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Effectiveness of Virtual Simulations in Improving Secondary Students' Achievement in Physics: A Meta-Analysis

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Physics instruction necessitates innovative strategies that can support students' achievement. Virtual simulations are digital tools that can offer students with meaningful learning experiences, albeit in an online distance learning setup. This meta-analysis examined the effectiveness of virtual simulations in improving students' Physics achievement at the secondary level. A meta-analysis guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol was used. Fifteen (15) studies that met the inclusion criteria were included and analyzed. Effect size (Hedges g) was mainly used to determine the magnitude of the effectiveness of virtual simulations. The overall weighted effect size of g = 0.941 suggests that virtual simulations have a significantly large and positive effect on students' achievement in Physics. Moderator analyses revealed that the effectiveness of virtual simulations did not significantly differ based on the region, students' grade level, and duration of the implementation. However, a significant difference was found among the effect sizes of the individual studies when grouped according to the specific field of Physics. The majority of the virtual simulation tools used were PhET simulations and Crocodile Physics, which were found to be integrated with constructivist instructional strategies that facilitated substantial improvements in students' achievement. Hence, professional development programs are recommended to further strengthen Physics teachers' technological and pedagogical knowledge on the effective utilization of virtual simulations to enhance students' Physics learning.

Keywords: virtual simulations, achievement, physics learning, secondary level, meta-analysis

INTRODUCTION

Science education aims to produce scientifically inclined learners excellent at the cognitive, social, and emotional aspects (Kelly & Erduran, 2019; Van Der Leij et al.,

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2021). A scientifically literate person can read, understand, and reflect on reliable scientific sources in making relevant decisions (Oliver et al., 2021; Smith & Siegel, 2004). Science education also aims to impart deep conceptual knowledge and experiential learning for students to solve real-life problems (Breytenbach, 2017). Hence, reforms in science education focused on emphasizing vital learning competencies (Adarlo & Jackson, 2017). In the secondary level curriculum, one of the major branches of science considered a core element is Physics (Radi, 2020).

Physics education is considered to be the basic index for understanding the complexities of modern technology and plays an important role in any country's scientific and technological growth (Coccia, 2020). However, physics education at the secondary level faces numerous challenges that result in low interest and performance (Orleans, 2007). Physics is viewed as irrelevant, conceptually abstract, and difficult to learn (Aksakalli et al., 2016; Baran, et al., 2018). Physics teaching and learning is typically presented in groups of formula (Wegener et al., 2012). Physics abstract concepts are difficult to demonstrate without the illustration of physical processor immersion through laboratory activities (Sus et al., 2019). Moreover, gaps in Physics teaching and learning are caused by a lack of instructional materials, insufficient functioning laboratories, and a lack of practical fieldwork (Kapting'ei & Rutto, 2014). This is especially evident in the current context of the pandemic, where most students have developed negative attitudes toward Physics due to issues concerning their home environment, a lack of teacher-student and student-student communication, and decreased concentration and access to experimental activities (Stefanidou et al., 2022).

Academic achievement is complex and intertwined with a variety of factors owing to communities, schools, social, economic, and cultural conditions (Kuh et al., 2011; Santyasa et al., 2020). Factors that may affect students' achievement include study habits, skills, and attitudes (Credé & Kuncel, 2008; Mendezabal, 2013). Moreover, instructional resources affect students' achievement in several subjects, including Physics, and sufficient learning resources have significantly influenced academic performance (Oladejo et al., 2011). Meanwhile, curriculum and instruction, which could improve key skills in Physics, are also factors that can promote achievement level (Hazari et al., 2007). Hence, Physics teachers are critical to students' achievement (Lawrenz et al., 2009). Learner-centered practices such as inquiry-based teaching and project-based science should be used to improve students' academic achievement (Arista & Kuswanto, 2018; Chang, 2019).

The rapid adoption of technology in education characterizes the twenty-first century (Khairil & Mokshein, 2018). The use of digital learning tools, such as virtual simulations, has grown in recent years, shaping instructional strategies that support students' learning (Selwyn, 2007). Virtual simulations are educational technology tools that create interactive environments that mimic real-world phenomena (Foronda et al., 2020). Virtual simulations enriched with activities help students understand abstract concepts in Physics that are difficult to observe in a real laboratory (Gnesdilow, 2021; Mešić et al., 2021; Sullivan, 2017). Radhamani et al. (2018) contend that information and communication technology (ICT) can potentially increase student engagement in science laboratory instruction through application simulations using virtual laboratories.

The use of interactive simulations benefits both students and instructors (Ben Ouahi et al., 2022). Virtual simulations can help students directly visualize the behavior of indirect macroscopic and microscopic phenomena and connect it to observable phenomena (Wibowo, 2017) and can be used as a computer-based simulation of some complex phenomena in real life (Winsberg, 2003). They have been shown to be effective in terms of saving time, being simple to use and conduct experiments, and providing multiple representations, including dynamically changing visual representations (Blake & Scanlon, 2007). They provide dynamic visualization and fast feedback and are appropriate for inquiry learning (Moore et al., 2013). According to Susilawati et al., (2022), physics instructional materials in the inquiry model with PhET virtual simulations resulted in positive cognitive results, processing skills, and student creativity.

