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Impact of Using Physics Education Technology (PhET) Simulations on Improving Students' Performance in Electrostatics

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Abstract: *This study aimed at assessing the impact of using Physics Education Technology (PhET) simulation to improve students' performance in electrostatics. A quasi-experimental design under quantitative methods was used. Electrostatics Achievement Test (Pre-test and post-test) were used to collect data. Four schools of the Muhanga district were selected purposively based on the presence of computer laboratories with 176 students from senior two. Two schools were used as the control group and the remaining two schools were used as the experimental group. Each group was composed of 88 students. The data were analyzed descriptively using an independent t-test to compare the mean for the experimental group and control group and paired t-test. Independent sample t-test results indicated that there was no significant difference in the mean score for the pre-test for both the control and experimental group (p>0.05). The results further show that there was a significant difference between the mean score for students of the experimental group and the control group after the intervention (p<0.05). These results showed that the use of PhET simulation has an improvement on students' performance in electrostatics for students taught using PhET simulations. The study recommends physics teachers use PhET simulation to teach abstract concepts like electrostatics to improve students' performance. Further, they should create an environment where the students can learn difficult concepts with a help of PhET simulation to motivate and engage the students for better performance in electrostatics.*

Keywords: *PhET Simulation, students' performance, Electrostatics, Information Communication Technology, Physics, Conceptual understanding*

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1. Introduction

Physics plays an essential role in explaining the events that occur in the universe and everything that takes place around us. Everything that happens around us is governed by physical rules and principles (Kaya & Boyuk, 2011). Physics is challenging to study because students tend to view some of the laws and concepts as abstract (Guido, 2018). This resulted in a decline in the percentage of secondary school students choosing physics as their major, and it continues to worry researchers and teachers globally (Barmby &Defty, 2006). For example, teachers in Malaysian secondary schools have discovered that their students struggle greatly with understanding fundamental physics concepts, which results in a lack of enthusiasm for the subject (Saleh, 2012). In Kenya, academic performance is low due to the learner's attitude towards the Physics subject, and inadequate, and expensive instructional resources which lead to poor content mastery (Chumba, 2020).

Electrostatics is among the crucial areas of physics and is also regarded as a challenging area of physics due to its complexity and abstract nature (Chang, 2011). Many students seem to find it challenging and hard to understand how two bodies become charged as well as the properties of electric field lines (Furió et al., 2004; Mbonyiryivuze et al., 2021; Furió & Guisasola, 1998). Also, the students frequently struggle to solve physics questions, and this struggle is largely due to their lack of conceptual knowledge of the physics subject (Hung & Jonassen, 2006).

Chang (2011) added that it seems to be challenging for them to fully comprehend the electrostatics idea and what happens when two electrically charged bodies are brought close to one another. Furthermore, according to Chang (2011), students struggle to comprehend the ideas of trajectories, field lines, and equipotential lines. In this regard, many students erroneously identify the boundaries of Gauss' and Coulomb's laws, as well as understanding electric force and electric field, and they struggle to comprehend how a test charge would move if it were free to do so in an electric field (Dede et al., 1997). For example, in South Africa, the report showed that students struggle to understand electrostatics, where these reports of learner performance at the end of each school year showed that electrostatics was the part of the subjects on which the average-performing learners perform poorly between 18% and 54% from 2011 to 2018 (Mazibe,2020). This is because they can't visualize the force distribution in a vector field and understand how that force distribution translates into the motion of the test charge, or even come close to understanding the concept of superimposed force. Additionally, to learn this concept of electrostatics, experimentation and experience are necessary, but some schools have a significant barrier due to a shortage of laboratories (Ndihokubwayo, 2017).

Information and communication technology (ICT) is important today as it plays a significant role in improving teaching and learning where in this 21 st century teachers were encouraged to be creative and originally fully use the available resources. Senkhikumar (2016) claimed that ICT is one resource that can be used as it draws students by making them more engaged in class and encourages their involvement during teaching and learning

According to Mbonyiryivuze et al. (2022), incorporating technology into teaching and learning has benefits. PhET simulations are essential to fast-developing conceptual knowledge to increase learning and compensate for the lack of actual laboratories in classrooms (Banda & Nzabahimana, 2021). Additionally, Batuyong & Antonio (2018) explained that PhET simulation is a very effective educational tool for use in teaching and studying physics because it raises students' achievement in the subject. The purpose of this study is to ascertain how the usage of PhET simulation, one of the ICT tools used in teaching and learning Physics concepts, including electrostatics concepts, affects the senior two secondary school students' performance in electrostatics.

The study was guided by the following questions:

1. Is there any significant difference in pre-test score of students in electrostatics between control and experimental group?
2. Is there any significant difference in post-test score between students learning electrostatics using traditional teaching method and students learning using of PhET simulations?

