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Article

The Effect of Using PhET Interactive Simulations on Academic Achievement of Physics Students in Higher Education Institutions

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Abstract

This research aimed to examine the effects of PhET (originally an acronym for "Physics Education Technology") Interactive Simulations on the academic achievements of students at higher education levels studying physics. To achieve this aim, a quasi-empirical design was utilized where two groups of students were compared (i.e., the empirical group with N =69 and the control with N=71). Traditional instructional methods were implemented with the control group and experimental groups were taught using PhET Interactive Simulations. The data was analyzed using SPSS. According to findings, the empirical group, where PhET simulators were used, had higher academic scores on average compared to the control group with traditional training methodologies. However, no effect of gender or overall GPA was observed in the academic performance in the empirical group. The study results then portrayed the use of PhET Interactive Simulations for physics education and suggested further research in other science courses.

Keywords

PhET Interactive Simulations, Academic Students' Achievement, Gender, Higher Institution

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Simulation is a powerful pedagogical tool of a high complexity but with the ability to immerse trainees in real-world scenarios and let them experience how they move personally free from any adverse consequences. In this way, experiential learning is possible as students tend not only to use theoretical knowledge elements but also to see how it applies in practical situations thus helping better retention and understanding. Depending on the learning objectives, simulations can be as simple as role-playing or can be very complex with a computer-generated environment (Lateef, 2010). The underpinning psychology of simulation in education is derived from constructivist learning theories that suggest new knowledge is constructed on existing cognitive frameworks through experiences (Vygotsky, 1978). Simulation with its real-world replica presents a brilliant way to bridge the gap between theoretical learning and practical application so that simulation can easily promote deep learning. It encourages critical reasoning, analytical and ethical skills using virtual simulations reflective of real-world difficulties (Mikropoulos & Natsis, 2011).

The use of simulations in the context of training and education has its historical roots back to the beginning of 20th century, mainly emerging in military and aviation training programs. Because the real-world aviation is complex and hazardous, they invented simulators that permitted pilots to exercise. Such instruments were indispensable to enhance their capabilities in different handling positions but without getting their neck on the line. The initial ones were mechanical systems that reproduced the elementary motions of airplanes (Hays & Singer, 1989). With the power to be utilized across a wide range of practical applications varying from military training to academic instruction, through business practices and more parallel forms including relief operations as well as entertainment updates, simulation has slowly but surely become an incremental tool in real life models (Dörner & Funke, 2017). The years since the late 20th century and early 21st have seen a dramatic transformation in simulation techniques, through the sheer scale, resolution, complexity, and scope like that which was experienced with theory and experiment generations before. Digital computing and virtual reality technology enabled the creation of realistic simulation environments that are as close to real world interactions as possible. These advancements have allowed the development of intricate simulations for numerous fields, giving students a way to experience things in a hands-on virtual environment. The growth of simulation promoted exploration in the realm as new trends as underlined and upheld by Alessi & Trollip (2001), signaling that a time spent on learning how to teach individual simulations would have limited benefits and advice has seldom been taken. In healthcare education, for example, simulators have been used extensively for training medical and nursing students in the performance of clinical skills, diagnostic reasoning and decision making without risking patients. Simulation has been demonstrated to enhance students' competencies and perceived capabilities in clinical readiness (Issenberg et al., 2005). There are several other interactions between simulation and teaching mechanisms, promoting a constructive learning delivery that is different from the traditional lecture-based method. Simulation offers a student-centered arena in which learners have an opportunity to trial and error, followed by self-assessment, as well as get feedback. This interactive mode joins together the theory with the practical application of knowledge in everyday situations (Weller 2004) (Alqawasmi, Alsalhi, & Al Qatawneh, 2024). In addition, simulation complements nicely with team-based learning approaches that promote not only teamwork but communication skills. Students in simulations also find themselves working on problems or scenarios within a group like their later collaborative environments. It serves to underscore how simulation is not only adjunctive to traditional learning but also to the higher-order cognitive skills that cannot be easily taught through other means (Dieckmann, Gaba, & Rall, 2007). Produced in 2002 by Nobel Laureate Carl Wieman, the PhET Interactive Simulation project at the University of Colorado Boulder provides an open-source system that changes students' understanding with computer simulations on physics and other sciences. This entire collection of title-based research activities is browsed in the kind of free running simulations that pay a lot in homework sections or permanent fun in organic physics, biology, earth sciences and mathematics. PhET has grown to go far beyond physics, focusing on supporting physical and mental models of scientific concepts that enable students to play with the sims in ways that encourage exploration. This engages people in a hands-on learning experience, with an access available across the globe and through most web browsers for learners individually or within the classroom.

