The Effects of PhET Interactive Simulation Activities on Secondary School Students' Physics Achievement

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List of tables

Table 4.1. Comparison of Pre-test and Post-test Performance 37
Table 4.3. Independent Samples t-test 39
Table 4.4. Paired samples T-Test 40
Table 4.5. Shapiro–Wilk Test for Normality 41
Table 4.6. Homogeneity of variances test 43
Table 4.7. Interpretation of the ANCOVA Model 45

Table of contents

Abstract iii
Аннотация iv
Аңдатпа v
1. Introduction 6
1.1 Background of the study 6
1.2 Importance of the Study 9
1.3 Statement of the Problem 12
1.3.1 The Cognitive Barrier of Abstraction and Mental Model Failure 13
1.3.2 The "Formula-to-Logic" Disconnect 13
1.3.3 Pedagogical Stagnation and the Passive Learning Trap 13
1.3.4 "Cognitive Noise" in the Customary Laboratory 14
1.3.5 Stability of Conceptual Misunderstandings 14
1.3.6 The Implementation and Contextual Research Gap 14
1.4 Study Objectives 15
1.5 Research Questions 15
1.6 Research Hypotheses 16
1.7 Contribution of the Study 16
2. Literature review 20
2.1 Theoretical Framework 20
2.2 PhET Interactive Simulations in Physics Education 21
2.3 Physics Education Challenges 22
2.4 Empirical Studies of PhET Simulation Use 24
2.5 Virtual Laboratories versus Physical Laboratories 25
2.6 Impact on student engagement, motivation and attitudes. 25
2.7 Determinants of the Simulations' Effectiveness 27
2.8 Research Gap 29
3. Methodology 30
3.1 Research Design 30
3.2 Participants and Sampling 30
3.3 Instructional materials and tools 32

3.4 Physics Achievement Test 33
3.5 Reliability and Validity of the Instrument 33
3.6 Data Analysis 35
4. Analysis and Results 37
4.1 Foundational Data Presentation and Visualization 37
4.2 Descriptive Statistics and Distribution Analysis 38
4.3 Inferential Analysis 39
4.3.1 Impact of the t-statistic and p-value 40
4.4. Paired samples T-Test 40
4.5 Normality Test 41
4.6. Levene's Test 43
4.7 ANCOVA 45
4.8 Correlation Analysis 47
5. Discussion 49
5.1 Interpretation of Key Findings 49
5.2 Comparison with Previous Research 50
5.3 Theoretical Implications 52
5.4 Practical Implications 52
5.5 Relevance to the Kazakhstan Context 53
6. Limitations 54
6.1 Sample Size and Generalizability 54
6.2 Research Design Constraints 54
6.3 Duration of the Intervention 54
6.4 Focus on Academic Achievement 55
6.5 Technological and contextual factors 55
6.6 Novelty Effect 55
7.Conclusion 58
References 60
APPENDIX A 64
APPENDIX B 70

Abstract

PhET Interactive Simulations refer to digital learning technologies extensively used to educate students regarding science theories using a highly engaging approach. In this research, the effects of the use of PhET interactive simulation-based teaching on the academic performance of secondary school students' in physics were investigated. A quasi-experimental research design was adopted with an experimental and a control group for each of the three participating schools. Ninety-six participants from the eighth grade were sampled for this study. The instrument was found to be reliable (Cronbach's $\alpha = 0.87$). Descriptive statistics, Shapiro-Wilk, independent samples t-test, and ANCOVA were conducted to analyze data.

The findings revealed that the mean score in the post-test was significantly higher for the experimental group than that of the control group (EG: $M = 10.40$, $SD = 2.75$; CG: $M = 7.35$, $SD = 3.06$). The independent samples t-test also showed that there was a significant difference between the post-test scores ($t = -5.12$, $p < .001$, Cohen's $d = -1.045$), indicating large effect size due to the use of PhET simulations-based teaching approach. Similarly, ANCOVA results revealed a significant influence of the intervention ($F = 23.9$, $p < .001$).

Based on the above analysis, the findings suggest that the use of PhET interactive simulation-based learning is more effective than traditional teaching method.

Аннотация

Интерактивные симуляции PhET — это цифровые образовательные технологии, широко используемые для обучения студентов научным теориям с помощью увлекательного подхода. В данном исследовании изучалось влияние использования интерактивных симуляций PhET на успеваемость учащихся средних школ по физике. Была применена квазиэкспериментальная схема исследования с экспериментальной и контрольной группами для каждой из трех участвующих школ. В исследовании приняли участие 96 человек из восьмого класса. Инструмент оказался надежным (коэффициент альфа Кронбаха = 0.87). Для анализа данных были проведены описательная статистика, тест Шапиро-Уилка, t-критерий для независимых выборок и ANCOVA.

Результаты показали, что средний балл в пост-тесте был значительно выше в экспериментальной группе, чем в контрольной группе (ЭГ: M = 10.40, SD = 2.75; КГ: M = 7.35, SD = 3.06). Независимый t-тест для двух выборок также показал значительную разницу между результатами пост-теста ($t = -5.12$, $p < 0.001$, коэффициент Коэна $d = -1.045$), что указывает на большой размер эффекта, обусловленный использованием подхода к обучению на основе симуляций PhET. Аналогично, результаты ANCOVA выявили значительное влияние вмешательства ($F = 23.9$, $p < 0.001$).

На основании вышеизложенного анализа можно сделать вывод, что использование интерактивного обучения на основе симуляций PhET более эффективно, чем традиционные методы обучения.

Аңдатпа

PhET интерактивті модельдеулері оқушыларды ғылыми теориялар туралы өте қызықты тәсілді қолдана отырып оқыту үшін кеңінен қолданылатын сандық оқыту технологияларын білдіреді. Бұл зерттеуде PhET интерактивті модельдеуге негізделген оқытуды қолданудың орта мектеп оқушыларының физика пәнінен оқу үлгеріміне әсері зерттелді. Қатысушы үш мектептің әрқайсысы үшін эксперименттік және бақылау тобымен квазиэксперименттік зерттеу дизайны қабылданды. Бұл зерттеу үшін сегізінші сыныптан тоқсан алты қатысушы іріктелді. Құрал сенімді болып шықты (Кронбахтың α = 0.87). Деректерді талдау үшін сипаттамалық статистика, Шапиро-Уилк, тәуелсіз үлгілердің t-тесті және ANCOVA жүргізілді.

Зерттеу нәтижелері тесттен кейінгі орташа балл эксперименттік топ үшін бақылау тобына қарағанда айтарлықтай жоғары екенін көрсетті (EG: M = 10.40, SD = 2.75; CG: M = 7.35, SD = 3.06). Тәуелсіз үлгілердің t-тестісі тесттен кейінгі ұпайлар арасында айтарлықтай айырмашылық бар екенін көрсетті ($t = -5.12$, $p < .001$, Коэннің $d = -1.045$), бұл PhET модельдеуге негізделген оқыту тәсілін қолдану салдарынан үлкен әсер мөлшерін көрсетеді. Сол сияқты, ANCOVA нәтижелері араласудың айтарлықтай әсерін көрсетті ($F = 23.9$, $p < .001$).

Жоғарыда келтірілген талдауға сүйене отырып, нәтижелер PhET интерактивті модельдеуге негізделген оқытуды қолдану дәстүрлі оқыту әдісіне қарағанда тиімдірек екенін көрсетеді.

1. Introduction

1.1 Background of the study

Physics, as one of the main sciences, plays an important role in fostering analytical skills and the ability to solve problems scientifically. The science provides the fundamental laws of nature and serves as an essential driving force behind technological inventions and innovations. Despite being an integral part of the curriculum of the secondary education system, physics is commonly perceived as a difficult subject because of its abstractness and the way it uses mathematical models. One of the major problems that a number of students encounter when studying physics is the ability to link mathematical symbols to corresponding physical processes and phenomena, which results in a conceptual gap – the ability to deal with mathematical formulations, but not necessarily understand the meaning behind them (Redish, 2006).

A notable area that has proved difficult for learners and instructors includes electricity and electrostatics. Whereas mechanics entails macroscopic properties such as motion, force, which are observable in real life, electricity is made up of microscopic events that cannot be seen, but are theoretical. This makes students develop misconceptions about electricity such as assuming that the electric current used in circuits gets consumed by the components of the circuit contrary to the fact that electrical current is conserved in a closed circuit (Engelhardt&Beichner, 2004; Küçüközer&Kocakülah, 2007). The same problems have been associated with learning electrostatics whereby learners fail to comprehend theories on charge interactions, electric fields, and charge distribution (Başer&Geban, 2007).

Research carried out within the scope of physics education indicates that many teaching methods used in teaching physics continue to be passive in nature, where lectures and the memorization of formulas prevail over actual active conceptual engagement (Freeman et al., 2014; Deslauriers et al., 2019). On the other hand, it has been shown that interactive technologies such as computer simulations are useful in

promoting active learning. Conventional laboratory instructions in physics classes may suffer from some limitations such as limited time periods and limited availability of necessary materials. This leads to the fact that conceptual understanding cannot take place due to the necessity of following procedures.

Another common simulation program that can be utilized in teaching and learning physics is PhET Interactive Simulations created at the University of Colorado Boulder. These simulations have been created using evidence-based guidelines for inquiry-based learning, and thus enable students to understand science concepts via interactive experimentation and visualization (Wieman et al., 2010). Several studies have reported the effectiveness of simulation-based learning environments like PhET, which facilitate better conceptual understanding of the subject by lowering the cognitive load related to handling equipment (Finkelstein et al., 2005; Perkins et al., 2016).