In a meta-analysis conducted by D'Angelo et al., (2014) on computer simulations in science, technology, engineering, and mathematics (STEM) learning in K-12 instructional settings, simulations pose a positive effect than treatments without simulations. This finding was supported by a recent meta-analysis on the effectiveness of virtual laboratory activities on student achievement, which found a medium effect size, indicating a positive use of virtual laboratories. Virtual laboratory simulations have also been noted to be widely used in a variety of scientific disciplines, including biology, chemistry, earth science, and physics (Santos & Prudente, 2021). However, in contrast to the potential benefits of virtual simulations in Physics instruction, some significant concerns have emerged, including students' passive behavior, distortion of laboratory reality if a proper simulation is not available, and loss of teamwork skills due to students' extreme individualism (Salmerón-Manzano, 2018). Furthermore, due to financial constraints, virtual simulation setups are seemed to be impractical (Anwyl-Irvine et al., 2021).

In light of the changing educational landscape caused by the COVID-19 pandemic, science teachers must become knowledgeable of the effective blended learning strategies that have been investigated and implemented to guide and support them in their instructional practices (Antonio, 2022). Particularly, innovative and effective instructional strategies in Physics are necessary to assist students in developing their learning achievement amidst the online distance learning setup. To our knowledge, there has been no quantitative synthesis of the literature that focuses on virtual simulations on students' achievement in Physics. Hence, the conduct of meta-analysis is deemed essential to investigate empirical evidence that can be used to inform the delivery of Physics instruction during and in the post-pandemic. The findings of this meta-analysis could be useful in developing a professional development training program to improve science teachers' technological and pedagogical knowledge and skills. Therefore, this study aims to examine the previously done studies on virtual simulations in improving students' Physics achievement. This study specifically seeks to answer the following questions:

1. How effective is the use of virtual simulations in improving students’ Physics achievement?
2. How do the effect sizes in the included studies differ in terms of:
   2.1. region;
   2.2. students’ grade level;
   2.3. field of Physics, and;
   2.4. duration of the implementation?
3. What are the different virtual simulation tools that have been investigated in Physics instruction?

METHOD

Research Design

A meta-analysis was used to examine studies on the effectiveness of virtual simulations on students’ achievement. Meta-analysis is a comprehensive statistical analysis and synthesis of the quantitative findings from independent and similar studies (Cohen, 1988). It aims to discern general trends in the quantitative findings (Creswell, 2013) by quantifying effect size results. Effect sizes measure the difference between the control and experimental groups (D’Angelo et al., 2014).

Literature search procedures

As shown in Figure 1, the selection of relevant studies was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses or PRISMA (Moher et al., 2009). Research articles were obtained from several meta-search engines such as Google Scholar, Microsoft Academic, SCOPUS, and PubMed. The researcher purposely chose to begin the search from 2016 until the third quarter of 2021. As in the previous meta-analysis conducted by Funa and Prudente (2021), the literature search was aided by Harzing’s Publish or Perish (PoP) software program. Furthermore, the following descriptors were strategically entered in meta-search engines, with some variations to account for specific retrieval sources: *virtual simulations*, *computer simulations*, *achievement*, *secondary*. These words were entered into meta-search engines at random and interchangeably, with the constant use of the word "*physics*" until all studies were exhausted.

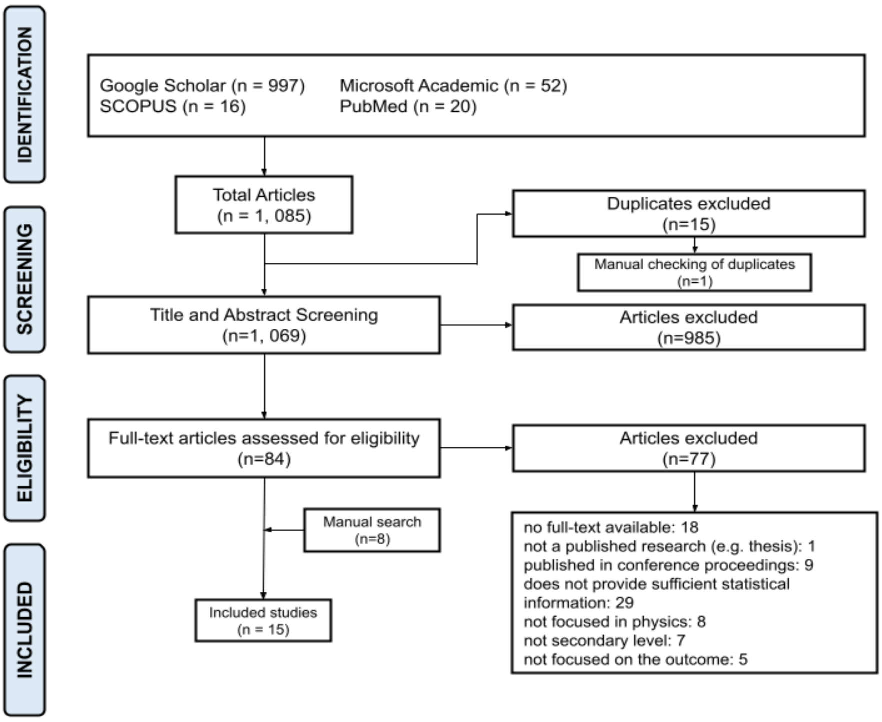

Figure 1
Flow chart of the literature search using PRISMA

From 2016 until September 2021, there were 1, 085 research articles returned by different databases as relevant at first sight. Using an online tool (www.dupelist.com) and manual removal, 16 duplicates were removed. After the abstract screening, only 84 articles were assessed using the inclusion and exclusion criteria.