Because these animations are based on accepted instructional methods and technologies and incorporate contributions from teachers and researchers, the PhET simulations are educationally effective as well as scientifically accurate, making them invaluable not only to instructors but also to learners (Perkins, Moore, & Chasteen, 2014; PhET Interactive Simulations, 2024). The most interesting is the use of PHET Simulations in physics which are a novel & innovative way of learning the very challenging concepts as Quantum Mechanics, Electromagnetism and Motion. Science can be a difficult subject to learn through conventional methods and visualization of scientific phenomena in real-time. The changes in the variables and view of outcomes make it easy for students to understand. Here, students observe real-world applications of theoretical principles to remove the abstraction from physics material and make the discipline more representational and interactive (Wieman et al., 2008). We will also use PHET physics simulations to examine the students´ academic achievements in this study for two teaching methods (traditional and simulation) based on its lack of previous studies.

Aim of the study

This study aimed to explore the use of PhET interactive simulations on students' academic achievement in physics at higher education.

Questions of Study

RQ1: What is the impact of PhET Interactive Simulations in Physics at Higher Education Level on student achievements?

RQ2: To what extent do gender and cumulative GPA influence the academic performance for students in physics experiments in the empirical group?

Significance of the study

The relevance of the study is illustrated in the following way:

- This study could help clarifying the effects of using PhET Interactive Simulations on the academic achievement of physics students in higher education institutions.
- Instructors will also gain from the benefits of this study. When properly guided, they can also create their own meaningful problems to deal with Physics topics applications by using PhET Interactive Simulations applications. It is also possible to obtain real-time feedback on their work.