Conversely, studies conducted on virtual and computerized laboratory settings indicate that such settings may lessen procedural distractions and enable the learners to concentrate more on concept-based thinking and reasoning. A meta-analysis by Brinson (2015) found that virtual laboratories are at least as effective as traditional hands-on laboratories for developing conceptual understanding in many physics contexts, and in some cases can enhance learning outcomes.

There has been a strong emphasis on the potential of technology-improved learning approaches, and an emphasis on the use of interactive digital technologies, such as computer-based simulations, to support the critical link for students from abstract theoretical concepts to their practical deployment. Tools such as these allow students to visualize and manipulate the variables at play as well as immediately see the effects and implications of their actions, providing students with active and meaningful learning experiences. One of the most widely used examples is PhET Interactive Simulations from the University of Colorado Boulder (Carl E. Wieman, Wendy K. Adams, and Katherine K. Perkins et al., 2008). PhET simulations are

designed based on inquiry-based learning, where students run interactive experiments to help them understand scientific concepts.

Multiple studies in educational research have shown the effectiveness of PhET simulations, including Eleo and Manguilimotan (2024), who found that Grade 11 students taught using PhET interactive simulations achieved significantly higher post-test Physics scores compared to those taught using conventional methods in a quasi-experimental study involving 60 students. The study further reported a significant difference in mean gain scores between the experimental and control groups, indicating that PhET-based instruction was more effective than traditional teaching approaches in improving students' Physics performance (Eleo&Manguilimotan, 2024).

A quasi-experimental study on Malawian secondary school students examined the impact of PhET simulation-based learning on motivation and academic achievement. Results showed a significant improvement in post-test achievement for the PhET group compared to the control group. Further analysis indicated that the improvement was not due to student background characteristics but was attributed to the PhET intervention ($p < 0.01$). Motivation also improved significantly, including self-efficacy, active learning strategies, and attitudes toward computer-based learning. Overall, the study concluded that PhET simulations enhance both conceptual understanding and motivation by providing interactive visualizations of abstract physics concepts. (Banda &Nzabahimana, 2022).

Simulation-based learning is associated with the constructivist learning theory, where active learning helps learners to engage and develop knowledge through the testing of hypotheses in a safe environment. PhET simulations contain animated diagrams that visualize the moving electrons, with the use of a "dual-coded" approach, reducing the cognitive load on the learner (Wieman et al. (2010)). Beyond academic performance, the simulations also provide students with a "positive meaning". A study on the effectiveness of interactive simulations in 2023 indicated

that they increase students' motivation for STEM subjects and a positive perception, based on the experience of using the simulation (Hamamous&Benjelloun, 2023).

These advantages have not translated into common use of simulations in education. This has been attributed to lack of teacher training, the failure to integrate simulations into a wider program, and some evidence that simulation effectiveness is subject to the design of the lesson. Improvement may not be statistically important if the students do not receive appropriate teacher guidance (Jayanagara&Lukita, 2023). Many schools in Kazakhstan do not have physical laboratories. Virtual labs provide a way to overcome this barrier and improve the quality of physics education in Kazakhstan in a cost-effective manner.

Therefore, this study aims at investigating the effectiveness of PhET interactive simulation activities on secondary school students' physics achievement, by comparing simulation-based instruction and customary physics instruction, and provide empirical evidence concerning the effectiveness of technology-based learning in improving students' academic achievement and conceptual understanding of physics (Najib et al., 2022).

1.2 Importance of the Study

Improving the quality of physics instruction by the use of effective technology-improved instruction should be the key concern. This will be a contribution to theory and practice, as it investigates the effect of PhET Interactive Simulations on secondary school students' academic achievement, conceptual understanding, and motivation, a problem that has been addressed in the literature. Learning physics in abstract domains like electricity and electrostatics continues to generate important challenges for students in terms of learning difficulties, lack of logical thinking, misconceptions, low achievement, and low motivation (Uwambajimana et al., 2023).

The study provides important implications to students for learning, as there seems to be a discrepancy between students' procedural knowledge and conceptual understanding in learning physics, wherein students tend to use equations and computational skills without comprehending the underlying physics concepts, hence

resulting in superficial learning outcomes (Redish, 2017). Based on virtual labs like PhET, simulations allow for visualization and manipulation of physical phenomena, which may support improved conceptual understanding and reduction of misconceptions (Wieman et al., 2010).

Research shows that students' academic achievements and conceptual understanding are considerably improved by simulation-based instruction (SBI) compared to conventional instruction (Banda &Nzabahimana, 2021; Uwambajimana et al., 2023). Research also shows the use of interactive simulations improves students' attitudes toward the learning of physics, which considerably improves students' academic achievement, as well as their motivation to learn, engagement, and interest. Thus, this study contributes to the improvement of students' learning experiences by validating simulation-based approaches to address the problems.

This study also contributes to the field of pedagogical research by providing recommendations for the effective pedagogical practices for implementing technology-improved instructional models in physics education compared to conventional pedagogical practices based on lectures and textbook-based explanations.

The effectiveness of simulations may depend more on the pedagogy used to implement the simulation than its technology. Results indicate that guided inquiry instruction, where the teacher provides guidance to students, increases the effectiveness of a simulation in the classroom (Najib et al., 2022). This study additionally corroborated these findings, with PhET simulations driving improved student achievement and engagement during teaching and learning activities.

Simulation-based learning can also help overcome some logistical limitations of the customary laboratory such as a lack of equipment or technical failure, allowing teachers to spend more time on conceptual and inquiry-based questions. Therefore, the findings can help teachers find evidence-based implementation strategies for these topics.

Another implication of the study at the institutional level underscores the need for incorporating digital technologies into the teaching and learning process when schools have limited laboratory resources and modern instructional facilities, especially in resource-constrained environments.

The use of interactive simulations is considered a cost-effective alternative to using the laboratory. This allows students to experience the laboratory environment and experiment with materials without the need for costly laboratory equipment. Some studies report that simulation-based learning environments may lead to equivalent or better learning outcomes than physical laboratories when implemented correctly.

Thus, this study recommends that simulation-based learning can be used to improve the quality of physics learning in various contexts of schools in the future.

These findings have implications for educational policy and curriculum development as systems across the world become digitally oriented, and experimental evidence of the proper manner in which to integrate technology within the process of education is needed.

A series of meta-analyzes have shown a highly important overall positive effect of simulation-based education on student learning outcomes, with many of the studies in the meta-analyzes reporting large effect sizes (Fadillah et al., 2026), suggesting the importance of using tools such as PhET simulations for student learning.

Furthermore, the study highlighted the importance of professional development programs to provide teachers with the necessary skills and knowledge to implement technology-improved instruction effectively, as their lack of training and support would obstruct the realization of the advantages offered by using simulations (Chazbeck&Ayoubi, 2018).

Contributions. This work contributes to the growing body of empirical technology-improved learning research that remains locally relevant, and context sensitive. There have been studies looking at the use of PhET computer simulations,

but there is a need for research using secondary school students, with a specific physics topic such as electricity.

To address these issues, this study focuses on academic achievement and conceptual understanding as cognitive outcomes, as well as students' engagement and motivation as affective outcomes. Furthermore, a quasi-experimental design and statistical analysis techniques (such as t-tests and ANCOVA) will be employed to increase the validity and reliability of the results.

Furthermore, the study also supports the constructivist learning theory that active learning in simulation-based environments encourages the construction of knowledge and conceptual understanding (Almadrones&Tadifa, 2024).

The above mentioned conclusions drawn from the results of the investigation have been proved by theory and empirical evidences to be a strong basis for the implementation of interactive simulations as an efficient means of teaching physics that improves academic achievement and contributes to better understanding of concepts and student motivation to learn. This study’s results are also significant concerning filling the gap between theory and practice by offering pedagogical insights for teachers and policy makers. Furthermore, they can serve as the point of departure for further research in the field.

1.3 Statement of the Problem

While considered the fundamental branch of STEM learning, students all over the world face problems understanding basic physics principles. This research aims to address the issue of failure of existing educational techniques in bridging the gap between physics explained by experts and students' understanding of physics. More specifically, the issue can be seen in electricity and electrostatics, whereby the invisible phenomenon of electric fields, voltage differences, and electrical charges create cognitive problems that are hardly covered by existing teaching methods (Hamamous&Benjelloun, 2022).

1.3.1 The Cognitive Barrier of Abstraction and Mental Model Failure

Since phenomena may not always be observed, physics puts a lot of stress on creating an exact scientific representation of concepts in science. As one example, in secondary school students are supposed to imagine the motions of subatomic particles and transfer of unseen energy. Without dynamic imagination, students often resort to adopting "naive" theories or shallow understandings of these subjects, resulting in perpetual underperformance and lack of interest. This could be due to the fact that without linking the abstract to the concrete via visualization, students cannot form cohesive ideas.

1.3.2 The "Formula-to-Logic" Disconnect

Procedural versus conceptual understanding is one of the most serious issues in the field of physics education. Many physics classes at secondary educational institutions have become merely about doing mathematics, in which the students use formulas that they have memorized, such as Ohm's law, to calculate numbers for problems related to electric circuits (Redish, 2006). The students can do the calculations to find out the answers, but they lack the ability to describe what happens to an electric circuit when its components are changed. For instance, the students may calculate the value of total resistance, but cannot provide explanations on why adding a bulb in parallel would increase the total current taken from the battery (Engelhardt & Beichner, 2004). In other words, being able to do physics means being skilled in mathematics rather than having conceptual knowledge.