Inclusion and exclusion criteria

To qualify for inclusion in the meta-analysis, the following inclusion criteria should be met: a) must be a published research article from the year 2016 to September 2021; b) must be conducted at the secondary level of education; c) must focus on a Physics concept; d) must use an experimental, quasi-experimental, or mixed-method research design with pretest/post-test control or posttest only, wherein virtual simulations were used in the experimental group; (e) must use achievement as the dependent (outcome) variable; f) must include an explicit reference to "virtual simulation" in its title or abstract.

From the 84 research articles, 77 studies were removed due to the following reasons: a) no full-text available; b) not a published research (e.g., thesis); c) published in conference proceedings; d) does not provide sufficient statistical information; e) not focused in Physics; f) not conducted at the secondary level and; g) not focused on achievement as the outcome variable.

Following the exclusion of the 77 studies, a manual search was carried out to exhaust the literature. This was done to reduce bias by explicitly hand-searching for research articles that may have been missed in the first search (Vassar et al., 2016). The manual search yielded eight research articles that were eligible for inclusion in the meta-analysis. In total, 15 research studies were included in the meta-analysis.

Coding procedures

In a coding sheet, relevant information from the research articles were analyzed and coded. The following essential information were carefully recorded by the researcher: (1) study title; (2) authors; (3) year of publication; (4) region; (5) research objective/s; (6) sample size; (7) subject matter; (8) virtual simulation used; (9) duration of implementation; (10) statistical results, i.e., posttest means and standard deviations; and (11) research findings.

Effect size calculation

Statistical analyses were performed using Comprehensive Meta-analysis Software version 3. Moderator analyses were also utilized to determine differences in the effectiveness of virtual simulations on students' achievement. The findings of the individual studies were converted into effect sizes. Effect size constitutes the dependent variable of any meta-analysis study (Dagyar & Demirel, 2015). Specifically, Hedges *g* was mainly used to detect the magnitude and strength of the effectiveness of the virtual simulations in improving students' achievement. Hedges *g* is the standardized mean difference equal to the difference between the mean values of experimental and control groups divided by the standard deviation. It is a more accurate version of Cohen's *d*, correcting bias in small sample studies without affecting larger samples (Hedges & Olkin, 1985). The magnitude of the effect size was decided according to Cohen's (1988) criteria: 0.80 and above (large); 0.50 to 0.79 (medium); 0.20 to 0.49 (small), and; less than 0.19 (no effect).

FINDINGS

Among the 1, 085 papers initially retrieved from the literature search, a total of 15 studies qualified in the meta-analysis. Table 1 summarizes the included studies, displaying key information such as the authors and year of publication, region (country), grade level, field of Physics, duration of the implementation, research design, virtual simulations tool/s used, and comparison between experimental and control group with pertinent statistical data.

Table 1
Summary of the included studies in the meta-analysis

Author/s and Year of Publication	Region	Grade Level/ Field of Physics	Duration	RD	Virtual Simulation Tool/s Used	EXPERIMENTAL			CONTROL		
						Mean	SD	n	Mean	SD	n
1. Al-Amri et al., (2020)	Asia (Oman)	JHS (Waves and Optics)	8 weeks	QE	3D-Virtual Environment: Eureka.in Top-Bottom 3D Content, PhET simulations, Skoool website	23.88	3.80	32	17.48	4.45	33
2. Banik & Biswas (2017)	Asia (India)	SHS (Electricity and Magnetism)	not reported	TE	unspecified	21.40	2.22	30	17.73	3.01	30
3. Cayvaz et al., (2020)	Eurasia (Turkey)	JHS (Mechanics)	3 weeks	QE	PhET simulations, Algodoo	12.95	4.19	98	10.13	3.24	90
4. Çetin (2018)	Eurasia (Turkey)	SHS (Electricity and Magnetism)	3 weeks	QE	PhET simulations, eduMedia simulations	4.90	1.79	24	4.56	1.98	25
5. Chumba et al., (2020)	Africa (Kenya)	JHS (Electricity and Magnetism)	not reported	QE	PhET simulations	55.65	17.01	100	38.79	14.55	100
6. Kibirige & Tsamago (2019)	Africa (South Africa)	JHS (Waves and Optics)	4 weeks	QE	Phet Simulation	56	19.5	53	39.6	13.35	52
7. Ngatia (2019)	Africa (Kenya)	JHS (Mechanics)	3 weeks	QE	Interactive Multimedia Simulation Advance Organizers	52.49	5.58	45	28.96	7.80	50
8. Ndihokubwayo et al., (2020)	Africa (Rwanda)	SHS (Optics)	12 weeks	QE	PhET simulations	10.93	11.03	45	8.73	8.19	45
9. Özcan et al., (2020)	Eurasia (Turkey)	JHS (Thermodynamics)	1 week	QE	PhET simulations	11.95	2.73	22	10.13	2.82	23
10. Ranjan (2017)	Asia (India)	SHS (Modern Physics)	not reported	QE	PhET simulations	1.20	0.98	105	0.89	0.99	103
11. Rosali (2020)	Asia (Philippines)	JHS (Electricity and Magnetism)	5 weeks	QE	PhET simulations	34.95	3.82	80	34.09	4.11	77
12. Sari et al., (2017)	Africa (Somalia)	SHS (Optics)	6 weeks	QE	PhET simulations, Crocodile Physics	15.98	4.75	40	12.73	4.26	40
13. Yehya et al., (2019)	Asia (Lebanon)	SHS (Electricity and Magnetism)	not reported	QE	PhET simulations, Crocodile Physics	13.82	3.02	44	9.43	4.04	42
14. Yildirim (2020)	Eurasia (Turkey)	JHS (Mechanics)	3 weeks	MM	Education Information Network (EBA), PhET simulations	62.90	16.62	31	48.70	17.88	31
15. Yunzal & Casinillo (2020)	Asia (Philippines)	SHS (Electricity and Magnetism)	not reported	QE	PhET simulations	3.97	0.22	32	3.70	0.26	40