Previous Studies

This wide adoption and application of PhET Interactive Simulations in physics education demonstrate the transformational change in the teaching pedagogy. The platforms are also designed to improve learning experience in physics as such they have incorporated different strategies like Open Source and Free Physics Simulation Tools which would not only offer routes for interactive engagement with complicated scientific concepts but significantly support student learning outcomes in terms of conceptual understanding, scientific skills development and changes on the attitudes toward learning physics (Banda & Nzabahimana, 2021; Shaker et al., 2022). Using PhET Interactive Simulations in physics education provides a multidimensional improvement to teaching and learning efforts. Perkins et al. (2014) detail much higher PhET use at high school and college levels to serve a range of pedagogical purposes, making effectiveness in so doing through implicit scaffolding. Simulation flexibility and availability to numerous learning objectives and implementation contexts respond to the requirements of new educators as well as experienced educators. They highlight the wide-ranging utility of PhET simulations, suggesting their flexibility and universal appeal to teachers wanting to enhance their teaching resources. The work shows one example of the use by teachers', at both high school and college levels, of these simulations for a variety of educational purposes regarding more meaningful engagement with science (Perkins et al., 2014; Suartha, Martha, & Hermanto, 2022). The study by Astutik and Prahani (2018) explains the advantages of PhET simulations and highlights how these tools can develop scientific creativity and critical thinking skills in students. These interactive tools not only enable a deeper understanding of concepts but also can considerably enhance problem solving ability of students (Alsalhi, Omar, Shehieb, Eltahir, & Al-Qatawneh, 2022; Yuliati et al., 2018) (Astutik & Prahani, 2018; Ceberio, Almudí, & Franco, 2016; Sulisworo et al., 2019; Taibu, Mataka, & Shekoyan, 2021). More closely related to our discipline, Salame and Makki (2021) present empirical data that PhET simulations positively influenced General Chemistry II courses in aiding conceptual understanding as well as creating a more positive attitude of chemistry learning, making these tools potentially transdisciplinary. Simulations help students grasp and interact with abstract ideas, promoting formative engagement and improving educational outcomes. Other research that was a quasi-experimental conducted by Mallari and Lumanog (2020) already supported the claim of PhET simulations in significantly improving academic performance of Grade 7 students with respect to science, thus emphasizing how PhET aids in enriching interaction and engagement in instruction. Both the higher student motivation, and the challenging nature of learning appeared to have an impact on academic performance when students engage in PhET interactive simulation activities over the control groups which performed traditional teaching methods. In that same line, Ajredini et al. study high school students' understanding of electrostatic charging and compared learning with real experiments to learning via PhET simulations (Kempa et al. 2013). Two empirical groups—one with real experiments and the other with PhET simulations—and one control group were considered in their study, which showed that these interactive and empirical methods were more effective to convey knowledge and skills than traditional ways of teaching. Mahtari et al. (2020) and Gani et al. (2020) provide more evidence for the positive effect of PhET simulations on student achievement, comparing their efficacy to traditional teaching methods in depth. The findings imply that implementation of integrated teaching strategies is necessary. Ozcan, Çetin and Koştur (2020) have suggested that simulation-based learning can significantly improve student understanding of concepts and help in identifying and correcting misconceptions. This research examined the achievements of students: One group used PhET-based experimental teaching approach and another control group using traditional procedures; the study showed that learners in the empirical group were considerably higher than in thecontrol one (using-constructive-learning). This contrasts with Ajredini, Izairi and Zajkov (2014) who revised Hai-Ry and Tali (2013) making uses actual experiments in addition to PhET simulations on understanding the electrostatic charge of high school students. With two empirical groups (one experimental and one with PhET-based simulations), as well as a control group, it was found that both empirical approaches were more effective in conveying nature of empiricisms skills, abilities compared to traditional teaching. Yunzal Jr and Casinillo (2020), however, offer a more critical reflection noting the small gains in student performance after using PhET simulations. It highlights the complexity of teaching and learning physics particularly through multimodal educational interventions (Khuddush & Prasad, 2022; Razzaiq et al., 2022; Yunzal Jr & Casinillo, 2020). These findings are vital in highlighting the multiple avenues through which PhET simulations work, from critical thinking (Putranta & Kuswanto, 2018; Putranta & Wilujeng, 2019) scientific creativity and critical thinking (Astutik & Prahani, 2018; Martínez-Costa, Amoedo-Casais, & Moreno-Moreno, 2022) to enhancing academic performance and promoting the development of learning disposition (Duggan et al., 2023; Mallari & Lumanog, 2020; Rohs, 2022). Meanwhile, Haryadi and Pujiastuti (2020) hold scientific research that examined the utilization of PhET simulation software to enhance students' science process abilities, especially in physics education. The results showed that the experimental group using PhET simulation had significantly better science process skills than the control group, with an improvement of 37%. The result of Inayah and Masruroh (2021) showed that students learning gains significantly improved with an average N-gain of 0.63 (categorized in a moderate gain group), in addition to the highly positive response from PhET simulations implementation in their classroom setting. This supports the research of Taibu et al. (2021) that there was an enhancement in science knowledge among students. The study by Yulianti, Zhafirah and Hidayat (2021). The work of Roller et al. (2021) demonstrates that using PhET simulation in the context of guided inquiry learning can significantly enhance students' understanding of difficult topics by promoting more critical thinking. This study also shows that this nanotechnology integrated guided inquiry model embedded in PhET simulation can be used to enhance students critical thinking skills. Similarly, the qualitative research study conducted by Rayan et al. (2023) revealed that simulations brought about a marked progression in students' scientific levels as they occur in active involvement and problem-solving behaviors during PhET simulation use. Also, Batuyong and Antonio (2018) were an evident improvement on students' learning outcomes in physics, emphasizing PhET capabilities to improve understanding and interest for these students. Moreover, the study showed that students were more engaged in and had a better understanding of physics as well as performed significantly better academically when PhET was integrated. Moreover, they have proven PhET simulations to significantly enhance student learning when used in educational environments. These simulations not only assist in conceptualization and questioning in science but also develop an attitude towards the physics and chemistry, which is why it is very important part of modern era education (Li, 2022; Mallari & Lumanog, 2020; Perkins et al., 2014; Salame & Makki, 2021). Together, these results make a strong case for the utility of PhET Interactive Simulations in physics education as they are distributed and used on a larger scale. These digital leaders underscore the importance of leveraging new kinds of digital tools to foster deeper, more active, and more equitable learning opportunities that better serve the needs and aspirations of 21st-century learners.

