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The impact of using PhET simulation on conceptual understanding of electrostatics within selected secondary schools of Muhanga District, Rwanda

Sylvere Uwambajimana [1*], Evariste Minani [2], Abraham Daniel Mollel [3], Pascasie Nyirahabimana [1]

[1] African Centre of Excellence for Innovative Teaching and Learning Mathematics and Sciences (ACEITLMS), University of Rwanda, RWANDA
[2] Department of Mathematics, Science and Physical Education, University of Rwanda, RWANDA
[3] Department of Educational Psychology and Curriculum Studies, University of Dar es Salaam, TANZANIA
***Corresponding Author:** uwambajimanasylvere@gmail.com

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ABSTRACT

Physics is considered by students as a difficult subject to learn because some physics concepts look like abstracts to students. Electrostatics is the one concept that challenges the students due to its abstract and difficulty to learn. This study aimed to assess the impact of using physics education technology (PhET) simulation on the conceptual understanding of electrostatics within the selected secondary schools of the Muhanga District. A quasi-experimental design was used to investigate the effect of PhET simulations on the conceptual understanding of electrostatics. The study explored the interaction between students and teachers when electrostatics is presented using PhET Simulation. Two groups were used, one group called the control group, which taught by using the traditional method of teaching and the experimental group was taught using PhET simulations. Pre- and post-test were administered to both the control and experimental group. Independent sample t-test results have shown that there was no significant difference in the mean score for the pre-test for both the control and experimental group ($p>0.01$) while there was a significant difference between the mean score for students in the experimental group and the control group after the intervention. The study used a paired sample t-test to determine whether there is a significant difference in the mean score in the pre- and post-test for the experimental group, the results showed that there is a significant difference in pre- and post-test scores ($p<0.01$). On the other hand, the observation showed that the interaction between students and teachers increased when PhET simulation was used as an ICT tool. These results show that the use of PhET simulation has an improvement on the conceptual understanding of electrostatics for students taught using this PhET simulation. The study recommends physics teachers use PhET simulation to teach abstract concepts like electrostatics to improve students' conceptual understanding. Further, they should create an environment, where students can learn difficult concepts with the help of PhET simulation to motivate and engage them for a better conceptual understanding of the concepts.

Keywords: PhET simulation, conceptual understanding, electrostatics, information communication technology

INTRODUCTION

The application of physics as a science is a crucial aspect of defining events in the universe and everything that happens in our local environment. Everything around us is subject to physical laws and principles (Kaya & Boyuk, 2011). Physics is more challenging than other sciences since students perceive some of its laws and concepts as abstract (Guido, 2018). This resulted in a decline in the proportion of secondary school students choosing physics as their major, and it still worries researchers and academics around the world (Barmby & Defty, 2006). Students struggle to solve physics problems because of formulae and equations and regard physics as a body of knowledge to be mastered (Mbonyiryivuze et al., 2021).

Teaching physics requires to use of a variety of strategies and approaches due to the principles that are so applicable to our daily lives (Veloo et al., 2015). However, several abstract physics concepts are among the problems that lead students to think that physics is very challenging (Mbonyiryivuze et al., 2021). The concept of electrostatics is one subject that presents difficulties for college and high school students (Ersoy & Dilber, 2014). 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).

Moreover, information and communication technology (ICT) is critical and contributes significantly to improving teaching and learning. In the 21st century, educators are encouraged to be creative and use all available technological resources. ICT is the only resource that can be used as it attracts students by increasing their level of engagement in class and promotes student participation in teaching and learning (Senthilkumar, 2016). The Ministry of Education has implemented ICT in teaching and learning by providing schools with computer-smart classes and one laptop per child to raise the standard of education in Rwandan schools by addressing the issue of some complex and abstract subjects during the teaching and learning process (Ministry of Education, 2016).