Note: Junior High School (JHS), Senior High School (SHS); Research Design (RD); Quasi-experimental (QE); True-experimental (TE); Mixed-method (MM)

The total number of samples both in the control and experimental group was 1, 562 students. As can be gleaned in Table 1, six studies were conducted in Asia (n=6), five studies in Africa (n=5), and four studies in Eurasia (n=4). As regards students' grade level, more than half of the studies were conducted at the junior high school level (n=8), while seven studies focused at the senior high school level (n=7). When it comes to the specific fields of Physics where virtual simulations were used, virtual simulations were noted to be widely utilized in the teaching and learning of concepts in electricity and magnetism (n=6) and mechanics (n=3). Other fields of Physics included optics (n=2), waves and optics (n=2), modern physics (n=1), and thermodynamics (n=1). Additionally, in terms of the implementation period, five studies utilized virtual simulations in 1-3 weeks (n=5); other studies utilized virtual simulations in 4-6 weeks (n=3) and more than 7 weeks (n=2). However, five studies (n=5) did not report the actual duration of the implementation. Furthermore, the majority of the included studies (n=13) used a quasi-experimental research design; other research designs used were true-experimental (n=1) and mixed-method (n=1). Individual studies used a variety of virtual simulation tools, including PhET simulations, Crocodile Physics, Skool, Algodoo, and others.

Table 2
Overall effect size and heterogeneity analysis

	k	ES (*g*)	SE	Variance	95% CI		z	*p*	Q	df (Q)	*p*	I^2
					Lower	Upper						
Fixed	15	0.786	0.053	0.003	0.682	0.891	14.766	0.000	124.161	14	0.000	88.724
Random	15	0.941	0.163	0.027	0.622	1.260	5.777	0.000				

Note. k=number of effect sizes; g=Hedges' g; SE=standard error; CI=confidence of interval for the average value of ES; Q=Homogeneity Value; df=degrees of freedom; I^2=level of heterogeneity

Table 2 reflects the heterogeneity value, average effect size, and confidence intervals based on the effect model in the analysis. Based on the table, it can be deduced that the heterogeneity analysis was significant ($p < .05$). The Q value was found to be 124.161 with degrees of freedom of 14, suggesting that studies included in the meta-analysis do not share a common effect size are thus significantly heterogeneous (Borenstein et al., 2009). Hence, the random-effects model should be employed (Ellis, 2010). Besides this, I^2 yielded a value of 88.724%, implying high heterogeneity level, thus moderator analysis can be performed (Higgins & Thompson, 2002). Meanwhile, the calculated effect sizes ranged from 1.260 (upper limit) to 0.622 (lower limit) at a 95% confidence interval from the random-effects model. The overall weighted effect size of 0.941 suggests that the use of virtual simulations has a significantly large and positive effect (Cohen, 1988) on students' achievement in Physics.

The forest plot distribution of Hedges *g* effect sizes, as shown in Figure 2, indicates that all of the studies included in the meta-analysis favored the experimental groups (B) exposed to virtual simulations over the control group that received conventional instruction (A). When individual studies were examined, the maximum effect size was $g = 3.412$ (Ngatia, 2019), while the minimum effect size was $g = 0.177$ (Cetin, 2018). In 12 studies, the p-value was found to be statistically significant ($p < .05$), indicating significant differences in posttest mean scores between the experimental and control groups in terms of students' achievement in Physics.

