) of each relevant article through several stages, namely formulating problems, collecting articles, grouping articles and calculating the effect size of each article. The results showed that there were 3 groupings of articles, namely based on the level of education, subjects and grade levels at the junior and senior high school levels. Effect Size based on the level of education obtained at the junior high school level was 1.517 with a very high category, and high school was 1.034 with a high category. The second grouping is based on subjects. Effect size based on subjects obtained in science subjects amounted to 1.517 with a very high category and for physics subjects amounted to 1.034 with a high category. The third grouping is based on grade level at the junior and senior high school levels. Effect size based on grade level for junior high school is obtained in grade VII with an effect size value of 2.61 with a very high category and for grade level at the high school level is obtained in grade X with an effect size value of 1.287 with a very high category. Based on meta-analysis, it is found that the discovery learning model assisted by PhET simulation can improve student learning outcomes.*

Keywords*: Discovery Learning; PhET Simulation; Learning Outcomes; Effect Size*

INTRODUCTION

Education is one of the sectors that continues to grow along with the changing times and technological advances. Education plays a vital role in the development of a nation, because it is through education that quality human resources can be formed. Education can make humans continue to develop as eternal individuals (Crawford, 2023). The rapid development of science and technology has affected all areas of human life. In the world of education, the use of computer technology is one of the most effective ways to deliver material (Suhardiman et al., 2022). Utilizing existing technology can help teachers in carrying out the learning process. The development of time and technology has also shifted learning methods from conventional approaches to more innovative and interactive approaches. One of the main challenges in education is how to improve student learning outcomes so that they can understand and apply the concepts learned.

Low student learning outcomes are often caused by the use of inappropriate learning models (Hamdani, 2021). The learning process that requires memorization and hoarding as much information as possible without understanding its meaning makes students bored in carrying out the learning process (Sakdiah & Sasmita, 2018). This boredom can reduce students' interest and motivation to learn so that student learning outcomes become low. Learning outcomes are events of changes in human behavior that can be observed and measured in the form of knowledge, attitudes, and skills (Rumansara et al., 2024).

Student learning outcomes can be improved by using the appropriate learning model (Purwaningsigh, 2022). One suitable learning model is the discovery learning model (D. Abdjul, 2022). Discovery Learning is a learning model that encourages students to be active in their learning process. Through this method, students are invited to find their own concepts and knowledge through exploration, discovery, and problem solving. The teacher acts as a facilitator who guides students to understand the material through discovery and direct experience. The discovery learning method is a learning activity that occurs when students are not presented with information directly, but students are required to organize their understanding of the information independently (Annisa, 2021). The main characteristics of the discovery learning model are; 1) exploring and solving problems to create, combine and generalize knowledge; 2) student-centered; 3) activities to combine new knowledge and existing knowledge (Irdam Idrus & Sri Irawati, 2019). In addition to choosing the learning model used in the learning process, teachers must also have innovations on how to support the learning model so that the discovery learning model itself can improve student learning outcomes. One way that teachers can do this is by combining the discovery model with PhET (Physics Education Technology) Simulation.

The discovery learning model, which emphasizes the process of discovering learning concepts, requires a medium that is able to provide opportunities for students to be able to carry out observation and experiment activities. PhET Simulations is one of the interactive simulation media that allows students to do practicum activities in science learning (Pujiningsih et al., 2022). PhET is an innovative project from the University of Colorado Boulder that can help students understand complex physics concepts. PhET Simulation is a media in the form of a virtual-based interactive simulation program that can be used to convey information in physics learning. PhET Simulation media can help students understand concepts, train students to think (Zaturrahmi et al., 2020). PhET Simulation can display abstract physics material clearly so that students can easily understand the material provided (T. Abdjul & Ntobuo, 2019). PhET Simulations provides a variety of interactive simulations that allow students to make observations and experiments, to find a learning concept about scientific phenomena that are usually difficult to observe (Pujiningsih et al., 2022). The discovery model assisted by PhET Simulation can simulate graphics and this simulation is easy to use.

Based on the problems that have been described, researchers are interested in conducting a meta-analysis of educational articles and research on the Discovery Learning Model assisted by PhET Simulation. The purpose of this study was to determine the effect of the Discovery Learning model assisted by PhET Simulation on student learning outcomes. The results of this meta-analysis are expected to provide a uniform view of the overall findings.

RESEARCH METHODS

The type of research used is survey research. The method used for this survey research is the meta-analysis method. Meta-analysis is quantitative because it uses numbers and statistics used to process information from many sources obtained for this research. The first stage in this research is formulating the problem. The formulation of this problem is the low learning outcomes of students.