Interactive simulation is one of ICT tools that can be used to guarantee students' conceptual understanding of science, particularly physics (Banda & Nzabahimana, 2021). The Moroccan study showed that interactive simulation (physics education technology [PhET] simulation) can enhance learning activities and help students understand scientific concepts clearly (Ouahi et al., 2022). ICT significantly affects how well students perform in the sciences, particularly when teaching physics. PhET simulation is essential to quickly establishing conceptual understanding to promote learning and compensate for the lack of actual laboratory equipment in classrooms (Banda & Nzabahimana, 2021).

Therefore, the study was conducted to determine how senior two secondary school students' conceptual understanding of electrostatics is affected by the use of PhET simulation as one of ICT tools used in teaching and learning electrostatics concepts by answering the following questions:

1. What is the initial conceptual understanding of electrostatics in senior two secondary schools?
2. How is the interaction between students and teachers when PhET simulation is used in teaching electrostatics?
3. What is the impact of using PhET simulation on conceptual understanding of senior two secondary schools?

REVIEW OF LITERATURE

This section highlights the review of related literature and studies. It is also divided into sub-topics.

PhET Simulation

PhET is a website developed by the University of Colorado with funding mostly provided by the National Science Foundation and the William and Flora Hewlett Foundation. The website offers free physics, biology, mathematics, and chemistry learning simulations that can be downloaded for use in the classroom or individual study (Coryunitha & Ama, 2017). PhET simulations are animated, interactive, and game-like environments, where students learn through exploration and emphasize the links between real-world phenomena and the underlying science. It assists students in accessing the conceptual models of expert scientists, enabling them to reason in situations or settings that call for the careful application of concepts, descriptions, relationships, or representations (Rouse, 2016). PhET simulations promote the conceptual understanding necessitates, where students can combine information and knowledge from well-known schemes and apply them in new settings (Arif, 2018; Banda & Nzabahimana, 2021).

Relationship Between Conceptual Understanding and Performance

Performance is the score students received on tests taken before and after the pertinent material was covered (Laurence, 2022). The best indicator of students' performance is their conceptual understanding (Andamon & Tan, 2018). However, students who excel at conceptual understanding problems also excel at problems involving data manipulation and computational issues (Niaz, 1995). Conversely, conceptual understanding is characterized as a person's capacity to comprehend particular concepts (Rouse, 2016). As they recognize and name mathematical concepts, provide examples, identify and apply principles, and use various signs, students are expected to demonstrate conceptual understanding (Coryunitha & Ama, 2017).

Students with conceptual understanding may apply concepts, descriptions, relationships, or representations in contexts that call for careful application (Rouse, 2016). Furthermore, conceptual understanding necessitates that students be able to combine information and knowledge from previously studied schemes and apply them to novel situations (Banda & Nzabahimana, 2021). Students need to be able to comprehend the concept clearly to apply their knowledge in daily life (Gunawan et al., 2018). Hill et al. (2015), demonstrate that students' performance in physics depends on learners' awareness, and the learning process can be improved when carefully designed online materials are used as pre-instruction.

Challenges and Difficulties of Students in Learning Electrostatics

Students find it difficult to learn electrostatics because some of the concepts, like electric field, electric flux, and electric potential, are not frequently used in daily life and are instead closely related. Due to their inadequate conceptual grasp of the subject, the majority of students find it difficult to conceptually represent electric field lines (Dogru, 2021). According to Moynihan and Hons' (2018) study, students are unable to distinguish between electric force and field intensity. Due to their inadequate conceptual understanding of static electricity and atomic structure, some students assume that charged objects only have one type of charge (Moynihan et al., 2016). Nevertheless, students view atoms as charges and use a north-south charge model (Moynihan et al., 2016).

Ndeleni (2017) added some of the difficulties that students run into when learning electrostatics: Students are unable to distinguish between magnetic and electric attraction when asserting positive electric charges are drawn to the north magnetic poles. Some mistakenly believe that the third charge type is "neutral"; some do not always understand the charge conservation principle; some do not fully comprehend the atomic composition and structure of solid materials. These issues can lead some students to the incorrect conclusion that the isolated material cannot be charged. Similarly, Ogegbo (2022) explains students can distinguish between an electric and magnetic field or between a charge that produces an electric field and a charge that is affected by an electric field. They can use the equations for Newton's law of universal gravitation and Coulomb's law and combine the equations for those two laws.