1.3.3 Pedagogical Stagnation and the Passive Learning Trap

Even though constructivism dominates education systems throughout the world, the form of teaching in most schools is based on lectures and results in passive learning where learners become mere receivers of knowledge rather than constructors of knowledge (Najib et al., 2022). Consequently, there is a disjunction between theoretical assumptions of education and educational reality since passive education discourages inquiry and discovery, results in rote learning needed for the exam, and makes learners forget what was learned (Wieman et al., 2010). The difficulty with

understanding formulas as recipes and the lack of interactive learning environments block critical and higher-level thinking skills development.

1.3.4 "Cognitive Noise" in the Customary Laboratory

Experimentation should be used theoretically to shed more light on physical concepts; however, in practice, the success of the experiments may be compromised due to limited finances, time, and inadequate or faulty equipment. Not all institutions have laboratories that are well equipped for experimentation. Even when equipment is available, students may experience cognitive overload caused by technical difficulties such as faulty multimeters, loose connections, or unstable power sources. As a result, students often focus more on making the equipment function properly rather than understanding the underlying physics concepts, which reduces the instructional value of the laboratory activity (Hofstein&Lunetta, 2004). This shift in attention can interfere with conceptual learning and reduce students' ability to meaningfully interpret experimental results.

1.3.5 Stability of Conceptual Misunderstandings

A further topic is that of misconceptions about physical phenomena. For example, students have a tendency to hold a 'consumption model' of current in which a bulb uses up current, or they think that batteries always provide a constant current no matter how much resistance exists in a circuit. Research suggests that these misconceptions are resilient to textbook diagrams and even verbal descriptions, and persist through a student's entire schooling, unless the student is given a tool which provides real-time visual evidence of conservation laws (Wieman, 2010.).

1.3.6 The Implementation and Contextual Research Gap

Despite such potential, there are still challenges regarding the implementation of PhET Interactive Simulations into the classroom (Wieman et al., 2008), and there are also gaps in terms of the design of teaching in that many simulations are implemented without appropriate scaffolding or structured inquiry tasks, limiting their effectiveness (Jayanagara&Lukita, 2023). Also, there are few context-based

empirical studies carried out at the secondary school level in the context of Kazakhstan, which shed light on the affective achievements (i.e. motivation, engagement, and retaining interest) that go hand in hand with cognitive learning outcomes (i.e. achievement) (Hamamous& Benjelloun, 2022).

In sum, the problem addressed in this paper is whether or not systematic use of PhET interactive simulations and guided by structured inquiry can reduce the cognitive gap, overcome secured misconceptions, and achieve better academic performance and affective attractiveness for secondary school students, compared to the customary lecture method (Najib et al., 2022). The study also focuses on overcoming the cognitive failures and pedagogical shortcomings, to provide an evidence-based framework for making changes to how physics is taught (Najib et al., 2022).

1.4 Study Objectives

This study aims at discovering the effect of the use of the PhET interactive simulations on secondary school students' achievement in physics by asking:

1. Comparing the academic performances of students taught with PhET simulations versus those taught with regular demonstration methods.

2. Investigate whether students' conceptions of electric circuits are altered following the intervention.

3. Evaluate the practicality of free digital simulation platforms as a high-quality, cost-effective solution for schools experiencing physical laboratory equipment shortages.

1.5 Research Questions

This section lists the research questions for the empirical investigation and the null and alternative hypotheses. They are based on the theoretical framework and the literature review. The following research questions were formulated in order to achieve the goals of this study:

RQ1: Is there a statistically meaningful difference between the post-test achievement scores of the experimental group and the control group?

RQ2: To what extent is it helpful for students to utilize PhET simulations to enhance their problem-solving skills for conceptual questions about current and voltage?

RQ3: How well can virtual simulation tools be incorporated into the current physics syllabus at the secondary school level, owing to a lack of physical laboratory facilities?

1.6 Research Hypotheses

H_0: The academic achievement and concept understanding of physics students taught using PhET simulations do not differ considerably from their counterparts instructed using customary methods.

H_1: Students taught using PhET interactive simulations will have statistically considerably higher academic achievement and more positive attitudes toward physics than a customary control group.

1.7 Contribution of the Study

The study contributes to the field of Physics Pedagogy and Technology Improved Learning (TEL) research as an empirical, theoretical, methodological and practical piece of work. The study seeks to explore the impact of PhET Interactive Simulations on secondary school students' academic achievement and supplement previous research with context-specific information on simulation-based learning to advance the understanding of educational simulations.

First, this study contributes to the empirical literature in the domain of physics education by providing context-specific evidence on the effectiveness of simulation-based pedagogical intervention in secondary school physics. This is important to note because some studies have shown a positive influence of PhET simulations on students' learning outcomes (Banda &Nzabahimana, 2021; Uwambajimana et al., 2023), but context-specific studies are lacking.

The study utilizes a quasi-experimental research design utilizing customary teaching as a control group and simulation-based teaching as the experimental group. The pre-test post-test design and inferential statistics (independent samples t-tests and Analysis of Covariance) are used to control for confounding variables and improve the internal validity of the study. This is consistent with previous research that recommends controlling for prior knowledge when comparing educational interventions with different content (Najib et al., 2022).

Second, this study contributes to the theoretical development of constructivist learning theory in technology-supported physics education. Constructivist learning theory states that learners construct new knowledge through the process of engaging, exploring and experiencing (Almadrones&Tadifa, 2024).

The results from this study also concluded that interactive simulations promote active learning by allowing students to manipulate variables, observe outcomes, and develop understanding through inquiry-based learning activities. This finding is consistent with other studies that have also shown that simulation-based instruction is effective in promoting concept learning, especially in difficult-to-understand concepts such as electricity and electrostatics (Tuyizere& Yadav, 2023).

The second contribution is to the conceptual change literature by showing how students can overcome misconceptions by visualizing and experiencing simulations to promote in-depth processing of information.

Third, the research contributes to methodological innovation in the field through the use of a mixed-methods approach in which quantitative and qualitative data are reported and considered. Unlike many studies that report only quantitative findings, data were collected on many fronts, including academic achievement, classroom observations, and student voices and experiences.

This approach allows capturing the complete effect of the simulation-based learning intervention. This is achieved by measuring the impact on both cognitive outcomes (achievement and conceptual understanding) and affective outcomes (engagement and motivation). Additionally, the use of advanced statistical methods

(e.g., ANCOVA) helps to control for pre-existing group differences and further improve the rigor of the results (Fadillah et al., 2026).

Fourth, the study suggests evidence-based recommendations from the results about effective teaching practices for educators. It is important to recognize that it is not just the technology but how simulation-based learning is being used in the classroom that contributes to its effectiveness (Najib et al., 2022).

This study supports previous research stating that structured and guided use of PhET simulations can lead to positive student outcomes, such as increased interest, participation, and academic achievement. Incorporating instructional support in the form of guided worksheets and inquiry-based assignments can elicit favorable outcomes.

A second benefit of simulation learning is overcoming logistical issues that may be present in the customary laboratory-based learning environments, such as resource limitations and technical difficulties.

Finally, the conclusions drawn can affect the policies concerning curriculum design. Since there is a great drive toward increasing the role of new technology in education, there is also a need for innovative pedagogic methods.

Meta-analyses concerning the effects of simulation on learning outcomes for students give strong support to the positive effects of using simulation in education, as proved by the results obtained in the study, which have yielded significant effect sizes (Fadillah et al., 2026). Consequently, this research will contribute to the existing body of knowledge on simulation efficacy as part of the process of planning educational programs.

Moreover, this research proves that teacher preparation and professional development should be equally emphasized, since pedagogical skills are no less important than technology access (Chazbeck&Ayoubi, 2018).

Contribution to the Academic Community and Future Research can add in general to the existing body of research related to the use of simulations in schools. Since the scope of research thus far conducted in this area is restricted to university

classes or general results, the study in question would provide a deeper understanding of electricity classes in high school.

The present study will also lay foundations for future studies concerning the use of simulation instruction; especially in relation to long-term memory acquisition and skill development. In this respect, further research can extend the findings of the current study by conducting research in the area of effectiveness of other teaching models, and using other subjects.

On a whole, this research is valuable academically speaking due to its empirical, theoretical, methodological and practical contributions. Particularly, it has been of importance to the study of simulation-assisted learning which is an efficient learning strategy in order to enhance academic success and conceptual knowledge acquisition in physics.

This research bridges the gap between theory and practice by providing empirical grounds for developing more effective and student-centered teaching methods.

2. Literature review

2.1 Theoretical Framework

The theoretical learning framework that acted as a foundation of this study was Constructivist Learning Theory, particularly as described by Jean Piaget and Lev Vygotsky. The constructivist perspective holds that learners construct knowledge through active engagement with the social and physical environments around them, rather than through passive acquisition from the teacher. In a physics context this means students learn better when they actively engage with ideas through exploration and inquiry rather than relying on rote memorization and passive listening.

Many physics concepts, such as current and resistance, are not directly observable. Piaget considered that learners must actively explore their environment and reorganize their cognitive structures in order to develop. When considering Vygotsky's theory of learning, which stresses guided learning and scaffolding through social interaction, interactive simulations can then help support learners' conceptual growth by providing opportunities for scaffolding, during which students receive guidance or support during their learning process.

When the PhET Interactive Simulations are used in the classroom, they can provide constructivist learning opportunities: students are able to manipulate different variables, test hypotheses and get immediate feedback, allowing them to build their own knowledge and refine their mental models. It has been shown in previous research that guided simulation-based activities can considerably impact learning as they transform the student from a passive learner to an active investigator (Najib et al., 2022; Wieman et al., 2010).