The second stage is collecting articles and selecting articles that are relevant to this research. The provisions of the articles analyzed are: 1) published in national or international journals; 2) year published 2014-2024; (The years 2014–2024 were selected for this article because they cover a significant decade in the advancement of educational technology, the implementation of new curriculum policies, and the response to the COVID-19 pandemic, all of which have had a substantial impact on learning practices. This period also provides access to the latest data and research, allowing for a comprehensive analysis of how well technology-based learning models, such as PhET simulations, improve the quality of education.) 3) the type of research is quasi experiment; 4) the independent variable is the discovery learning model assisted by PhET simulation, and 5) the dependent variable is student learning outcomes. The results of this article collection obtained 14 relevant and eligible articles presented in Table 1.

Table 1. Data of the Analyzed Articles

Article Code	Author	Year
A1	TW	2015
A2	DP	2016
A3	HL	2018
A4	MF	2018
A5	AS	2019
A6	BI	2020
A7	TR	2020
A8	RA	2023
A9	MA	2023
A10	AS	2022
A11	KA	2023
A12	NA	2023
A13	GH	2023
A14	MR	2024

Based on Table 1, a total of 14 articles were obtained, with the specified years being 2014-2024, and the table meets the criteria for the articles analyzed. Each article was assigned a code and sorted by the year of publication.

The third stage is grouping articles. Relevant articles are grouped into 3 large groups. The first grouping of articles is based on junior and senior high school education levels. The second grouping of articles based on physics and science subjects, and the third grouping of articles based on grade levels at the junior and senior high school levels.

The fourth stage is to calculate the effect size of each article. The analysis technique used is a quantitative approach through calculation and analysis of data already in the article. The effect size can be determined in the following statistical parameters.

a. Mean and standard deviation in one group (pretest-posttest) (F1)

$$ES = \frac{\bar{X}_{post} - \bar{X}_{pre}}{SD_{pre}} \quad (1)$$

b. Mean and standard deviation of two group posstest only (F2)

$$ES = \frac{\bar{X}_E - \bar{X}_C}{SD_C} \quad (2)$$

c. Mean and standard deviation of two group pretest posttest (F3)

$$\frac{(\bar{X}_{post} - \bar{X}_{pre})_E - (\bar{X}_{post} - \bar{X}_{pre})_C}{SD_{preC} + SD_{preE} + SD_{postC}} \quad (3)$$

d. Chi-Square (F4)

$$\frac{2r}{\sqrt{1-r^2}}; r = \sqrt{\frac{x^2}{n}} \quad (4)$$

e. uji-t (F5)

$$ES = t\sqrt{\frac{1}{n_E} + \frac{1}{n_C}} \quad (2)$$

There are 5 formulas used to analyze data. The formula used will be matched with the data in the article to calculate the effect size.

After the effect size is calculated based on the appropriate formula, then the effect size is categorized at the level presented in table 2.

Table 2. Effect Size Criteria (ES)

Effect Size	Criteria
$ES \leq 0{,}15$	Negligible
$0{,}15 < ES < 0{,}40$	Low
$0{,}40 < ES < 0{,}75$	Medium
$0{,}75 < ES < 1{,}10$	High
$1{,}10 < ES < 1{,}45$	Very high

The table above explains the effect size criteria for the articles analyzed. The criteria for the articles analyzed are divided into five categories. The effect size criteria start from negligible criteria to very high criteria. These criteria can be categorized based on the results of the effect size values analyzed.

RESULTS AND DISCUSSION

Results

In this study, 14 articles were analyzed. All the collected relevant articles pertain to the impact of the discovery learning model aided by PhET simulations on student learning outcomes. The effect size for each article was calculated. The results of the effect size test, using predetermined statistical parameters for each analyzed article, are presented in Table 3.

Table 3. Effect Size Category

Article Code	Formula	*Effect Size*
A1	F5	4.07
A2	F5	0.54
A3	F5	0.666
A4	F2	1.552
A5	F5	0.292
A6	F1	1.272
A7	A	0.51
A8	F5	0.246
A9	F2	0.163
A10	F3	0.045
A11	F5	0.796
A12	F1	3.71
A13	F1	3.71
A14	A	1.51

Table 3 explains the formula used to calculate the effect size and the corresponding effect size values. The results of this study demonstrate the effect size of the impact of the discovery learning model assisted by PhET simulations on student learning outcomes. The first grouping is based on the level of education. There are two groupings based on the educational level used, namely junior high school (SMP) and senior high school (SMA). Below is Table 4, which shows the effect size test results for all articles based on the level of education.