Ogegbo (2022) asserts that students are unable to recognize or display the direction of field lines when solving equations. The majority of students struggle to accurately represent electric field lines because they have a variety of misconceptions about the idea of the electric field (Fredlund et al., 2015). Furthermore, students' difficulties understanding the concept of an electric field indicate that they have functional fixations based on the knowledge they acquired from the instructions and frequently use Coulomb's conceptual profile to explain electrostatic interactions (Furió et al., 2003). Students do not understand the inverse-square relationship between force and distance when it comes to the electrostatic force; instead, they believe that the distance between charges doubles the force of their interaction (Mazibe, 2020). Nonetheless, it has also been observed that students struggle to distinguish between charges that generate an electric field and those that test for the presence of the field at the location of interest (Mazibe, 2020).

Students' Conceptual Understanding of Electrostatics With Different Teaching Approaches

Physics learning materials cannot be explained verbally but must be supported with hands-on activities to support the physics learning activities (Kusumawati & Wahyuni, 2022). Students lack a thorough understanding of the concepts because most textbooks present electrostatics principles in abstract terms. However, the use of numerous representations, which is the use of a variety of representational techniques, models, and communication to make complex and abstract ideas more easily accessible and understandable during teaching and learning Physics including the electrostatics concept (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). Adebayo (2018) makes a strong case for this by pointing out that secondary students who were taught using instructional aids and those who were not quite different in academic performance. The use of 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).

Furió et al. (2004) demanded instructional sequences must allow teachers to link students' conceptual understanding to the cognitive demands of a subject like the electric field so that students can learn electrostatics. However, Batuyong and Antonio (2018) investigated how learners can learn at their own pace and relate/associate concepts with real-life situations almost immediately when they participate in the video. Furthermore, guided inquiry materials can help students adjust their mental models to consider information that modifies their initial conceptual understanding of electrostatics (Moynihan et al., 2016).

Importance of PhET Simulation in Teaching and Learning Electrostatics

PhET simulation can significantly enhance students' conceptual understanding of physics courses and integrated them into a variety of learning environments (Banda & Nzabahimana, 2021). In an ongoing effort to provide a comprehensive selection of simulations to enhance the way physics and other sciences are taught and learned, PhET interactive simulations was created (Bello, 2022). These interactive simulations help students draw connections between phenomena in the real world and the underlying science that underlies them (Bello, 2022). The learning process may become more engaging, enjoyable, and difficult thanks to this PhET simulation (Kusumawati & Wahyuni, 2022).

PhET simulations can be used in a classroom setting, where real equipment is either unavailable or impractical to set up (Wieman et al., 2010). It can be used for impossible experiments and possibly to change variables in response to student inquiries that would be difficult or impossible to do with real devices. Simulations created using PhET aim to involve students in scientific inquiry and pique their interest in the subject to enhance their conceptual understanding of science (Lancaster et al., 2013). However, PhET simulations are created to be entertaining and interesting, relate to the real world, provide a variety of representations, and speed up an inquiry (Lancaster et al., 2013). Thus, PhET simulations are created with the following goals in mind: to be entertaining and engaging for students throughout the learning process; to connect to the real world; to provide multiple representations; and to enable quick inquiry (Lancaster et al., 2013).

The essential elements of PhET simulation, such as visualization, interactivity, efficient context utilization, and computation, greatly aid students in understanding complex ideas. It allows learners to see something that would otherwise be invisible, PhET simulations benefit both teachers and students (Ndihokubwayo et al., 2020). In addition, the PhET simulations help instructors and students see intangible objects like atoms, electrons, photons, and electric fields (Ismail et al., 2022). The same is true for PhET simulations, which can aid learners of all ages, skill levels, and learning capacities in comprehending complex phenomena (Ersoy & Dilber, 2014).

By examining the effects of virtual experiments and laboratories on students' comprehension of electrostatics and whether or not these virtual experiments can replace or improve students' performance in actual labs, the usefulness of PhET Simulations as virtual laboratories were established (Hamed & Aljanazrah, 2020; Ziya'ulhaq, 2021). Ajredini et al. (2014) discovered that when they compared the outcomes of actual experiments and PhET simulations for studying electrostatics, they were remarkably similar.