Another important theoretical framework that informs this research is the Cognitive Theory of Multimedia Learning presented by Mayer. This model holds that people acquire knowledge using two principal channels: a visual channel and a verbal channel. The combination of the two in an equally balanced manner contributes to successful learning since it does not overwhelm the individual cognitively (Mayer, 2009).

Instruction in most physics classrooms relies mainly on verbal instruction and symbols. This approach often leads to overloading students' minds with the material taught. However, the use of a multimedia approach to learning, such as PhET, involves the use of visuals and interaction. It means that learners can read about something, see images, or interact with objects in real-time. Students who learn the concept of electric currents through PhET can read about the topic and see a demonstration of electrons flowing within a circuit.

Sweller's theory of cognitive load further supports this point of view. According to Sweller (2011), learning is better performed when instructional materials enable individuals to focus their minds on what needs to be learned by reducing other mental activities. As a result, simulations reduce unnecessary cognitive load by making processes visible and presenting feedback that makes sense instantly. Therefore, the success of PhET can be attributed to its ability to promote cognitive processing.

2.2 PhET Interactive Simulations in Physics Education

PhET Interactive Simulations (University of Colorado Boulder) are one of the most widely used online learning tools, aimed at improving students' learning of science concepts with interactive, visual and inquiry-based approaches (Perkins et al., 2006).

PhET simulations are based on physics education research and cognitive research to address common student misconceptions, support the development of conceptual understanding, and promote active student engagement. With the PhET simulations, students manipulate the variables they can control, see instantaneous results, and develop an understanding of cause and effect, not just memorizing information.

One of the major advantages of PhET is to make the invisible visible. For example, in electricity, students can visualize how charges move, how the electric field behaves, and how changing the resistance affects the current. This makes the

simulations especially valuable for teaching topics that are not easily visualized through other means.

Research has shown that the use of PhET simulations improves student learning for science and physics concepts. Perkins et al. (2006) found that students in the PhET treatment group had a greater understanding of the concepts than the control group because PhET encouraged exploration, engagement and guided inquiry. Wieman et al. (2010) also found that PhET simulations are particularly effective when used as part of a guided learning exercise rather than alone.

2.3 Physics Education Challenges

Teaching physics at schools may be quite difficult; for example, students find physics difficult to study as it deals with processes that cannot be seen and with abstract relationships. In the case of electricity, learners are required to study phenomena that are invisible to them and that are represented mathematically. This may cause misconceptions and a lack of motivation and poor achievement.

Research indicates that customary lecture instruction tends towards rote memorization, which means that students might able to use the appropriate formulas and perform the steps to get to a solution without fully understanding the underlying rationale. McDermott and Redish (1999) pointed out that many students solve problems in a physics course, but do not explain the importance of their answer. This apparent dissociation of procedural from conceptual knowledge is one of the fundamental problems in physics education.

Limited access to laboratory equipment and experimentation may exacerbate the issue, where learners in schools where supplies are limited do not have opportunities to test their ideas and apply their theoretical knowledge to real-world scenarios. This lack of experience reinforces the lack of understanding and of problem solving.

The challenges indicate that there are important teaching practices that involve engaging in visualization, active learning and inquiry, and as such, technology-improved learning environments such as the PhET simulations provide an effective

means of creating the sort of conditions in which students can grapple with complex physical ideas.

Electricity is one of the most commonly misunderstood topics in physics and there have been multiple studies that show common student conceptions such as: that electric current becomes depleted as it moves through a circuit, that batteries provide a constant current regardless of the resistance, and that voltage and current are the same (McDermott & Redish, 1999).

It becomes hard to change these misconceptions since they come from mental models which seem natural to humans but are wrong, as well as since conventional teaching methods often do not allow learners to verify their assumptions against the truth effectively.

Thus, the introduction of PhET simulations into physics education in Kazakhstan does not solely constitute a practical means of overcoming the resource problem; it is rather a step towards alignment with country-specific national educational requirements. As has been mentioned above, science education in Kazakhstan puts emphasis on the development of literacy, problem-solving skills, and critical thinking. All these values are reflected in PhET simulations.

In addition, the use of simulations is consistent with the curriculum goals of promoting inquiry-based education and connecting theory with practice. With the help of interactive simulations, educators will be able to create an interesting and engaging learning environment to facilitate understanding of physics phenomena and prepare students for future studies and career opportunities.

Thus, it is obvious that introducing physics education in Grade 8 in Kazakhstan will contribute to the enhancement of students' scientific literacy and problem-solving skills. However, some issues are associated with the process, namely, the abstract nature of some physics concepts and lack of uniformity in educational resources across schools. To solve these problems, one should introduce interactive simulations into physics education.

The use of simulation-based learning can also be used to promote conceptual change by having learners alter their original conceptualization based on the result obtained through simulation, which contradicts their previous predictions. The misunderstanding held by learners that current is being utilized can easily be changed once learners notice that current does not change in a simple series circuit.

It has been found that conceptual change is much more possible in those learning situations that have visualization, collaboration, and inquiry embedded in them (de Jong & van Joolingen, 1998; Zacharia, 2007). Under such circumstances, use of PhET simulations becomes extremely useful because students are provided with visual images and means to get their predictions validated instantly.

2.4 Empirical Studies of PhET Simulation Use

Many studies have assessed the effectiveness of PhET simulations used in physics instruction. A systematic review of 31 experimental and quasi-experimental studies conducted by Banda and Nzabahimana (2021) concluded that PhET simulations had an overall positive effect on the students' academic achievement and conceptual understanding.

Banda et al. (2022) found that students who were taught with PhET simulations performed better than students who were taught with customary instruction in the topic of oscillations and waves, and also reported greater motivation, self-efficacy, and engagement with the topic.

Similar positive trends have also been found in relation to electrostatics. Uwambajimana et al. (2023) conducted a quasi-experimental study and found PhETsimulation_groups post-test scores to be considerably higher than customary instruction groups. The authors reported that the simulations helped students visualize phenomena like charge interactions and electric field lines.

Electricity: Wieman et al. (2010) found that using simulations improved students' understanding of energy-related concepts and their ability to read graphs, indicating that they are well-suited for studying electricity, particularly in conjunction with a module or guided learning.

Not all studies are positive: Jayanagara and Lukita (2023) note that the success of simulations can depend on the quality of the instruction delivered and the extent to which teacher mediates the experience. Likewise Najib et al. (2022) proposed that technology alone does not make a successful learning experience as simulation based learning is effective once the pedagogy aligns alongside the simulation.

2.5 Virtual Laboratories versus Physical Laboratories

Not all sources consider the virtual laboratory a replacement for the real laboratory, where students are given 'hands-on experience' with equipment and materials. Use of the real laboratory may be restricted by problems of equipment shortages, safety, time constraints and other technical issues.

Advantages of virtual laboratory simulations include prompt feedback, unlimited repeats, lower technical barriers, and opportunities to investigate phenomena quickly and safely. In this context, learning may be focused on reasoning scientifically rather than troubleshooting equipment.

Finkelstein et al. (2005) found that students develop a better conceptual understanding when engaged in simulation activities compared with customary laboratory, and Zacharia and Olympiou (2011) found laboratory experiences were better received by students when preceded by virtual experiences compared with a laboratory-only group. Additional studies suggest that virtual laboratories could be considered as complementary to physical laboratories, rather than alternatives for instruction.

2.6 Impact on student engagement, motivation and attitudes.

Simulation-based learning contributes to positive affective outcomes. Students engaged in simulation-based learning have been seen to be more motivated, interested, and engaged. Students report feeling more involved with their education, finding the material presented in simulations to be more engaging and interesting. Wieman et al. (2010) found simulation instruction positively impacted students' views of physics, and that students were more interested in an active role in their

learning. Active student engagement is important for persistence, deeper learning, and interest in STEM fields.In addition, simulations can foster confidence in students because it is possible to try out different values of a parameter in a safe environment without fear of making a mistake that cannot be undone. This is especially true of electricity and electrostatics.

A recent quasi-experimental study investigated the impact of PhET simulation-based learning on students' motivation and academic achievement in learning oscillations and waves among Malawian secondary school students. The research focused on answering research questions about the motivation and achievement level of students at baseline, the impact of the PhET-based intervention on post-test results, and whether any differences could be attributed to individual student factors or the intervention. A sample of 280 Form Three students (44.6% females) with a mean age of 17.5 (SD = 1.424) from four secondary schools in Blantyre urban district was selected using a non-equivalent group design. The experimental group was taught using PhET Interactive Simulations, while the control group received conventional lecture-based instruction. (Banda, H., &Nzabahimana, J. (2022))

Data were collected using pre-test and post-test measures of academic achievement, together with questionnaires measuring motivational constructs. The independent samples t-test showed a significant difference in the post-test academic achievement scores of the experimental and control group subjects. Regression analysis also showed that the score differences in the post-tests were not influenced by the background factors of the students, but were significantly influenced by the instructional approach used ($p < 0.01$). In addition, ANCOVA results showed significant differences in the motivational constructs, including self-efficacy, active learning approach, achievement goal, learning environment stimulation, and computer learning attitude. (Banda, H., &Nzabahimana, J. (2022))

Overall, the findings suggest that PhET simulation-based instruction significantly improves both academic achievement and motivation in learning oscillations and waves. The study concludes that PhET simulations enhance learning

by providing interactive visualizations and dynamic representations that facilitate easier understanding of abstract physics concepts, thereby improving students' engagement and conceptual understanding.(Banda, H., &Nzabahimana, J. (2022))

2.7 Determinants of the Simulations' Effectiveness

According to studies on computer-mediated learning environments, there is evidence that these environments make considerable contributions to promoting conceptual knowledge as well as encouraging learners to actively participate in the learning process (De Jong & van Joolingen, 1998; Linn &Eylon, 2011). The use of interactive simulation allows learners to examine causality in situations that would otherwise be challenging to observe using traditional experimental methods (De Jong, 2006; Wieman, 2008). By combining interactive simulations with appropriate instructions, such as making predictions, observing outcomes, and receiving feedback, one can develop metacognition.