Table 4. Effect Size Results by Educational Level

Educational Level	**Article Code**	***Effect Size***	$\bar{X}$ ***ES***
SMA	A1	4.07	1.034
	A2	0.54	
	A3	0.666	
	A4	1.552	
	A5	0.292	
	A6	1.272	
	A7	0.51	
	A8	0.246	
	A9	0.163	
SMP	A10	0.045	1.517
	A11	0.796	
	A12	3.71	
	A13	3.71	
	A14	1.51	

Table 4 presents the average effect size values of the articles grouped by educational level. The effect size results show a slight difference between senior high school (SMA) and junior high school (SMP). The detailed average effect size for each educational level is as follows: ES = 1.034 with a high category for SMA, and ES = 1.517 with a very high category for SMP. Based on the calculations and effect size categories for the article groupings by educational level, it is found that the discovery learning model assisted by PhET simulations is most effective in improving student learning outcomes at the junior high school level, with 5 articles analyzed. For senior high school, the quantum learning model has an average effect size in the high category, making it also effective for

enhancing student learning outcomes, although not as effective as at the junior high school level.

The difference in effect size results between SMP and SMA is noted. This may be due to junior high school students typically being at the formal operational stage of cognitive development according to Piaget, where they begin to think logically and abstractly, but are still in the early stages. The Discovery Learning method encourages students to explore and discover concepts on their own, which aligns with their developmental needs to understand new concepts through direct experience and exploration.

The second result of this study is the effect size of the impact of the discovery learning model assisted by PhET simulations on student learning outcomes based on subjects. There are two groupings based on subjects: physics and science (IPA). The effect size calculations for all relevant articles analyzed by subject are presented in Table 5.

Table 5. Effect Size of Articles by Subject

Subject	Article Code	*Effect Size*	$\bar{X}$ *ES*
Physics	A1	4.07	1.034
	A2	0.54	
	A3	0.666	
	A4	1.552	
	A5	0.292	
	A6	1.272	
	A7	0.51	
	A8	0.246	
	A9	0.163	
Science	A10	0.045	1.517
	A11	0.796	
	A12	3.71	
	A13	3.71	
	A14	1.51	

Table 5 presents the average effect size values grouped by subject. The effect size results for physics and science (IPA) show a slight difference. The average effect size for each subject is as follows: ES = 1.034 with a high category for physics, based on 9 analyzed articles; and ES = 1.517 with a very high category for science (IPA), based on 5 analyzed articles.

Based on the analysis of the articles, the discovery learning model assisted by PhET simulations is most effective when applied to science (IPA) with an effect size of 1.517, where 5 articles were analyzed. This is because science education is often related to students' everyday experiences. Discovery Learning allows students to connect scientific concepts with their real-life experiences, making learning more relevant and meaningful when supported by PhET simulations.

The third result of this study is the effect size of the impact of the discovery learning model assisted by PhET simulations on student learning outcomes based on grade levels in junior high school (SMP) and senior high school (SMA). There are 6 groupings based on grade levels: 3 for SMA and 3 for SMP. The effect size calculations for all relevant articles analyzed by grade level are presented in Table 6.

Table 6. Effect Size of Articles Based on Grade Level

Class	Article Code	Effect Size	$\bar{X}$ *ES*
XII	A7	0.51	0.51
XI	A3	0.666	0.913
	A4	1.552	
	A6	1.272	
	A9	0.163	
X	A1	4.07	1.287
	A2	0.54	
	A5	0.292	
	A8	0.246	
IX	A10	0.045	0.045
VIII	A11	0.796	2.253
	A12	3.71	
VII	A13	3.71	2.61
	A14	1.51	

Table 6 presents the effect size values for each article. The fourteen articles, each with a determined effect size, were grouped

into six categories based on grade levels: VII, VIII, IX, X, XI, and XII.

The average effect size for each grade level is as follows: ES = 0.51 with a moderate category for grade XII in senior high school (SMA), based on 1 analyzed article; ES = 0.913 with a high category for grade XI in senior high school (SMA), based on 4 analyzed articles; ES = 1.287 with a very high category for grade X in senior high school (SMA), based on 4 analyzed articles; ES = 0.045 with a negligible category for grade IX in junior high school (SMP), based on 1 analyzed article; ES = 2.253 with a very high category for grade VIII in junior high school (SMP), based on 2 analyzed articles; ES = 2.61 with a very high category for grade VII in junior high school (SMP), based on 2 analyzed articles.