Model	Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
	Al-Amri et al., (2020)	1.526	0.279	0.078	0.979	2.074	5.465	0.000
	Banik and Biswas (2017)	1.370	0.284	0.081	0.813	1.926	4.825	0.000
	Caywaz et al., (2020)	0.746	0.150	0.023	0.451	1.041	4.959	0.000
	Çetin (2018)	0.177	0.282	0.079	-0.375	0.729	0.628	0.530
	Chumba et al., (2020)	1.061	0.151	0.023	0.766	1.356	7.049	0.000
	Kibirige and Tsamago (2019)	0.973	0.205	0.042	0.571	1.374	4.743	0.000
	Ngatia (2019)	3.412	0.321	0.103	2.784	4.041	10.641	0.000
	Ndihokubwayo et al., (2020)	0.225	0.210	0.044	-0.186	0.636	1.071	0.284
	Özcan et al., (2020)	0.644	0.301	0.090	0.055	1.233	2.141	0.032
	Ranjan (2017)	0.314	0.139	0.019	0.041	0.586	2.256	0.024
	Rosali (2020)	0.216	0.159	0.025	-0.096	0.528	1.355	0.176
	Sari et al., (2017)	0.713	0.229	0.052	0.266	1.161	3.122	0.002
	Yehya et al., (2019)	1.224	0.233	0.054	0.767	1.681	5.247	0.000
	Yildirim (2021)	0.812	0.261	0.068	0.300	1.324	3.110	0.002
	Yurzal and Casinillo (2020)	1.099	0.252	0.063	0.605	1.592	4.363	0.000
Fixed		0.786	0.053	0.003	0.682	0.891	14.766	0.000
Random		0.941	0.163	0.027	0.622	1.260	5.777	0.000

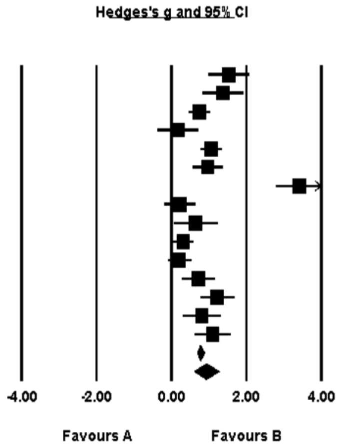

Figure 2
Forest plot showing the distribution of effect sizes of the individual studies (n=15)

Given the heterogeneity of the studies included in the meta-analysis, Table 3 presents the moderator analysis when the following variables were taken into account: region/country, grade level, field of Physics, and duration of implementation. Moderator analyses revealed that virtual simulations improved students' Physics achievement regardless of where the studies were conducted. It was found out that it had the largest effect in Africa (g = 1.427), followed by Asia (g = 0.923), and had a medium effect (g = 0.643) in Eurasia. No significant differences were observed among the effect sizes of these studies ($Q_b = 2.771$; $p > .05$). In terms of the students' level of education, it was noted that the use of virtual simulations had a positive and larger effect size on students at the junior high school level (g = 1.143) than that of students at the senior high school level (g = 0.714). However, no significant differences were found among the effect sizes of the studies ($Q_b = 1.813$; $p > .05$). In relation to the field of Physics, it can be seen from the findings that using virtual simulations had the largest effect in the teaching and learning of concepts in mechanics (g = 1.636), followed by waves and optics (g = 1.217), and electricity and magnetism (g = 0.850).

Meanwhile, virtual simulations had a medium effect in the teaching and learning of thermodynamics (g = 0.644) and a small effect in optics (g = 0.461) and modern physics (g = 0.314). According to these fields, significant differences were observed among the effect sizes of the included studies ($Q_b = 12.920$; $p < .05$). Furthermore, in terms of the duration of the implementation, the studies that used virtual simulations for 1-3 weeks had the largest effect size (g = 1.130). Virtual simulations implemented in 4-6 weeks and more than seven weeks yielded medium and large positive effect sizes of g = 0.628 and g = 0.853, respectively. However, some studies did not specify the duration of implementation but obtained a large effect size of g = 1.000. No significant differences were observed among the effect sizes of the studies ($Q_b = 1.019$; $p > .05$).

Table 3
Moderator analyses

Moderator	k	Effect size (g)	95% CI LL	95% CI UL	Q_b	p
Region					2.771	0.250
Africa	5	1.247	0.461	2.033		
Asia	6	0.923	0.456	1.391		
Eurasia	4	0.643	0.396	0.891		
Grade level					1.813	0.178
Junior high school	8	1.143	0.633	1.652		
Senior high school	7	0.714	0.355	1.074		
Field of Physics					12.920	0.024*
Electricity and Magnetism	6	0.850	0.430	1.271		
Mechanics	3	1.636	0.180	3.092		
Modern Physics	1	0.314	0.041	0.586		
Optics	2	0.461	-0.018	0.939		
Thermodynamics	1	0.644	0.055	1.233		
Waves and Optics	2	1.217	0.678	1.756		
Duration of the implementation					1.019	0.797
1-3 weeks	5	1.130	0.501	1.759		
4-6 weeks	3	0.628	-0.158	1.415		
More than 7 weeks	2	0.853	-0.130	1.837		
Not reported	5	1.000	0.386	1.613		

*Random-effects model, *p < 0.05*

When the individual studies were examined in terms of the specific virtual simulation tools used, it was observed that the majority of the studies (87%) employed PhET simulations in the teaching and learning of Physics. Following this, thirteen percent (13%) of the included studies utilized Crocodile Physics as the simulation tool (e.g., Sarı et al., 2017). On the other hand, seven percent (7%) of the studies utilized 3D-virtual environments as the main simulation tool. Other simulations used were Skool (Al-Amri et al., 2020), Algodoo (Cayvaz et al., 2020), eduMedia (Çetin, 2020), interactive multimedia advanced organizers (Ngatia, 2019), and Education Information Network (Yildirim, 2021).