Based on the above mentioned perspectives, the present researchincorporates several theoretical frameworks to support the development of an instructional approach for use in promoting HOTS among participants. According toDe Jong's (2006) inquiry-based learning framework offersa theoretical orientation to guide learners through a gradual shift from guided teacher assistance to self-directed student learning and reflection to foster active knowledge construction by learners. Moreover, Sweller (2011) emphasizes the significance of reducing extraneous cognitive load during instruction via use of visual aids, worked examples, and structured instruction to enhance schemata development among learners.

The current research focuses on understanding the need for an organized instructional strategy by identifying and testing a pathway for a well-defined problem chain that aims at fostering HOTS. The instructional strategy is based on inquiry-based learning along with the King et al. (1998) three-tiered HOTS model and hence qualifies as an effective instructional model.

While many studies show the benefits of using simulations for training, their efficiency largely depends on how they are used. According to research, better

outcomes are achieved when simulations are incorporated into a planned lesson instead of being used casually (De Jong, 2006). The ability to interact with variables gives learners the chance to see changes right away, thus facilitating a more profound understanding of the scientific concepts presented.

Moreover, computer simulations stimulate students' ability to link the acquired theoretical information to practice and think critically at the same time. Compared to conventional learning materials like text and pictures, interactive simulations usually result in better academic achievement because they actively involve learners in the process.

According to the literature review, there are different factors which affect the effectiveness of simulation-based learning. Some of these factors include the instructional design of the simulation itself, its context, and its intended purpose. For instance, studies have found out that simulations tend to produce more effective results when the learners undertake certain tasks in a guided manner compared to those who explore on their own.

Another factor is the need for proper facilitation by the instructor. This entails questioning by the instructor during the simulation process and making connections between the simulated situations and theoretical knowledge.

Third, the amount of knowledge the learner possesses before utilizing simulation software will have a major impact on their ability to extract meaningful information from simulations. The student that enters with prior knowledge and a solid grasp on the material will better understand and make sense of the outputs generated by simulations. The initial knowledge possessed by the learner will essentially place an upper limit on what the learner will be able to comprehend and utilize.

Ultimately, the involvement of the learner is a very important element. Interactive educational materials are known to be the most effective in cases where the learner participates actively in the process, becoming a participant of the process rather than just a recipient of the information presented.

2.8 Research Gap

Several key patterns deserve to be pointed out with regard to the current state of literature on the subject under consideration. First, despite the vastness of this literature, a rather small percentage of papers focuses specifically on Grade 8 learners or on electricity and electrostatics, which are the subject matters of this particular study. Second, most of the papers explore either cognitive effects or affective effects of the proposed approach without paying attention to both issues at once. Third, little research exists on situating the simulation learning in the realistic secondary school environment. Finally, studies applying such advanced statistical methods as ANCOVA are also scarce in this literature.

Considering the deficiencies found in the discipline, it appears prudent to focus on the following research problem. Specifically, this study aims at examining the effect that learning approaches using PhET simulation have on physics learning outcomes and student engagement levels.

3. Methodology

3.1 Research Design

The design used in this study was a quasi-experimental research design which employed a nonequivalent control group pre-test-post-test design with two groups, namely, an experimental and a control group. Both groups were pre-tested and post-tested to determine the effect of the instructional strategy on the students' academic achievement in the subject of physics.

The experimental group was taught using PhET Interactive Simulations-based activities while the control group was taught using customary lecture-based instruction. Random assignment of students was not possible as students were organized in intact classroom groups in the school. Accordingly, a quasi-experimental design was appropriate for study, as the investigation needed to take place within the context of real educational settings.

The research design provided a means for comparing learning from each of the instructional conditions and a better understanding of the effect of using simulation as a method of instruction. The use of a pre-test and post-test provided a means for assessing the intra-group improvement and the inter-group differences in academic achievement.

3.2 Participants and Sampling

The study population consisted of 96 Grade 8 students from three selected secondary schools. The study design consisted of an experimental group (n = 48) and a control group (n = 48). To ensure equivalence across groups at the baseline level, intact classroom groups were assigned based on age and prior semester physics achievement.

The experimental group (EG) was instructed in a computer media classroom, which would provide students with the opportunity to either work in pairs or work individually on PhET Interactive Simulations to actively engage in simulation-based learning activities as a part of instruction.

Control group (CG): Treatment (teacher presentation, textbook activity, and board presentation) as it had been used in typical instructional classes in this course.

The study used convenience sampling by using intact groups who were already in their natural school settings, as random assignment of students to groups is generally not possible in school settings due to grouping practices or other practical considerations. Intact groups were also used in order to improve the study's ecological validity by modeling classroom settings.

Secondary schools of Kazakhstan were targeted as the setting for the study, but the particular attention was paid to the institutions which placed an overt focus on scientific education and the STEM approach. Among the studied institutions, it is important to highlight the participation of the Bilim-Innovation Lyceums (BIL), Nurorda schools based in Almaty and Oskemen, and other similar private schools which provide quality training in physics and mathematics.

These choices were made due to the intent to introduce variation into the pool of participants through the variety of academic support provided, educational resources and the instructional environment offered. In particular, it should be noted that Bilim-Innovation Lyceums are famous for providing intensive education in science and math, while Nurorda schools offer structured education in physics with professional guidance and enriched environment.

Variation was important for the assessment of the impact of the use of PhET interactive simulations on the achievement of students in Physics class.

After assuming both groups were matched based on educational history (they were), both groups of students were pre-tested, with both groups being in the same grade learning the same physics curriculum. The pre-test was administered to test the students' prior knowledge and understanding of the physics concepts that the students would be tested on. Pre-test scores were also used to confirm that the groups were equivalent, and were included in the analysis of the results (an Analysis of Covariance), which controlled for differences between groups among the pre-test scores.

Students in both groups were taught by teachers with similar qualifications and years of teaching experience, in order to control for the influence of these characteristics on the measured outcomes, and thus to improve the chances that differences in student performance were mainly attributable to the kind of instruction they received.

The assignment and grouping of participants were administered in a way that preserved the internal validity and reliability of the study, while still being similar to an actual classroom.

3.3 Instructional materials and tools

The electronic and more customary teaching resources consisted of the material that could be used for teaching electrostatics, and for introduction into electricity. These were chosen as carefully as possible to be appropriate to the relevant school curriculum, and as similar as possible for the experimental and control groups.The following instructional materials were used:

- PhET Interactive Simulations, Charges and Fields, Balloons and Static Electricity
- Standard physics textbooks in accordance with the national curriculum (AstanaKitap)
- Structured worksheets and guided activity sheets for both groups
- Pre-test and post-test assessment instruments

In the experimental group, the PhET simulations were initially used as the main instructional tool to learn about the topic, whereby the students learned and interpreted the content via interactive visualizations and manipulating the variables to observe in real-time how different physical phenomena behave. This helped students understand cause-and-effect relationships and develop an understanding of abstract concepts such as electric charge, electric fields, and the interaction between charged particles. Using guided worksheets helped to ensure that students' exploration was focused and on-topic for the learning objectives of the class.

The control group was taught using customary techniques such as studying from a textbook, teacher explanation, and from the blackboard demonstration. Both groups were taught the same subject matter with the same cognitive objectives but in different ways. The experimental group (EG) received instruction in a more inquiry-based and student-centered manner while the control group (CG) was taught in a more teacher-centered manner.

3.4 Physics Achievement Test

In this study, the primary data collection instrument was a 30-item Physics Achievement Test, which was used to assess students' ability to explain electricity conceptually across multiple contexts.Assessment had included multiple choice, fill-in-the-blank, matching exercise, true/false and constructed responses. Items were adapted from existing tests and administered as a pre-and post-test. The test covered the following topics:

- Basics of electric current, voltage and resistance;
- Ohm's Law and its applications;
- Series and parallel circuit configurations;
- Power and energy in DC circuits;

The items were in multiple-choice format to increase objectivity and ease scoring, consistent with the curriculum and the different levels in Bloom's Taxonomy of understanding, application, and analysis. Using the same test for pre-test and post-test provided cognitive consistency, thus making comparisons of what students learned during the course of the intervention valid and meaningful.

3.5 Reliability and Validity of the Instrument

In addition, the instrument employed in the data collection was tested to ensure that it is reliable, valid, and credible.The items in the Physics Achievement Test (PAT) were validated for content by three trained physics teachers. Items were analyzed for alignment with the national curriculum, national learning objectives,

and the cognitive level according to Bloom's Taxonomy of Educational Objectives. Evaluators decided upon the following test criteria:

- Relevance to the curriculum
- Clarity of wording
- Appropriateness of difficulty level
- Concepts of key physics discussed

Further modifications were made based on the students' responses to the items to verify that the test instrument assessed conceptual mastery of the topics of electricity by the students fairly and accurately.

Furthermore, because the same instrument could be used for both pre-test and post-test purposes, measurement consistency could be ensured and growth in learning across the two students could be measured directly.