Hamed and Aljanazrah (2020) also discovered that PhET simulations can be used as virtual laboratories due to the impact that virtual experiments and labs have on students' learning of physics and whether or not these virtual experiments can replace or enhance students' performance in real laboratories. The simulation (a cognitive process required for improving skill application) helped the experimental group perform and comprehend more efficiently. According to Moynihan and Hons (2018), the simulation assisted the experimental group in resolving particular learning issues. Whereas this is made possible by the PhET and the use of implicit scaffolding in simulation enables students to investigate natural phenomena in ways that would otherwise be impossible. It was remarked that students have a noticeable impact on students' attitudes toward science learning, their engagement, and their capacity to solve problems or observe phenomena without the assistance of a teacher (Byrne, 2020). Additionally, PhET simulation can be used to instruct students in subjects that are risky, difficult to understand, and require a small number of practical tools (Ismail et al., 2022).

Theoretical Framework

The study was conducted using the cognitive theory of multimedia learning (CTML) founded by Richard Mayer in 1947. The theory examines how designers should structure multimedia development and implement effective cognitive strategies to help learners learn efficiently (Mayer, 2014). Graphics in textbooks, PowerPoint with audio, listening to or watching narrative presentations, animations (simulations), and instructional videos are all examples of multimedia instruction that can be used (Mayer, 2014). Multimedia learning is used to help students learn more efficiently and simultaneously process information and this procedure helps students retain the information in long-term memory. Therefore, the theory was used because one principle of CTML is to encourage learners to build a coherent mental representation from the material presented. Here the task of the learners is to understand the presented material as active participants and ultimately to construct new knowledge (Supurwoko et al., 2017).

METHODOLOGY

This section highlights the research design, population and sampling, an instrument used, validity and reliability, statistical treatment of data, and ethical consideration.

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 mixed research design to collect quantitative and qualitative data on how employing PhET simulations in teaching and learning affected the conceptual understanding of senior two students in electrostatics.

Population and Sampling

In this study, the population consists of all senior two students and their physics teachers in the 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: the control and the experimental group. In the control group, 89 students were taught using traditional teaching methods while in the experimental group, 87 students were taught using PhET Simulations.

Data Collection Method

The following steps were used to collect data and to answer the research questions.

Step 1. Pre-testing: The physics conceptual understanding of electrostatics pre-test was administered to 176 students before the use of interventions of PhET Simulation to identify the current (initial) level of senior two students' conceptual understanding of electrostatics when the teachers use the traditional teaching methods.

Steps 2. Classroom observation: At this step, students from the two groups were taught electrostatics differently. One group called the control group composed of 89 students studying this concept by using traditional teaching methods while an experimental group composed of 87 students studied this concept using PhET Simulations whereby the teachers were given simulations related to electrostatics concepts. The observation tool protocol was used to conduct whether there is an interaction between students and teachers when PhET simulations are used in teaching electrostatics. The observers were observed in each class of the experimental group while a researcher was non-participating to avoid bias.

Step 3. Post-test: Physics conceptual understanding of electrostatics test (PCUET), which was the same as the test given in the pre-test was administered to both groups (control and experimental group) after teaching this top to see the extent to which the use of PhET simulation has on conceptual understanding compared to students taught using the traditional method of teaching electrostatics.

Validity and Reliability

Research questionnaires are used to collect pertinent data most accurately and validly possible (Taherdoost, 2018). PCUET employed in this study was given to the researcher's supervisor and a team of education specialists for validation and correction. For PCUET, 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.

Ethical Consideration

Before going to the field to collect data, we wrote a letter to the Mayor of the Muhanga District requesting for conducting this study in her district. The permission was obtained, and we started to visit the schools, where the study was to be conducted.