Based on the analysis of the articles, the discovery learning model assisted by PhET simulations is most effective when applied to grade X in senior high school (SMA) with an effect size of 1.287, based on 4 articles. Meanwhile, the discovery learning model assisted by PhET simulations is most effective when applied to grade VII in junior high school (SMP) with an effect size of 2.61,based on 2 articles.

Discussion

Based on the results of the research that has been conducted on the effect of the discovery learning model assisted by PhET simulation on student learning outcomes, which consists of 14 articles used can be reviewed based on the level of education, subject and grade level.

First reviewed based on the level of education, which can be seen in table 4. The high effect size of 1.517 is found at the junior high school education level. It can be seen that the junior high school education level is more influential than the high school education level. This proves that the use of discovery learning model assisted by PhET simulation is more influential to improve student learning outcomes at the junior high school level. This opinion is in line with (Sinaga, 2023) which states that the discovery learning model with the help of interactive simulation phet media can improve the learning outcomes of junior high school students.

The second is based on subjects, which can be seen in table 5. The high effect size is 1.517 in science subjects. The discovery learning model assisted by PhET simulation is effective for improving student learning outcomes. This is supported by the opinion (Zahra et al., 2015) which states that learning with the use of PhET (Physic Education Technology) can improve student science learning outcomes. The average Effect Size results obtained from science subjects are significantly different than physics subjects. This shows that the discovery learning model assisted by PhET simulation can improve student learning outcomes.

Third, based on grade level, it can be seen from table 6, the effect size is very high, which is 2.61 for grade VII and 2.253 for grade VII. If the highest one is chosen, it is obtained at the VII grade level. It can be seen based on the effect size analysis that has been carried out that the discovery leraning learning model assisted by phet simulation is more influential in improving the learning outcomes of seventh grade students compared to other classes.

Judging from the level of education, subjects and grade levels, the analysis results show that the highest effect size is obtained in article A1 with the author TW which is 4.07. In this A1 article, the discovery learning model assisted by PhET simulation has a higher effect on improving student learning outcomes compared to other articles. This A1 article is about the application of the guided discovery learning

model with the help of phet software to improve the learning outcomes of class X students. This shows that the discovery learning model assisted by phet simulation is effective for improving student learning outcomes.

The discovery learning model assisted by PhET simulation has an influence and is able to improve student learning outcomes. Through this learning model, student learning outcomes can increase because the learning atmosphere is made more independent. This learning model allows students to learn actively and constructively by building their own knowledge through experimentation and discovery. Discovery learning is a model for developing an active way of learning students discover for themselves and investigate for themselves, the discovery learning model assisted by PhET Simulation simulation provides an interactive and interesting learning environment that can help students to understand complex scientific concepts more easily. PhET has an effect on student learning outcomes (Adlina et al., 2019). The use of discovery learning model assisted by PhET simulations learning provides information that students' learning outcomes are greater than using conventional learning models (Ramadhan & Djudin, n.d, 2020). The effect of the discovery learning model assisted by PhET simulations affects student learning outcomes (S & Hamsar, 2023). Through this meta-analysis research, it was found that there was an effect of the discovery learning model assisted by PhET Simulation on student learning outcomes. The effect of the discovery learning model and PhET can be seen from various levels of education, subjects and class levels of the education level.

CONCLUSION

This research resulted in 3 conclusions. First, based on the level of education that is more effective for applying the discovery learning model assisted by PhET simulation is the junior high school level, while at the high school level the effect of the discovery learning model assisted by PhET simulation is in the high category but not as effective as at the junior high school level. Second based on the subject, the discovery learning model assisted by PhET simulation is effectively applied to science subjects with a very high category, while the most applied discovery learning model assisted by PhET simulation is in physics subjects. Third, based on the class level at the junior and senior high school levels. At the junior high school level, the discovery learning model assisted by PhET simulation is most effectively applied to class VII, while for the high school level, the discovery learning model assisted by PhET simulation is most effectively applied to class X.

Based on the research analysis, it was found that the discovery learning model assisted by PhET simulations can improve student learning outcomes. The discovery learning model supported by PhET simulations has proven effective in enhancing students' understanding of physics and science concepts. Interactive simulations provide students with the opportunity to actively explore complex physical phenomena in a safe and supportive environment. This allows students to independently discover key concepts.

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