Methodology

Study Approach

A quasi-empirical study with design of two groups (one empirical group with 69 students and the other control group with 71 students). Physics experiments were taught to the control group using traditional teaching methods, while for the empirical group, the physics experiments were taught by PhET Interactive Simulations. Table 1 Details information on the topics of physics outreach taught.

Table 1: *Course Topics and Content of Week-By-Week.*

Week	Practical	Reference	Activities
1	**Review of Error Analysis**	**Instructions' sheets in lab Manual**	
2	Introduction to Basics of Electrical Components, Devices and Circuits	Lab manual Lab manual & Computer	Homework "application in error calculation" Application of Excel program in graphing and Discussion
3	The Charge of the Electron	Lab manual	Lab report and Disc.
4	Electric Field Mapping	Lab manual	Lab report and Disc.
5	Ohm's Law & Resistors in Series and Parallel	Lab manual	Lab report and Disc.
6	Wheatstone Bridge	Lab manual	Lab report and Disc.
7	Power Transfer	Lab manual	Lab report and Disc.
8	Kirchhoff's Rules	Lab manual	Lab report and Disc.
9	The RC Circuit	Lab manual	Lab report and Disc.
10	Force on a Current-Carrying Wire in a Magnetic Field	Lab manual	Lab report and Disc.
11	Magnetic Field of a Circular Loop	Lab manual	Lab report and Disc.
12	Revision	Lab manual	Lab report and Disc.
13	Examination		

Study Participants

This study was conducted with these students, 75 male and 65 females, during the second semester of the 2022/2023 academic year and PhET Interactive Simulations were used to accompany their Physics Experiments Course. Demographics of the participants are shown in Tables 1. Table 2 provides further information on demographics and Figure 1 presents a visual representation.

Table 2: *Participant Demographic Details.*

Study Group	Number of Students	Gender		Percentage (%)
		Female	Male	
Empirical	69	31(44.9%)	38 (55.1%)	49.30%
Control	71	34 (47.9%)	37 (52.1%)	49.50%
Total	140			100

Empirical	Student academic evaluation (GPA)				
	2 – less than 2.5	2.5 – less than 3	3 – less than 3.5	3.5–4	Total
f (Frequency)	21(30.4%)	27(39.1%)	13(18.9%)	8(11.6%)	69 (100%)