Table 1. Independent sample t-test

Test	Group	n	Mean	Standard deviation	Significance (2-tailed)
Pre-test	Control group	89	38.16	9.813	.180
	Experimental group	87	40.05	8.755	.179
Post-test	Control group	89	47.53	8.383	.000
	Experimental group	87	62.32	9.098	.000

Table 2. Paired sample t-test

		Paired difference			t	df	Significance (2-tailed)
		Mean	Standard deviation	Standard error mean			
Pair 1	Pre-/post-test (experimental group)	-14.621	5.829	.625	-23.394	86	.000

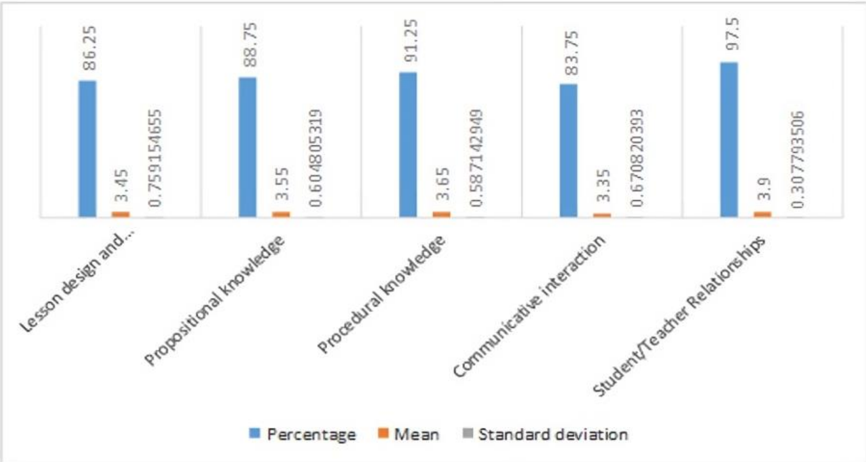

Figure 1. Observation results for the experimental group (Source: Field Data, June-July 2022)

Additionally, the participants voluntarily completed the consent forms, and the names of the schools and the names of students were not mentioned.

Data Analysis

To analyze the data, descriptive statistics were employed using SPSS to find the difference between the pre-test and post-test results. On the other side, the observation data were analyzed thematically in terms of percentage to investigate how the students-teachers interacted when PhET simulation is used.

RESULTS AND DISCUSSION

Presentation of Findings

This section highlights the findings of the study based on the research questions of this study.

Before that the intervention took place, all participants were given the test called pre-test to investigate the current conceptual understanding of senior two students in electrostatics. After the intervention, also the post-test was given to the student to check whether the use of PhET simulations has an impact on the conceptual understanding of students in electrostatics. The results were highlighted in **Table 1**.

According to **Table 1**, there were 89 participants in the control group and 87 in the experimental group. Both the control group and the experimental group had pre-test means of 38.160 and 40.050, respectively. The computed standard deviations for both groups were 9.813 and 8.755, respectively. These results showed that there is a low conceptual understanding of electrostatics during the time teachers used the traditional teaching method and there was no significant difference in mean score between both groups as the significant value is greater than the p-value ($p>0.01$). The results of the post-test revealed that the mean scores for the control and experimental groups, respectively, were 47.530 and 62.320. And it was discovered that these groups' respective standard deviations were 8.383 and 9. 098.This showed that there was an increase in conceptual understanding of electrostatics for the students taught using PhET simulation compared to those who taught using the traditional teaching method and there is a significant difference in mean score for both groups as the significant value is smaller than the p-value ($p<0.01$).

Table 2 shows the pre-/post-test results of the experimental group, it is clear that the p-value is less than 0.01, which means that there is a significant difference in scores for the experimental group before and after using PhET simulation.

Classroom observation was done during the school practice while the teachers used PhET simulation in an experimental group. **Figure 1** presents the findings, as follows.

Observation results obtained in an experimental group were displayed in **Figure 1** with the following percentages: 86.25% for lesson design and implementation, 88.75% for propositional knowledge, 91.25% for procedural knowledge, 83.75% for communicative interaction, and 97.5% for student-teacher relationships.