2. Literature Review

2.1. How do traditional teaching methods affect students' performance?

In traditional teaching, the teacher controls the learning environment, he is in charge of making decisions about the curriculum's content and its specific outcomes, and is in charge of holding both power and responsibility (Agbele et al., 2020). Dimitrios (2013) stated that in traditional teaching, students are regarded as having the knowledge to be filled with the required and specific instruction. In traditional teaching, teachers emphasize facts, definitions of physics concepts, and using formulas to solve physics problems Mulhall & Gunstone, (2008). Also in the traditional teaching method, the teachers wrote notes on the chalkboard about the definition of the concept, explained the facts, and solved the questions while the students took notes throughout the lesson (Taşlıdere & Eryılmaz, 2009)..

2.2. Relationship between conceptual understanding and performance

Performance is the grade that students earned on pre- and post-tests after the relevant topics were covered (Laurence, 2022). Andamon & Tan (2018) stated that the students' conceptual understanding was the best predictor of the students' performance. Niaz (1995) found that the students who perform better on problems requiring conceptual understanding, also perform better on problems requiring the manipulation of data and computational problems. On other hand, Conceptual understanding is defined as an individual's ability to understand specific concepts (Rouse, 2016). Students are expected to demonstrate conceptual understanding as they recognize and name mathematical concepts and generate examples, identify, and apply principles, and use different signs (Coryunitha & Ama, 2017). Students with conceptual understanding may apply concepts, descriptions, relationships, or representations in contexts that call for careful application (Rouse 2016).

2.3. Challenges and difficulties of students in learning electrostatics

The electrostatic phenomenon is a branch of physics that deals with events caused by electric charges' attraction or repulsion but does not depend on how they move. Coulomb's law is used to describe this phenomenon (Coryunitha & Ama, 2017).

Students find it difficult to learn electrostatics since some of the concepts, such as electric field, electric flux, and electric potential, are not frequently employed in daily life and are instead closely connected.

In research on students' poor conceptual understanding of electrostatics, the forces imposed by electric fields on charges known as electric fields have been the main subject (Doğru, 2021) Also, the majority of students struggle to conceptually represent electric field lines because they have a poor conceptual understanding of the subject (Doğru, 2021) The study conducted by Moynihan (2018) results show that students can't tell the difference between electric force and field intensity, where the students had little trouble applying vector component reasoning throughout the electric field tutorial when sketching the electric field around two charged bodies in various places. Some students incorrectly believe that there is only one form of charge present in charged objects due to their inadequate conceptual understanding of static electricity and atomic structure (Moynihan et al., 2016).

2.4. Students' conceptual understanding of electrostatics with different teaching approaches during the teaching and learning process

Physics learning materials cannot be explained verbally but must be supported with hands-on activities to support the physics learning activities (Ismalia et al., 2022). Because electrostatics principles are typically presented in abstract ways in textbooks, students often struggle to fully comprehend the concepts. However, when teaching and studying physics, including the notion of electrostatics, the use of multiple representations, is the use of a diversity of representational approaches, modes, and communication (Orulebaja et al., 2021).

As a result, various resources are employed to enhance verbal explanations of the subject and make the lesson more applicable to the student (Lusiyana et al., 2019). When teachers use these resources which may be divided into audiovisual, audio, and visual categories, students will find them appealing both visually and aurally (Lusiyana et al., 2019). Banda & Nzabahimana (2021) made a strong case for this by pointing out that secondary students who were taught using instructional aids and those who weren't had quite different academic outcomes.

The use of information and communication technology (ICT) tools is also vital in reducing the reasons why students perform poorly in physics, including a lack of facilities (resources) and a lack of enthusiasm for the topic (Mekonnen, 2014). Further, Interactive simulations are one ICT resource that may be utilized to make sure students have a conceptual understanding of science, especially physics (Banda & Nzabahimana, 2021; Karamustafaoglu, 2012; Kotoka & Kriek, 2014). According to Furió et al. (2004), instructional sequences can assist teachers in bridging the conceptual knowledge of students with the cognitive demands of a subject like the electric field.

2.5. Importance of PhET simulation in teaching and learning electrostatics

PhET (Physics Education Technology) simulation is a set of interactive research-based Science and Mathematics online simulations and it was created at the University of Colorado at Boulder (Coryunitha & Ama, 2017) .Studies from many literatures works show that PhET simulation can greatly improve students' conceptual understanding of physics courses and can be integrated into numerous learning environments (Banda & Nzabahimana, 2021). .The PhET simulations stress the linkages and give students access to the visual and conceptual models used by scientists to bridge the gap between real-world occurrences and the underlying science (Taibu et al., 2021). They are animated, interactive, and game-like settings where students learn via discovery.