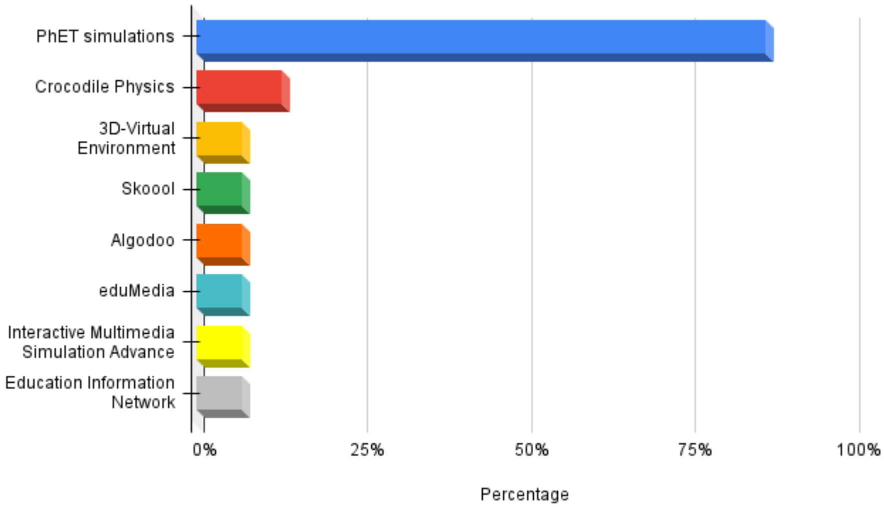

Figure 3
Virtual simulations tools utilized in the included studies (n=15)

Publication Bias

As shown in Figure 4, the funnel plot analysis through visual inspection revealed that the effect sizes of the studies show an asymmetry. To confirm this finding, Begg-Mazumdar rank correlation and fail-safe N tests were conducted. The Begg-Mazumdar rank correlation yielded Kendall's tau of 0.32381 ($p > 0.05$).

In Table 4, the classical fail-safe N test results indicate that 953 more studies are needed to be added to the analysis to bring $p > 0.05$. Taken together, the quantitative analyses show that the meta-analysis has no presence of publication bias.

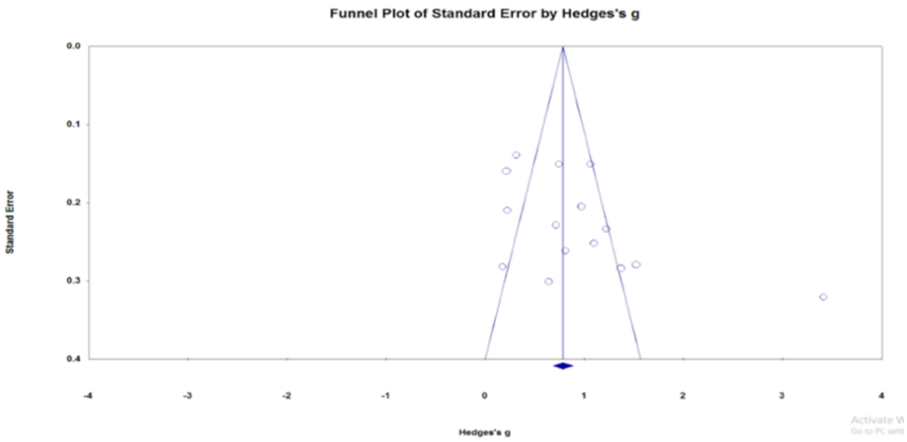

Figure 4
Funnel plot of standard error by Hedges *g*

Table 4
Classic fail-safe N results

The Resistance of the Meta-Analysis versus Publication Bias	
Z-value for observed studies	15.74399
P-value for observed studies	0.00000
Alpha	0.05000
Tails	2.00000
Z for alpha	1.95996
Number of observed studies	15.0000
Number of missing studies that would bring p-value to > alpha	953.000

DISCUSSION

The present meta-analysis was statistically done by reviewing and analyzing fifteen (15) empirical studies that investigated the effectiveness of virtual simulations in enhancing students' achievement in Physics. The overall weighted effect size of 0.941 suggests that the use of virtual simulations has a significantly large and positive effect (Cohen, 1988) on students' achievement. The result of the present study conforms to the findings of previously done meta-analyses, establishing the effectiveness of simulations for having a positive and strongly significant effect on the students' achievement (D'Angelo et al., 2013; Santos & Prudente 2021; Talan, 2020). The use of simulations enhances the learning experience, significantly improving student performance and understanding of scientific concepts (Gnesdilow, 2021; Hou et al., 2021; Mešić et al., 2021; Sullivan, 2017). When properly used in classroom instruction, it can actively engage students in meaningful inquiry, facilitate their knowledge and understanding, help them confront their misconceptions, and develop their scientific process skills (Huang & Liaw, 2018; Bell & Smetana, 2008).