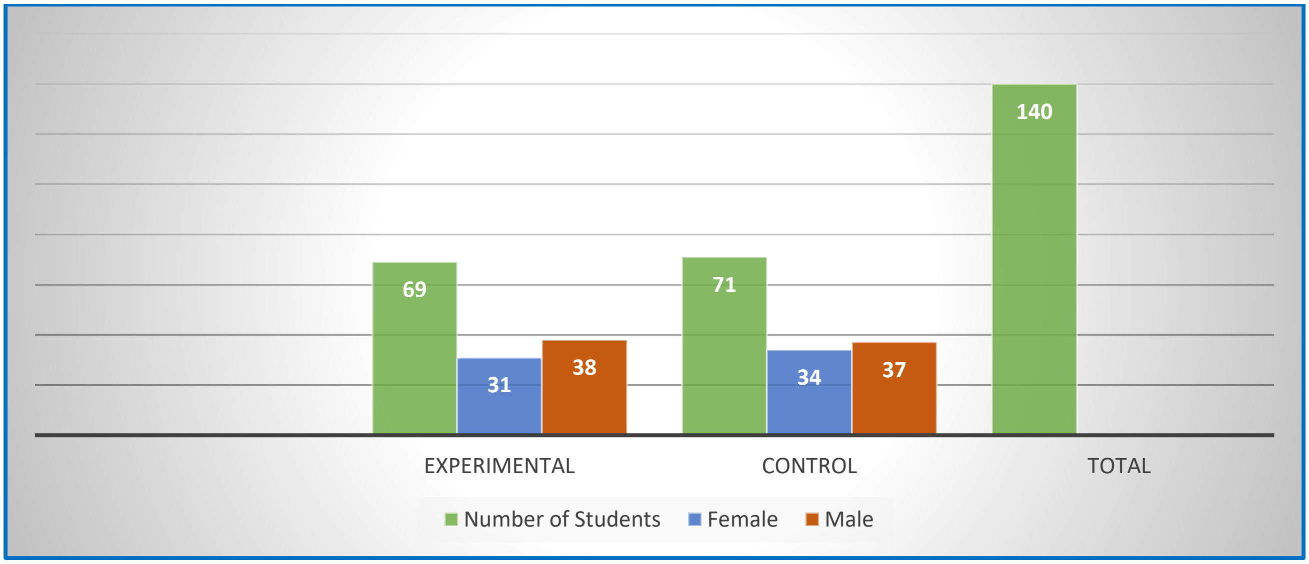

Figure 1: *Participant Demographic Details.*

Equivalency of the Groups (Pre-test)

An equivalence test to compare the empirical and control groups was conducted. The results of a t-test comparing pretest scores to post-test ones are presented in Table 3.

Table 3: *T-Test Comparison of The Pre-Test Outcomes for The Two Study Groups.*

Group	N	Mean	Std deviation (SD)	T. value	Sig. (tailed)	Sig. level
Empirical	69	11.80	2.27	0.024	0.491	Not Significant
Control	71	11.79	1.92			

* Statistically significant at ($p<0.05$)

In Table 3, p-value of 0.491 < 0.05 was not significant. Thus, between the two study groups, there were no statistically significant differences. As such, the empirical and control groups could be assumed to have been equivalent before any of the quasi-experiment began.

Methods of Statistical Analysis

With the aid of the SPSS program, the study's data were examined, and results such as means, frequencies, and independent sample t-tests were computed.

Findings

Results of the Study Related to Question 1

RQ1: What is the impact of PhET Interactive Simulations in Physics at Higher Education Level on student achievements? The comparison was performed measuring the average value in the scores of the experimental class which used PhET Interactive Simulations and those in the control group experimenting by the traditional teaching. Table 3 presents t-test for two independent samples.

Table 3: *Means and Standard Deviations of Post-Test Outcomes.*

Group	N	Mean	Std. Deviation	Std. Error Mean
Empirical	69	17.57	1.29	0.155
Control	71	14.49	2.21	0.262
Total	140			

Table 3 reveals that students who were taught using PhET Interactive Simulations had different scores (M= 17.57, SD= 1.29) from those who were taught by the traditional methods (M= 14.49, SD= 2.21).