Studies from many literature works show that PhET simulation can greatly improve students' conceptual understanding of physics courses and can be integrated into numerous learning environments (Banda & Nzabahimana, 2021). The study conducted by Wieman et al.(2010) stated that using PhET simulations has the same benefits as a demonstration using real equipment and has been discovered to have several additional advantages, including being able to be utilized in a classroom where genuine equipment is either unavailable or difficult to set up; they can be used for unrealistic experiments; it is possible to modify variables that would be challenging or impossible to modify with actual instruments in response to student inquiries; students can imitate using their computers at home as a class experiment to further their learning; they can also openly connect several representations while showing invisible. Also Students can relate real-world occurrences with the underlying science by using these simulations, which are interactive tools (Bello, 2022). This PhET simulation can make the learning process more interesting and fun (Ismail et al., 2022).

2.6. Theoretical framework

The cognitive theory of multimedia learning (CTML) was employed in this study to help the students to build a mental representation of the electrostatic concept. By using this cognitive theory of multimedia learning (CTML), textbook images, PowerPoint with audio, listening to or watching narrative presentations, simulations, and instructional videos are all examples of multimedia instruction that can be employed during teaching and learning (Mayer & Moreno 2002). To help students learn more effectively and process information simultaneously, cognitive multimedia learning is used. This approach helps the students remember the material for a long period (Supurwoko et al., 2017).

3. Methodology

3.1. Research design

Research design is the broad approach that a researcher uses to integrate the many study components logically and coherently (Reeves et al., 2010). This study employed a quasi-experimental research design to collect quantitative data on how employing PhET Simulations in teaching and learning affected senior two students' performance in electrostatics. A pre-test was used to check the performance of students before the intervention. After that the teaching electrostatics was commenced, one group was taught using traditional method and another group was taught using PhET simulation. After teaching electrostatics, both groups were administered a post-test to evaluate their performance in electrostatics.

3.2. Population and Sampling

In this study, the population consist of all senior two students and their physics teachers in Muhanga district. From the population, four schools composed of 176 students were selected purposively based on the availability of computer laboratories. Therefore, the four schools were randomly divided into two groups: control and experimental group each group composed of 88 students. In control group, the students were taught using traditional teaching methods while in experimental group, the students were taught using PhET Simulations.

3.3. Instrument of the study

This study aimed at using the PhET simulation on the notion of electrostatics using the Electrostatics Achievement Test (EAT), which was created by the researcher. Students took a pre-test to determine their prior knowledge and a post-test to evaluate the effectiveness of PhET simulation after the intervention.

3.4. Validity and reliability

Research questionnaires are used to collect pertinent data most accurately and validly possible (Taherdoost, 2018) Electrostatics Achievement Test (EAT) employed in this study were given to the researcher's supervisor and a team of education specialists for validation and correction. For Electrostatics Achievement Test, a test- retest was done by students to calculate the reliability of this test. The Cronbach's Alfa calculated was 0.803. This showed that the test was reliable.

3.5. Data analysis procedures

The Electrostatics Achievement Test (EAT) quantitative data were analyzed using SPSS version 20. T-test analysis was required to compare the means acquired during the pre-test and post-test.

3.6. Ethical consideration

The Department of Research and Innovation at the University of Rwanda provided a recommendation for ethical clearance in support of the request for authorization to carry out this research in the Muhanga District. Also, before going to the field to collect data, we wrote a letter to the Mayor of Muhanga district requesting for conducting this study in her district. The permission was obtained, and the researcher started visiting the schools where the study was to be conducted. Additionally, the participants voluntarily completed the consent forms, and the names of the schools and names of students were not mentioned.

4. Results and Discussion

4.1. Presentation of Findings

Question 1. Is there any significant difference in pre-test score of students in electrostatics between control and experimental group?

To answer this question, the Electrostatics Achievement Test (EAT) was used to obtain the results. There was a pre-test given to both classes. 176 students participated in total. These students were divided into two groups: 88 students from the other school served as the experimental group, while 88 students served as the control group. Using the SPSS software, a descriptive analysis of the data from those two groups was performed.

Therefore, the research findings were summarized as follows:

Table 1: Group statistics

	Group	N	Mean	Std. Deviation	T	df	Sig. (2-tailed)
Pre-test	Control	88	38.06	9.813	-1.346	174	.180
	Experimental	88	40.09	8.755			

According to the results obtained in (table 1), both the control group and the experimental group each had 88 participants. Pre-testing was conducted on both, for control group (M=38.16, SD=9.813) while for experimental group (M=40.09, SD=8.755). The independent sample t-test calculated whereby the p-value obtained was 0.180 and it was greater than p-value (P>0.05). Therefore there is no significant difference in mean score between control and experimental group before the intervention.