Applied two methods to estimate the reliability of the Physics Achievement Test to ensure robustness**: Pilot study and KR-20**

The test's internal consistency was measured in the pre-research project phase on a different group of students using Kuder-Richardson Formula 20 (KR-20), a reliability estimate which is appropriate for measuring internal consistency for tests that have dichotomous or multiple-choice items. The analysis produced a reliability coefficient of: ***KR-20 = 0.82***

A high value such as this indicates an acceptable level of internal consistency, with 0.70 being standard in educational research. The reliability of the measure was further assessed by calculating a Cronbach's alpha: $\boldsymbol{\alpha = 0.87}$. The finding also supports the instrument as a valid measure of students' academic achievement with respect to their physics knowledge.

Taken together, expert judgment and empirical reliability analyzes indicate that the test is a valid and reliable measure of students' academic achievement. It is the result of a systematic test construction that reflects a valid measure of students' conceptual understanding of electricity, electrostatics, and related phenomena.

Overall the systematization of the technique in this study shows that the data collection tool is reliable, valid and credible for the procedure used in the study.

3.6 Data Analysis

From the raw pre-test and post-test scores, a descriptive and inferential statistical analysis was conducted to determine whether there was an impact on their instructional strategy. Descriptive and inferential statistics were computed using the IBM SPSS Statistics Software, in order to be confident of the validity of the results.

On the basis of the data available, **descriptive statistics** (M and SD) were computed for the experimental and control group to present a summary of the students' performance on the pre-test and post-test. In addition to this, the overall academic achievement of the two groups was summarized.

Before inferential statistics were conducted, data were tested for normality using the **Shapiro-Wilk test**, as it has a high power to detect departures from normality in small- to moderate-sized samples. Where $p > 0.05$, the data followed a normal distribution, making the use of parametric statistical tests appropriate.

The research hypotheses were analyzed using several **inferential statistical tests**:

- To measure within-group difference, a paired-samples t-test was conducted between pre-test and post-test scores of control group and experimental group to show whether there is statistically meaningful difference in students' academic achievement in pre-test and post-test after instruction.
- An independent samples t-test was used to determine if the difference between the post-test scores of the experimental group and the control group was statistically meaningful, and whether the simulation-based instruction positively impacted the students' performance.
- Analysis of covariance (ANCOVA) was used as the main statistical procedure to account for initial group differences on the pre-test. Covariates (i.e., the pre-test scores) are incorporated to control for any

differences that may exist between groups prior to treatment, thereby providing a clearer estimate of the treatment effect on post-test scores.

To further assess the effectiveness of the intervention, **Hake's Normalized Gain (g)** was calculated using the following formula:

$$g=(Post\text{-}test-Pre\text{-}test)/(100-Pre\text{-}test) \quad (1)$$

Gain is defined as the ratio of measure improvement divided by the maximum possible improvement. A normalized gain of between 0.40 and 0.50 has been interpreted as a meaningful instructional effect for the experimental group.

The assessment instrument was also examined for its **reliability** by determining its internal consistency using the Cronbach's alpha (α) statistical test. An acceptable value of $\alpha \geq 0.70$ was used. The instrument was found to have a reliability coefficient high enough to measure students' academic achievement.

Statistical significance was obtained by determining a p value of less than 0.05, while effect size (Cohen's d) was used to describe the magnitude of differences between groups. Although p-value will indicate whether the difference is statistically meaningful, the effect size will indicate how important the result is from a practical point of view.

The results of this chapter are drawn from a four week quasi-experiment of the use of PhET Interactive Simulations in a Grade 8 science classroom. The quasi-experiment was designed to measure the impact of PhET Interactive Simulations on closing the "conceptual gap" in Grade 8 physics abstract domains of electrostatics. This path is descriptive and Independent Samples t-tests and Analysis of Covariance (ANCOVA) are conducted at the level of inference for the highest degree of statistical validity (Najib et al., 2022).

4. Analysis and Results

4.1 Foundational Data Presentation and Visualization

The primary data set consists of assessment scores from 96 students, equally divided into an Experimental Group (EG, n=48) and a Control Group (CG, n=48). Table 1 establishes the baseline and final achievement levels for both cohorts.

Table 4.1. Comparison of Pre-test and Post-test Performance

Test Stage	Group		Mean	Median	SD	SE
Pre-test	CG (Control)	48	4.60	4.50	1.84	0.266
	EG (Experimental)	48	5.38	6.00	1.38	0.199
Post-test	CG (Control)	48	7.35	7.00	3.06	0.442
	EG (Experimental)	48	10.40	11.00	2.75	0.397

Table 4.1 shows the stats for the control and experimental groups in both the pre-test and post-test phases, giving us what we need to compare them.One of the most important quasi-experimental validity threats is the equivalence of groups. As shown in Table 4.1, they also had similar pre-test CG (M = 4.71) and EG (M = 5.46) scores, which indicate that the two groups had an initially low level of understanding (Najib et al., 2022). This is consistent with other secondary physics studies that show numerous pre-existing misconceptions and a lack of prior knowledge in units such as electrostatics. The low pre-test scores indicate that the target material was indeed

difficult for the students and required wide-ranging re-conceptualization efforts (Najib et al., 2022).

4.2 Descriptive Statistics and Distribution Analysis

Following the intervention, the data reveals a marked divergence in learning trajectories. While both groups showed growth, the **Experimental Group's** achievement significantly outpaced that of the Control Group.

As presented in ***Table 4.1.***, the experimental group achieved a higher mean post-test score (M = 10.4, SD = 2.75) compared to the control group (M = 7.35, SD = 3.06). This indicates that students who were taught using PhET Interactive Simulations demonstrated better academic performance than those who received traditional instruction.

While there was some differences in the scores of both groups, as demonstrated by the lower standard deviation in the scores of the students within the experimental group, students in the experimental group generally performed more consistently than those in the control group, as shown by the lower standard deviation.

On the whole, the descriptive findings provide more evidence for the efficacy of simulation-based instruction in improving student learning in physics.

The EG achieved a post-test mean of **10.4 (SD = 2.75)**, whereas the CG achieved only **7.35 (SD = 3.06)**. This figure of 3.05 points is an essential indicator of the effect that the PhET simulation has on the students. In a curriculum where 14 points might represent the total possible score, this gain represents a substantial portion of the academic scale.

A noteworthy finding is the lower standard deviation in the Experimental Group (SD = 2.75) compared to the Control Group (SD = 3.06), meaning the results were more consistent with simulation-based instruction. In a non-interactive, lecture-based, customary environment, the individual student results were more variable; some students understood the material, but many did not. However, the visual and interactive scaffolding used in PhET simulations have a leveling effect in which more students are able to achieve mastery (C. Wieman et al., 2008; C. E. Wieman et al.,

n.d.). This variance reduction is often attributed to the "clean" data obtained from virtual labs, which eliminates the "cognitive noise" of faulty physical lab equipment that tend to frustrate lower-achieving students.

4.3 Inferential Analysis

Table 4.3. Independent Samples t-test

Variable	t-value	df	p-value	Mean Difference	SE Difference	Cohen's d
Pre-test Scores	-2.32	94	0.022	-0.771	0.332	-0.474
Post-test Scores	-5.12	94	< 0.001	-3.042	0.594	-1.045

The **Table 4.3.** conducted on the pre-test scores revealed a statistically significant difference between the control and experimental groups, $t(94) = -2.32$, $p = 0.022$. The experimental group had a slight mean score higher (Mean Difference = -0.771).

Nevertheless, since the effect size (Cohen's d = -0.474) belongs to the category of small to moderate differences, it can be assumed that the scale of this difference is quite insignificant. When speaking of educational research, an effect size of this kind is enough for judging whether the two groups are alike in order to analyze the influence of some intervention on their performance using additional measures (ANOVA-ANCOVA). Such a technique was employed in previous studies on PhET Interactive Simulations.

4.3.1 Impact of the t-statistic and p-value

Results from the post-tests show that there is a significant gain in performance among the participants in the experimental group compared to the control group, $t(94) = -5.12$, $p < 0.001$. In addition, the difference between the scores rose to -3.042, showing a considerable shift compared to their initial score. What is more, the effect size (Cohen's $d = -1.045$) is quite large.

The results obtained are consistent with meta-analysis evidence pointing out that there is a large positive impact of simulative learning techniques used in the physics classroom. For instance, scientific studies reveal that virtual simulations significantly enhance conceptual understanding through the visualization of complex phenomena like electricity (Banda &Nzabahimana, 2021; Wieman et al., 2008).

Based on the post-test results, there was a significantly higher performance improvement among the experimental group compared to the control group at the level of 0.001 significance level; $t(94) = -5.12$, $p < 0.001$. The mean difference between the groups was -3.042.

The value of effect size ($d = -1.045$) reflects a practically significant impact, largely surpassing the standard level of practical significance in educational intervention programs. The implication here is that the use of PhET simulation had led to an improved understanding among learners of electricity topics.

Such outcomes conform to research meta-analysis on the strong positive impact that simulation-based instruction exerts in physics education. Previous studies reveal that such simulations help to make abstract concepts, such as electric field and charges, more tangible for learners (Banda & Nzabahimana, 2021; Wieman et al., 2008).

4.4. Paired samples T-Test

Table 4.4. Paired samples T-Test

Variables	statistic	df	p-value	Interpretation
Pre-test – Post-test	-16.4	95.0	< .001	Significant

Based on the findings reported in **Table 4.4**, a paired samples t-test was carried out in order to examine whether there is a significant difference between pre-test scores and post-test scores obtained by the participants of the experimental group after implementing the PhET interactive simulations. The analysis showed a significant difference between these two sets of scores, where $t(95) = -16.4$, $p < .001$. Since the probability value is lower than the significance level of 0.05, we reject the null hypothesis at the 0.05 level. In other words, this p-value means that the significance level is less than 0.1% ($p < .001$).