Table 4: *Results of the Independent Sample T-Test for The Post-Test.*

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	T	df	Significance One-Sided p	Significance Two-Sided p	Mean Difference
Equal variances assumed	19.753	0.000	10.012	138	0.000	0.000	3.0723
Equal variances not assumed			10.083	113.300	0.000	0.000	3.0723

*Statistically significant at ($p < 0.05$)

Based on Table 4 above, the p-value is obtained as 0.000, which is less than 0.05. It implied that at the 0.05 level of significance, there is significant difference between the empirical group students, who were taught using PhET Interactive Simulations in Physics. The effect size is defined by Kelley and Preacher (2012) as a measure of the strength of a relationship between two variables in a population. In this evaluation, similarly, statistical significance can be related to the difference between the measured value of a statistic from sample data and the hypothetical value of a population parameter. It calculated the effect sizes to determine the difference between knowledge gains through using PhET Interactive Simulations in Physics, by the above formula.

$$\eta^2 = \frac{t^2}{t^2 + df}$$

Table 5: *The ANOVA Results.*

			Sum of Squares	df	Mean Square	F	Sig.
Score * Group	Between Groups	(Combined)	330.290	1	330.290	100.241	0.000
	Within Groups		454.703	138	3.295		
	Total		784.993	139			

*Statistically significant at ($p < 0.05$)

Table 6: *The ANOVA Results.*

	Eta	Eta Squared
Score * Group	0.649	0.421

The effect size of the impact of PhET Interactive Simulations on Physics on academic achievement, as gauged from Eta Squared obtained from data presented in Tables 5 and 6, is large. Its magnitude is 0.421.

Results of the Study Related to Question 2

RQ2: To what extent do gender and cumulative GPA influence the academic performance for students in physics experiments in the empirical group?

Gender Variable

The difference in the average scores of students regarding the empirical group (PhET Interactive Simulations) was calculated. We then ran a t-Test for 2 independent samples as described in Table 7.

Table 7: *Means and Standard Deviations of Post-Test Outcomes of Empirical Group Students.*

Group	N	Mean	Std. Deviation	Std. Error Mean
Male	38	17.605	1.1977	.1943
Female	31	17.548	1.3866	.2490

Table 8: *The Independent Sample t-test Results of Empirical Group Students.*

	Levene's Test for Equality of Variances		t-test for Equality of Means				
	F	Sig.	t	df	Significance: One-Sided p	Significance: Two-Sided p	Mean Difference
Equal variances assumed	1.008	0.319	0.183	67	0.428	0.856	0.0569
Equal variances not assumed			0.180	59.702	0.429	0.858	0.0569

The figures given in Tables 7 and 8 show that the observed p-values (One-Sided p = 0.428; Two-Sided p = 0.856) are higher than the chosen level of significance. Accordingly, the test is none significant at a 0.05 level. The male (17.605) and female students (17.548) do not show important differences in the average scores of the empirical groups.

Cumulative GPA Variable

The means and standard deviations were computed, while one-way ANOVA carried out as shown in the Table 9.

Table 9: *One-way ANOVA Results.*

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.638	3	0.213		
Within Groups	110.174	65	1.695	0.125	0.945
Total	110.812	68			

Table 9 shows the p-value of 0.945, which is higher than 0.05, indicating that that the cumulative GPAs of students in the experimental group and their academic achievement in physics experiments do not differ statistically.