Discussion of Findings

Based on the mean pre-test scores that were derived for the two groups and showed no statistically significant difference, the study's findings indicated that the students had a limited conceptual understanding of electrostatics. According to Kizito et al. (2019), they discovered that the students' conceptual knowledge of static electricity and other topics was lacking. This result was similar to that of Were et al. (2011) who found that the use of ICT resources in schools has not been exploited by teachers and even by learners. Similarly, Bazina (2022) found that due to the lack of enough ICT tools affect methodology in terms of time-consuming for lesson when ICT is integrated into teaching. The pre-test results showed that the student's performance in electrostatics for the experimental group and the control group was law. That is also another challenge encountered by teachers during teaching and learning electrostatics. Also indicated that there is no significant difference between the students' performance of the two groups in the pre-test. These results were similar to those of Ndihokubwayo et al. (2019) 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. Similarly, these results were similar to that of Kotoka and Kriek (2014) who found that the experimental group achieved higher scores on the pre-test than the control group

In comparison to the students who were taught using the traditional technique, the post-test results for both groups demonstrated that the students who were taught using PhET simulation had a greater conceptual understanding compared to the students who were taught using traditional teaching methods. According to Ersoy and Dilber (2014), 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. PhET simulation can also be used to teach subjects that are difficult to understand, risky, and need a restricted number of practical tools (Kusumawati & Wahyuni, 2022).

Nyirahabimana et al. (2022) showed that when multimedia including PhET simulation was used in teaching, the students were more motivated. Ersoy and 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. Results showed that when a PhET simulation is employed, students can recall the lessons they had learned. Also, the students were more enthusiastic and actively involved in their learning when PhET simulation is used (Rustana et al., 2020). Weiman et al. (2010) found that PhET simulation can assist teachers in introducing new material, developing concepts or skills, reinforcing concepts, and offering a final opportunity for review and reflection. Makamu and Ramnarain (2022) commented that teachers were able to assist students in reconciling their new knowledge with prior beliefs by using the PhET simulation.

The use of PhET simulation played a major role in enhancing teaching and learning activities. Stated that when PhET simulation is employed, students can recall the lessons they had learned. The findings of this study also concurred with those of Kumar (2013), who looked into the effectiveness of PhET simulations. Kumar (2013) found that PhET simulations could enhance students' learning compared to traditional instruction, and those simulations enhanced their conceptual understanding by demonstrating how theories can explain physical observations.

Additionally, according to Batuyong and Antonio (2018), PhET simulation is a very effective educational tool for use in teaching and studying physics because it raises students' achievement in the subject. These findings, together with those from (Kusumawati & Wahyuni, 2022), indicated that the usage of PhET simulation enhanced teaching and learning electrostatics, where the students learning outcomes experienced more improvement after learning activities using PhET simulation. In his study of using PhET simulation to teach basic electrostatics concepts, Bello (2022) recommended that physics teachers use PhET simulation to prepare the most effective and interesting procedures that students could perform in their hands-on activities. Results obtained by Cigrik and Ergul (2009) and Constante and Agsalud (2019) also showed that the average score in the experimental group on students' achievement was significantly higher than the control group. The performance of students in the experimental group was attributed to the fact that computer simulations enable learners to visualize, contemplate and explain abstract concepts (Chumba, 2020)

CONCLUSIONS AND RECOMMENDATIONS

According to the findings of the first research question of this study showed that the students faced challenges in learning electrostatics in abstract way, the students memorize without understanding the real meaning of this concept, this caused them to be bored when they were learning this related concept. However, on the other side, the finding of the second research question of this study showed that the schools, where the teachers used PhET simulation played an important role in conceptual understanding of electrostatics as the students can visualize unseen phenomena of electrostatics and this led them to be more attractive during learning this concept of electrostatics. Therefore, the results of the Post-test for the experimental group found that the conceptual understanding of electrostatics was improved compared to the result found in the control group.

The study recommends physics teachers to use PhET simulation to teach some abstract concepts like electrostatics to improve the conceptual understanding of students and Teachers should create an environment, where the students can learn difficult concepts with the help of PhET simulation to motivate and engage the students for better conceptual understanding of that concept.

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Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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