The forest plot analysis revealed that all studies (n=15) favored the experimental group exposed to virtual simulations. Out of the 15 included studies, 8 studies obtained positive and large effect sizes ($g \geq 0.80$). Interestingly, the largest effect size ($g = 3.412$) was seen in the study of Ngatia et al. (2019), who established the effectiveness of virtual simulations in maximizing students' achievement in Physics. In his study, interactive multimedia simulations, alongside advanced organizers, were used in teaching and learning of mechanics. The interactive multimedia simulations allowed students to perform simulated activities, where they used and manipulated digital apparatuses and received immediate feedback on their task performance. On the other hand, the integration of advanced organizers in the simulations enabled the students to anticipate and organize information leading them towards meaningful learning of the concepts (Ausubel et al., 1978; Ngatia et al., 2019).

In addition, positive and large effect sizes were observed in other studies (Al-Amri et al., 2020; Banik & Biswas, 2017; Chumba et al., 2020; Kibirige & Tsamago, 2019; Yehya et al., 2019; Yildirim, 2021; Yunzal & Casinillo, 2020). These studies share similarities when it comes to the virtual simulations, i.e. PhET simulations, used in their studies. In the study of Al-Amri et al. (2020), the virtual lab simulations created opportunities for students to manipulate different variables, predict and visualize the results in their experiments. More specifically, students used different simulation tools like PhET simulations, Eureka.in Top-Bottom 3D Content, Skool website, which offered a variety of learning resources that enriched their learning.

Meanwhile, three studies (n=3) found positive and medium effect sizes (Cayvaz et al., 2020; Özcan et al., 2020; Sar et al., 2017), indicating that virtual simulation has the potential to improve students' Physics achievement. These studies investigated various simulation tools, such as PhET simulations and Algodoo (Cayvaz et al., 2020; Özcan et al., 2020), as well as Crocodile Physics (Sar et al., 2017). In two of these studies, virtual simulations were employed to foster inquiry-based learning experiences (Özcan et al., 2020; Sar et al., 2017). Using the 5E instructional model, students' attention and curiosity were captured, allowing them to construct their knowledge in the topic using virtual simulations. Students were also able to explain their findings and apply what they had learned in different but related situations. Consequently, they gained hands-on interactive experience as they received immediate feedback about the effect of the changes they made in the simulation (Sarı et al., 2017).

Three of the included studies (n=3) had effect sizes that can be interpreted as having positive but small effects (Ndihokubwayo et al., 2020; Ranjan, 2017; Rosali, 2020). Ndihokubwayo et al. (2020) used a projector to manipulate PhET simulations in their study. The teacher asked questions during the simulation, and students responded using what they already knew and what they saw on the screen. Similarly, Rosali (2020) supplemented the concepts learned during the hands-on laboratory activities with PhET simulations. Instead of allowing the students to manipulate the simulations, the teacher presented them as overheads via direct instruction. Altogether, such a teacher-led virtual simulation could explain the small effect size found in the previous studies.

Only one study (n=1) obtained an effect size that can be interpreted with no effect (Cetin, 2018). Although his study has provided evidence that simulation-based cooperative learning could facilitate students' Physics achievement, no significant difference was found compared to the group of students exposed to conventional instruction. However, it can be noted that virtual simulations were also used in conventional set-up in which the teacher lectured, provided notes, and solved sample examples. Apart from this, students exposed to simulation-based cooperative learning environments had a higher effect size than those exposed to conventional instruction, supported with simulations, based on the comparison of pre-test and post-test mean scores. These results only imply the effectiveness of virtual simulations in facilitating substantial improvements in students' achievement in Physics.

When the individual studies with positive effect sizes were critically examined, it was noted that the majority of them employed constructivist learning opportunities for the students while using virtual simulations. In the study of Çetin (2018), different simulation tools from PhET and eduMedia simulations were used as part of the different inquiry phases of the 5E inquiry cycle. Along with the advantages that virtual simulations could provide for students, constructivist instructional strategies appeared to be potential explanations for their significantly higher achievement in Physics. Students participate actively in the teaching and learning process by expanding their understanding (Reid-Martinez et al., 2018). This also helps them develop their confidence and motivation to embark on more complex challenges (Han, 2005). Based on the included studies, specific constructivist instructional strategies were coupled with the use of virtual simulations, which include inquiry-based learning (e.g. (Cetin, 2018; Özcan et al., 2020; Sarı et al., 2017), collaborative learning (e.g., Çetin, 2020), and use of advanced organizers (Ngatia, 2019). The integration of PhET simulations in inquiry-based learning can help facilitate the teaching and learning process (Yuliati et al., 2018).

Furthermore, as reported in the studies with small effect sizes where teachers themselves utilized virtual simulations as part of the discussion, it can be emphasized that the student-centered use of virtual simulations should be better promoted to assist students in developing their understanding of the concepts. Bell and Smetana (2008) argued that the utilization of virtual simulations in the classroom should remain student-centered and inquiry-based to promote students' deep and meaningful learning. Performing laboratory activities in Physics should occur in small student groups under the guidance of the teacher and should feature authentic real-world problems (Ünal & Özdemir, 2013). Students should be actively involved in the teaching and learning process when simulations are teacher-led, by encouraging them to ask questions, predict, generate hypotheses, test, and draw conclusions (Soderberg, as cited in Bell & Smetana, 2008).