Question 2. Is there any significant difference in post-test score between students learning electrostatics using traditional teaching method and students learning using PhET simulations?

To answer this question, both group were given the Electrostatics Achievement Test (EAT) to assess the outcomes following the teaching of electrostatics to both groups.

Also, an independent sample t-test was used to compare the performance of students in two groups, and paired sample t-test to compare the performance of students in the experimental group, the findings were summarized as follows:

Table 2: Post-test results for Control and Experimental Group

Group		N	Mean	Std. Deviation	T	df	Sig. (2-tailed)
Post-test	Control	88	47.52	8.431	-11.222	174	.000
	Experimental	88	62.16	9.174			

The table 2 summarize the results of performance of students in post-test. For control group (M=47.52, SD=8.431) while for experimental group (M=62.16, SD=9.174)

The results of the post-independent test's sample t-test had a p-value of 0.000. (Table 2). (p= 0.05) This value is less than 0.05. The post-test mean scores for the experimental group and the control group are thus likely to be significantly different from one another. These findings from the post-test for both groups demonstrate that using PhET simulation, students in the experimental group performed better in electrostatics than students in the control group.

Table 3: Paired Samples t-test

		Paired Differences					T	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre-test – Post-test	-15.750	12.265	.925	-17.575	-13.925	-17.036	175	.000

To ascertain whether there was a change in the students' performance for both groups, the outcomes of the pre-test and post-test were also compared using the paired t-test. The results showed a significant difference in mean scores between the experimental and control groups (p 0.05) as shown in table 3.

4.2. Discussion of findings

The pre-test results indicated that there is no significant difference between the students' performance of the two group in pre-test. This comparability of the two groups made sure that no group is better than other and their performance in electrostatics was low. These results were similar to those of Ndihokubwayo et al. (2019) who discovered that the students' conceptual knowledge of static electricity and other topics was lacking. Asgari et al. (2018) insist on this by stating that students often lack an in-depth understanding of these concepts because the majority of texts frequently explain electrostatics principles using abstract language. The results thus far have shown that the students struggle greatly with drawing electric field lines and determining the source of electric fields. Students found that it was challenging to explain and interpret Coulomb's law because they did not connect electrostatics to their mental model of the world. This is comparable to the research done by Monyihan et al. (2014), who discovered that using pre-instruction made it difficult for students to relate the mental model of electrostatics.

The post-test results showed that the mean score obtained by students in the Electrostatics Achievement Test (EAT) after the intervention was statistically different for the two groups. The post-test score was higher than that of the pre-test. These demonstrate how the use of PhET simulation in teaching and learning affects the students' performance in electrostatics. These results were similar to that of Ersoy & Dilber (2014) who found that learners can change the settings of the virtual world within the simulation and develop a fresh understanding of the underpinning concepts through inference and prediction of possible outcomes. Nyirahabimana et al. (2022) showed that when multimedia, including PhET simulation was used in teaching, students were more motivated. Ersoy & Dilber (2014) went on to say that simulations broadened the range of student discovery by making the abstract more concrete and by providing quick feedback on the experience.

5. Conclusion and Recommendation

5.1. Conclusion

The objective of this study was to investigate the impact of using Physics Education Technology to improve students' performance in electrostatics. This study concluded that students' performance using PhET simulations perform better than the students learn using traditional teaching methods. This study showed that the schools where the teachers used PhET simulation played an important role in improving students' performance in electrostatics as the students can visualize unseen phenomena of electrostatics which leads them to be more attracted during learning this concept of electrostatics, the students were able to observe and identify the relationship between charge distribution and electric field lines, were also able to interpret and explain the physical meaning of Coulombs 'law by stating the factors that affect the magnitude of electrostatic force.

5.2. Recommendation

According to the objectives and findings of this study, it recommends:

1. Physics teachers to use PhET simulations in teaching abstract concepts like electrostatics to improve students' performance. Teachers should create an environment where the students can learn difficult concepts with a help of PhET simulation to motivate and engage the students for a better conceptual understanding of that concept to enhance performance in electrostatics.
2. School leaders should encourage their teachers to use PhET simulation as it can eliminate the abstraction of some concepts by making them more concrete so that the students can understand by learning this concept. The school leaders should also give facilities to the teachers such as getting internet connectivity, and access to computer rooms for using them during the learning and teaching process.
3. The schools to organize training, and seminars on the use of PhET simulation so that the teachers could be able to use this technology and it can be more productive on the students' performance in teaching science subjects, including Physics, especially teaching and learning electrostatics.

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