Discussion

The results of the first research question showed that the empirical group students (PhET interactive simulation program for physics) achieved statistically a higher average success. The mean values were low compared to the traditional teaching method-based successful performance than the control groups. The results of this study are consistent with the results of several previous studies which have shown that PhET interactive simulations had led to increased student learning. Mallari and Lumanog (2020) reported that students who learned using PhET simulations consistently outperformed those that learnt the same concept following traditional teaching approaches. This new study also supports Ajrediniet al's. results. One such study that supports the use of real hands-on experimentation and PhET simulations, compared to traditional teaching methods is a study by Borges de Lima Sena et al. Additionally, Ozcan et al. (2020) also backed up this statement They also provided evidence to justify that using PhET simulations in education is closer to a traditional teaching method. Results drawn from numerous studies are in agreement and they show advantages of interactive simulations, especially for (physics) educational purposes. This necessitates the change in analogue teaching or teacher centered pedagogy to digitalized interactive and student-centered method that is inclusive of technology integration in education. With PhET interactive simulation ability to significantly enhance students´ academic achievement, their value as an effective educational intervention is highlighted, showing that this approach allows a greater comprehension and mastery of difficult scientific topics. It focuses on the importance of change that intelligently combines digital tools to cater for differing learner needs and promote teacher-pupil dialogue. In addition, Mallari and Lumanog (2020), Ajredini et al. (2014) and Ozcan et al. (2020) has given an insight into a change in the kinesthetic approach to scientific contents by student that emphasizes the infusion of PhET simulations for a better academic outcome and catches up with an advancing modern world. Additionally, Shudayfat and Alsalhi (2023) found the positive impact of simulation-based environments on students' academic performance and attitudes towards learning science. Robust evidence from multiple studies confirms that the PhET interactive simulations improve student achievement and learning of scientific concepts, supporting their integration into modern education for a more impactful pedagogical experience. In addition, PhET simulations increase student engagement and motivation highlighting the need to use technology in inquiry- based learning environments to fulfill the needs of 21st century learners.

The results show no statistically mean differences in the academic achievement of the students by gender and Mean Cumulative GPA using PhET interactive simulation program in physics based on 2nd null hypothesis.

Mallari and Lumanog (2020), Astutik and Prahani (2018) and Perkins et al. (2014) assert the effectiveness of PhET simulations to improve students' achievement indeed, but has not explored variations related to gender or Grade Point Average (GPA) specifically. In this view, PhET simulations offer a pedagogic benefit that should help all students, independent of being male or female, or even the existed proficiency in Physics. Thus, thisstudy results echo prior works and confirm PhET simulations as an efficacious intervention across broad categories of students. PhET interactive simulations are an effective way to spark student learning regardless of gender or Grade Point Average (GPA), suggesting that differences in students' academic success should be small. This adds to previous research that shows the potential of PhET simulations to support conceptual understanding in challenging domains, and across diverse populations. That is, its use by students with different genders and GPAs, did not correlate to differences in academic achievement (gender vs. gender or GPA vs. GPA). So, it makes PhET simulations present educational equality opportunities, that are promoting the sense of inclusive learning environment where everyone can be encouraged to participate and understand the subject of Physics independently from their initial level or if they belong to a certain sex group. The reason for this is the possibility of PhET simulations to be more engaging and interactive, as they can help different learning styles and needs. In addition, their designs concentrate on compelling interactive material to resonate with all ages. This reasserts PhET simulations as a powerful tool in contemporary educational systems to utilize technology in pedagogy for enriching learning with a pleasant experience.

Implications

In the current study, we looked at the outcomes of using PhET Interactive Simulations on academic performance in higher ed physics students. This shows a significant increase in the outcomes compared to the control group, who received traditional instruction. This implies that the implementation of interactive simulations can contribute to a deeper understanding and a better retention of physics. Very notably, this simple technique helps all students equally irrespective of their gender or prior performance implying that it is universally applicable. From a practical perspective, it emphasizes the need to incorporate technology-based learning tools in educational environments for better learning results. Institutions need to facilitate educators with required resources as they migrate to these technologies, which would change pedagogical strategies and results in a deeper learning in science education.

Recommendations

PhET was found to be useful for teaching physics and possibly other sciences as indicated by the results of this study. This study recommended additional research on the PhET interactive simulation program in other content areas. Furthermore, enough resources should be given to educators to make use of this novel equipment. It is also recommended for formal training programs to be prepared in advance showing teachers and students how to best take advantage of the PhET interactive simulation program, to enhance learning outcomes. Moreover, institutions of higher education need to encourage the use of PhET interactive simulation exercise for better learning outcome in science education.

Conflict of Interest

The authors declare that they have no competing interests.

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