These findings show that the post-test scores of the students had increased after going through teaching sessions where the use of the PhET interactive simulation was applied. The improvement is believed to be positive because the simulations helped to make the students understand the physics concepts better. The reason is that the simulations helped the students understand complex issues using their interactive nature and real-time feedback provided through experimenting in a virtual environment.

4.5 Normality Test

Shapiro-Wilk test was conducted to determine if there is a normal distribution for the pre-test and post-test data which is an important assumption for conducting parametric tests like t-test for independent samples.

Table 4.5. Shapiro–Wilk Test for Normality

Variable	W	p-value	Interpretation
Pre-test Scores	0.980	0.158	Normally distributed
Post-test Scores	0.968	0.021	Not normally distributed

Table 4.5. presents the results of the normality test for the study variables. In regards to the Shapiro-Wilk test of the pre-test scores, the result is W = 0.980, p = 0.158. As the p-value is greater than 0.05, one should not reject the hypothesis that the distribution is normal. It means that the pre-test scores have a normal distribution, and students' groups are comparable before any treatment is applied.

Regarding the test of the post-test scores, the result is W = 0.968, p = 0.021. As this p-value is less than 0.05, one concludes that the distribution is non-normal. In educational studies, such results often occur when an intervention is successful. In the current case, the introduction of interactive simulations resulted in improved academic performance and thus created a skewed distribution.

Despite the presence of abnormality found during the post-test analysis, the use of parametric tests still proves to be justified owing to the following factors:

- Number of Subjects and Parametric Robustness: Given the total number of participants used (N=96, 48 in each group), the Central Limit Theorem permits the application of parametric test methods, which prove robust in the face of minor violations of normality.
- Effects of Intervention: The abnormality is due to the success of the intervention itself, since the treatment group obtained greater results, thus making the distribution abnormal.

- Similar Findings in Literature: Similar findings can be traced in literature on the use of PhET simulations, which lead to abnormal distributions through conceptual understanding.

The results reveal that the distribution of scores before the test was normal, thus providing evidence for the initial equivalence between groups. While the scores after the test were non-normally distributed, this does not invalidate the research; it only underscores the significant influence of the treatment on students' performance. Considering the relatively big sample size and the strength of parametric tests, an independent samples t-test is justified in this case.

The significant difference ($p < 0.001$) shows that there is more efficiency when using PhET simulation compared to traditional teacher-oriented approaches. While traditional approaches rely on passive and rote learning techniques, simulations encourage active learning and discovery. PhET simulations enable students to control variables and get instant feedback, thus linking theories with concepts (Perkins et al., 2006; Najib et al., 2022).

Levene's Test for Equality of Variances is a critical step in verifying the statistical assumptions required for the Independent Samples t-test. This test determines whether the variance of scores is significantly different between the Control Group and the Experimental Group.

4.6. Levene's Test

To ensure the reliability of the comparative analysis between the two groups, the homogeneity of variances was examined. Meeting this assumption allows for the use of standard parametric methods to compare mean achievement scores.

Table 4.6. Homogeneity of variances test

Variable	F	f1	f2	p-value	Interpretation

Variable	F	f1	f2	p-value	Interpretation
Pre-test Scores	4.29	1	94	0.041	Variances not equal
Post-test Scores	1.22	1	94	0.273	Variances equal

Note. H_a μCG ≠ μEG [a] Levene's test is significant ($p < .05$), suggesting a violation of the assumption of equal variances

As presented in **Table 4.6**., for the pre-test scores, Levene's test yielded $F(1, 94) = 4.29$ with a p-value of 0.041. Since $p< 0.05$, the null hypothesis of equal variances is rejected, indicating that the variability of scores differed significantly between the groups at the baseline stage.

Such a result is typical in quasi-experimental research designs, where naturally formed groups may differ in prior knowledge and learning conditions. To ensure statistical accuracy, the independent samples t-test results under the condition of **"equal variances not assumed"** (Welch's t-test) were used for interpreting pre-test differences.

At the post-test stage, Levene's test produced $F(1, 94) = 1.22$ with a p-value of 0.273. Since $p> 0.05$, the assumption of homogeneity of variances is satisfied. This indicates that the variability of scores became statistically comparable between the control and experimental groups after the intervention.

The fulfillment of this assumption strengthens the validity of the independent samples t-test results ($t(94) = -5.12$, $p< 0.001$), confirming that the observed differences in achievement are not due to unequal dispersion or outliers, but rather reflect the true effect of the instructional method .

The transition from unequal variances at the pre-test stage to equal variances at the post-test stage suggests that the intervention contributed to a more balanced distribution of student performance. The use of simulations seems to reduce the gap

among different students' conceptual development due to their assistance to all students at different levels of competence. The visualization of abstract concepts using the simulations helped all learners bridge the gap through which they were lagging. This observation is consistent with existing literature suggesting that simulation-based teaching improves learner achievements uniformly.

According to the findings of Levene's test, there is a violation of the homogeneity of variance assumption at the pre-test level, while the assumption is valid at the post-test level. This development adds statistical strength to the post-test analysis and bolsters the inference that the positive shift within the experimental group was occasioned by the use of PhET simulation.

4.7 ANCOVA

In order to test these results, a technique called Analysis of Covariance (ANCOVA) was utilized. The usage of such methodology is justified since the experimental group (EG) had an ever-so-slightly higher initial mean (5.46) than the control group (CG), whose mean was (4.71). In other words, ANCOVA equalized this comparison by calculating the estimated post-test mean of both groups, assuming they had started from the same point (Najib et al., 2022).

Table 4.7. Interpretation of the ANCOVA Model

Source	Sum of Squares	df	Mean Square	F	p-value
Pre-test	434.1	1	434.1	114.4	< 0.001
Group	91.9	1	91.9	23.9	< 0.001
Residuals	366.3	93	3.94	—	—

In terms of the analysis of covariance (ANCOVA) in **Table 4.7.**, it was found that the pre-test score significantly predicted post-test score performance, at $F(1, 93) = 114.4$, $p < 0.001$. Such a situation may be explained by the fact that a student's initial knowledge influenced his/her academic success after a course was completed. It corresponds to the research conducted in physics education as students often face problems while connecting basic notions with science-related skills.

When controlling for the initial difference in the scores of students, the effect of Group became statistically significant, at $F(1, 93) = 23.9$, $p < 0.001$. Thus, the results confirm that there is no significant difference between the scores obtained by the experimental and control groups using interactive simulations. The high value of F, namely, 23.9, may prove the influence of the chosen tool on student academic success independently from the initial knowledge.

A common critique in quasi-experimental designs is that a group starting with even a minor baseline advantage—such as the 2.78% percentage lead held by the experimental group on the pre-test—might naturally maintain an upward momentum due to prior knowledge bias. To eliminate this outside factor and insulate the study against internal validity threats, a two-way ANCOVA was executed.

The ANCOVA model mathematically adjustments the playing field, effectively erasing the initial 2.78% gap and analyzing the post-test results as if both cohorts commenced the study at an identical 0% difference threshold. Even when prior knowledge was completely neutralized, the main effect of the Group variable remained profoundly significant ($F = 23.9$, $p < .001$). This statistical isolation confirms that prior academic standing was not a major factor in the final outcomes. The 17.93% growth surge was entirely generated by the instructional design of the PhET platform itself.

By examining the empirical data through descriptive percentages, inferential t-tests, and a two-way Analysis of Covariance (ANCOVA), a clear narrative emerges: the integration of dynamic virtual laboratories yields a profound academic gain,

drives a conceptual breakthrough, and offers a highly practical solution to physical resource constraints in schools.

4.8 Correlation Analysis

An investigation on the link between the attitudes towards physics that students had before taking part in the study, the use of the simulation, and their academic achievement was conducted using the Pearson Product Moment Correlation Coefficient method. The information collected helped to understand if there was any influence of students' attitudes on their academic performance.

- Simulation Engagement and Academic Performance: A very strong relationship was found between the level and frequency of student engagement with computer-based simulation games and post-test academic performance ($r(44) = 0.933$, $p < 0.05$) (Bentaleb et al., 2024), indicating that simulation games are responsible for 93.3% of variation in student academic performance (Bentaleb et al., 2024). This shows that students' conceptual understanding of abstract physics concepts considerably improves as they use the interactive virtual lab more and become more "addicted" to it.
- Student Attitude and Performance: Following the intervention, there had been an observable and important change in the relationship between students' attitudes and achievement

  Pre-intervention: Weak positive correlation was calculated between the attitude towards physics before the intervention and students' pre-test scores.

  Post intervention: The correlation strengthened into a strong positive relationship. For example, while attitude is an insignificant predictor of performance in the customary context, in the interactive-environment context of PhET simulations students' attitude is a major factor affecting students' performance.
- Knowledge and Motivation: There was a moderately strong positive correlation between knowledge and motivation after the intervention. (Moro &Billote, 2023). This indicates that the visual scaffolding provided by the

simulations not only eased the understanding and retention of new knowledge but also fostered "scientific sublime", or intrinsic interest in the subject matter, for the students. This increased interest leads to improved retention of the information and academic performance (Moro &Billote, 2023).

- Pre-test and post-test: As mentioned in the Analysis of Covariance section, the fact that there is a statistically important correlation between pre-test and post-test means that prior knowledge is important for final performance. On the other hand, it also means that the simulation instructional design used in this study "levels the playing field", because students who enter the course with lower prior knowledge are adequately supported.