Furthermore, when the effect sizes of the studies were grouped by region or country of implementation, moderator analyses revealed no significant differences ($Qb = 2.771$; $p > .05$). This points to the effectiveness and appropriateness of virtual simulations in enhancing Physics teaching, resulting in students' improved Physics achievement regardless of varying curricula and students' background. Thus, this result further suggests that virtual simulations may positively affect students' Physics achievement regardless of the region where the studies were implemented. Regarding students' level of education, no significant differences were found among the effect sizes of the studies (Q_b = 1.813; $p > .05$). This result explains that the effectiveness of virtual simulations did not vary according to the students' grade level. When virtual simulations are used, they may produce similar positive results, whether at junior or senior high school level. It further implies that students, whether at the junior or senior high school level, need further instructional scaffolding or support when it comes to learning Physics concepts, which could be achieved through virtual simulations. On the contrary, when it comes to the field of Physics taught, significant differences were observed among the effect sizes of the included studies (Q_b = 12.920; $p < .05$). These results show that the use of virtual simulations may produce varying results when they are used as instructional tools in different fields of Physics. Therefore, the appropriateness of virtual simulations to several Physics topics must be first considered before utilizing it in classroom instruction. The appropriateness of educational technology tools must be assessed for their potential utilization to meet educational aims (Fastiggi, 2014; Hulon & Shivers, 2013). Finally, as for the duration of implementation of the virtual simulations, no significant differences were observed among the effect sizes of the studies (Q_b = 1.019; $p > .05$). Thus, it can be stated that the effectiveness of virtual simulations on students' Physics achievement did not vary according to the duration of implementation. Students may still attain positive changes in their learning regardless of the implementation period of virtual simulations in classroom instruction.

As regards the virtual simulation tools used, majority of the studies (87%) employed PhET simulations in the teaching and learning of Physics. PhET simulations provide animated, interactive, and game-like environments in which students learn through exploration (Perkins et al., 2006). They can be used in different teaching and learning activities, including lecture-discussion, group activities, homework activities, and laboratory activities. While exploring the simulations, students can be introduced to a new topic, deepen their understanding, develop their skills, reinforce their ideas, and support them through final review and reflection (Wieman et al., 2010). Following this, thirteen percent (13%) of the included studies utilized Crocodile Physics as the simulation tool (e.g., Sarı et al., 2017). Crocodile Physics offers a digital laboratory environment simulator for Physics topics such as optics, electricity, wave, kinetics, energy, and dynamics (Karagoz & Ozdener, 2010). On the other hand, seven percent (7%) of the studies utilized 3D-virtual environments as the main simulation tool. In the study of Amri et al. (2020), the 3D-virtual environment was aided by Eureka®, which offered a large collection of digital units, animated movies, and simulations in different Physics topics. Other simulations used were Skool (Al-Amri et al., 2020), Algodoo (Cayvaz et al., 2020), eduMedia (Çetin, 2020), interactive multimedia advanced organizers (Ngatia, 2019), and Education Information Network (Yildirim, 2021).

CONCLUSION

The meta-analysis of fifteen (15) studies that investigated the effectiveness of virtual simulations in improving students' Physics achievement yielded an overall effect size of

$g = 0.941$. This suggests that incorporating virtual simulations into Physics instruction is highly effective, as it has a significant and positive effect on student achievement. Through moderator analysis, no significant differences were found in the effect sizes of the individual studies when grouped according to the region, students' grade level, and duration of the implementation. This means that the effectiveness of virtual simulations in improving students' Physics achievement does not differ significantly depending on the region where it was implemented, students' grade level, or the duration of the implementation. However, when the effect sizes of the individual studies were grouped according to the field of Physics, a significant difference was found, indicative of the importance of assessing the appropriateness of virtual simulations to several Physics topics. The virtual simulation tools employed by individual studies were mostly PhET simulations and Crocodile Physics. Other virtual simulation tools used were 3D-virtual environment, Skool, Algodoo, eduMedia, Interactive Multimedia Advanced Organizers, and Education Information Network. The utilization of these virtual simulation tools had been coupled with constructivist instructional strategies that facilitated significant improvements in students' Physics achievement. The study has limitations, including the small number of studies included in the meta-analysis. The study was also restricted from 2016 to September 2021 in order to provide more recent and substantial information on the current state of literature on the effectiveness of virtual simulations in improving students' Physics achievement. This generated empirical evidence may guide and support Physics teachers in their practices during and in the post-pandemic instruction. Furthermore, this study only looked at student achievement and did not investigate other constructs, such as attitudes toward the use of virtual simulations.

RECOMMENDATION

Given the positive impact virtual simulations have on student achievement, teachers may continue to utilize virtual simulations in the teaching and learning of Physics. Inquiry-based instructional strategies that promote student-centered instruction may be used to better maximize the effectiveness of virtual simulations and foster meaningful Physics learning. The conduct of professional development programs is also suggested to further capacitate Physics teachers' technological and pedagogical knowledge on the effective utilization of virtual simulations to enhance students' Physics learning. Aside from student achievement in Physics, future meta-analyses could look into the effectiveness of virtual simulations in developing important constructs in science education, such as scientific attitudes and process skills, as well as other critical skills in the 21st-century education.

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