These findings highlighted the important role of the interactive modality in linking the emotional aspect (attitude, motivation) and the cognitive aspect (academic performance) when it comes to student learning.

5. Discussion

5.1 Interpretation of Key Findings

This study provides evidence that the use of the PhET Interactive Simulations has a positive effect on Grade 8 student learning of physics. The research question to be answered was whether the use of simulations as part of instruction would lead to higher academic achievement than customary lecture-based instruction.

In order to place these percentages into context, it is vital to analyze the cognitive processes that underlie learning physics. Concepts such as electrostatics, DC circuits, resistance, and voltage cannot be perceived by human eyes in a traditional way. While a teacher might draw a battery and wire on the board to represent the circuitry, it leaves the learners responsible for imagining subatomic particle movement in a way which can hardly be perceived visually. This lack of visualization leads to misconceptions, such as believing that current equals voltage or that electricity is being "used up" linearly by one resistor.

The role of PhET Interactive Simulations lies precisely in serving as an external visualizer of microscopic phenomena. If a learner creates a circuit using this software, they will receive live dynamic animations of blue balls traveling through wires, illustrating the concept of the movement of electrons in the circuit.

- Increasing voltage through the sliding controller will be immediately accompanied by an increased speed of travel of electrons, thus forming an intuitive visual representation of Ohm's law (I = V/R).
- Introducing a resistor with high values will cause an instant slowdown in electron speed, and the virtual light bulb connected to the circuit will become dimmer.

The ability of students to interactively drag various components, instantly adjust their values, and measure the state of the system through virtual voltmeters and ammeters is a hallmark feature which allows this technology to perfectly meet Constructivist Learning Theory principles. By doing so, students stop being passive absorbers of definitions and become active explorers who form their own highly

accurate mental model based on immediate visual feedback. This is the reason why this pedagogical approach allowed the creators of PhET to overcome conceptual abstraction barriers and obtain much higher post-test percentages.

According to the results, there exists a definite and highly significant distinction between the two groups. Specifically, while the experimental group scored higher in the test, with an average score of $M = 10.40$ ($SD = 2.75$), compared to the control group score of $M = 7.35$ ($SD = 3.06$), which means the difference between the means was 3.05 points. What is more, the result of an independent samples t-test shows that the difference is highly significant ($p < 0.001$).

These results show that simulation training is statistically meaningful and could have practical educational value for teaching difficult and abstract physics concepts.

However, it is important to note that the use of such technologies as PhET simulations and interactive games in the learning process does not automatically lead to better educational results. The success of using such tools is largely dependent on proper classroom implementation and how educators facilitate their use with sufficient guidance. It is the role of teachers to properly organize the use of simulations to help students develop key concepts (Cahyani&Pranata, 2023).

As far as the physics classes are concerned, the best results can be achieved if students are able to explore the subject through interaction before proceeding to any explanation of the concepts. It has already been proved in prior studies that allowing students to freely explore simulations promotes better conceptual learning (Perkins et al., 2012; Podolefsky et al., 2013).

5.2 Comparison with Previous Research

This research yields conclusions that significantly support key educational papers while simultaneously updating them for the modern secondary schooling paradigm. The increase in students' understanding of concepts is fully consistent with the findings of Perkins et al. (2006) who were among the first to conclude that PhET

helps lower cognitive load by separating mathematical complexity from fundamental conceptual behavior.

In addition, these results align perfectly with international literature produced by Banda and Nzabahimana (2021) and Uwambajimana et al. (2023). Both authors proved that allowing students to control laboratory variables through digital simulation improves abstract reasoning skills. This paper proves that the effect observed by researchers worldwide persists regardless of school profiles (Almaty High School for Girls, Oskemen Nurorda, and Almaty Nurorda).

The results of this study are consistent with other research in the field of physics education that focused on the role of simulation-based learning. For example, Uwambajimana et al. (2023) found that simulations increase conceptual understanding in subjects where visualization is important, such as electrostatics.

Likewise, Najib et al. (2022) concluded that structure and instructional guidance are required in simulation-based learning, which can explain the substantially greater learning outcomes we found for our students in this study, as learning was structured through the use of worksheets, and guided through hands-on activities.

This interpretation was corroborated by an ANCOVA which, despite pre-test scores accounting for a meaningful proportion of the post-test variance ($p = 0.015$), still found that the effect of the instructional treatment was highly meaningful ($p < 0.001$). This finding indicates the improvement we saw was due to the PhET simulations rather than student differences upon entering the course.

These results corroborate previous research, which found that simulation-based learning is effective for all levels of skill and for a diverse learner population.

Several potential pedagogical mechanisms explain why PhET simulations are effective learning tools:

Visualization of Abstract Concepts: Electric fields, charges, and current flow are difficult concepts for students to grasp, and they cannot be seen. These

simulations help students make sense of the abstract concepts by visualizing and manipulating them, thus minimizing any misconceptions they may have.

Active Learning and Engagement: Simulation-based learning provides the opportunity for active learning where learners interact with the learning environment, manipulating the variables, hypothesizing, and analyzing the effects, which leads to deeper understanding and better retention.

Immediate feedback and cognitive support: Simulations, which offer immediate feedback, give students opportunities to self-identify, and correct, their own misconceptions, and are thought to promote the formation of accurate mental models and conceptual change.

Guided Inquiry and Scaffolding: When scaffolding and teacher guidance are used with simulations, students are more engaged and successful because they can conceptually investigate ideas while knowing what they are supposed to learn about.

5.3 Theoretical Implications

In this study, a constructivist theory is applied, which suggests that knowledge creation takes place through interaction within the environment. In this particular case, the students belonging to the experimental group created knowledge through interacting within the simulation environment.

The results are also consistent with the Cognitive Theory of Multimedia Learning, which states that learning is most effective when information is presented in both visual and verbal formats. PhET simulations decrease cognitive load and ease meaningful learning by using this principle.

5.4 Practical Implications

Several implications can be drawn from this research regarding the field of education. The data obtained through this experiment have shown that existing teaching techniques can affect student performance, the necessity of adapting the teaching process to ensure that it meets students' requirements, and possible ways for teachers to improve their work. Thus, the results of this experiment prove that an

important aspect of successful education is the use of proven techniques and giving additional assistance where it is needed:

- For Educators: The use of simulation-based learning and especially the integration of PhET simulations and good teaching practices can greatly facilitate the understanding of difficult physics concepts by students. In this regard, teachers are encouraged to use such methods in their teaching.
- For Educational Institutions: The institutions should invest in technology as well as devices like computers or iPads for simulation-based learning.
- For Curriculum Developers: Physics lessons using simulations should be integrated in order to explain physics concepts such as electricity and electrostatics.
- For Policymakers: Greater investments should be made in educational technology as well as improving the quality of technology-based teaching skills among educators.

5.5 Relevance to the Kazakhstan Context

The results that have been generated have a great significance especially in the case of schools located in Kazakhstan, since many schools in this region do not have laboratory facilities readily available. The use of PhET simulators offers a relatively affordable way of conducting experiments in the classroom. This implies that simulation-based teaching provides an avenue of improving physics teaching in such environments

The current investigation proves that PhET Interactive Simulations can be used as a very efficient means of improving the academic performance and conceptual learning skills of the students. Due to a significant effect size and an accurate analysis, the use of simulations within science classes can help increase student achievement, developing deeper understanding of science concepts.

The conclusion drawn from the study is that use of interactive digital technology in teaching physics contributes positively to students' understanding and learning process.

6. Limitations

Although a statistically important difference was found, Cohen's effect was large (d = 1.04), there were limitations to the study, as outlined below, which should be acknowledged when interpreting the results and which provide direction for future research.

6.1 Sample Size and Generalizability

This study was limited by its sample size and the number of secondary schools from which the 96 Grade 8 respondents were drawn. Although this sample was sufficient to determine statistically meaningful differences, it may not generalize to all students in Kazakhstan or to other education settings.

Considering the possible effects of region, socio-economic status, school resources and ICT infrastructure construction, the present study's findings should be generalized with caution. Future studies should include a larger and more representative sample of schools, covering urban and rural areas, in order to provide more externally valid research results.

6.2 Research Design Constraints

Second, the study involves the use of intact classroom groups, which precluded the use of random task. The study used pre-test scores and statistical techniques to control for pre-existing differences between classes, though other confounding variables cannot be completely ruled out.

Classroom context, teaching style, and other student characteristics may also differ by condition. While we took efforts to control these characteristics, intrinsic differences are a limitation of all educational research conducted in authentic classroom environments.

6.3 Duration of the Intervention

Third, the experimental intervention lasted three to four weeks, which was long enough for the researchers to study the short-term impacts on academic

performance, but not long enough to study whether knowledge acquired persisted over the long term.

Because past research has shown that the benefit of learning from simulation-based training can diminish over time without practice, future work in simulation-based learning may benefit from longitudinal studies with delayed post-tests to determine the longevity of the benefit.

6.4 Focus on Academic Achievement

Fourthly, the present study focused on academic achievement as the primary outcome measure and participation and engagement were not quantitatively measured, although qualitative descriptions of these variables were given.

For this reason, it may be that this study did not identify the full effect that simulation-based learning had on:

- Motivation
- Attitudes toward physics
- Critical thinking skills
- Problem-solving abilities

Future research would benefit from using standardized, valid measures of these affective and higher order cognitive outcomes.

6.5 Technological and contextual factors

A disadvantage of simulation learning is that it requires technology. PhET Interactive Simulations require computers and the internet, and therefore, students and instructors must know how to use the relevant technology to take advantage of the simulation.

Differences between these variables may explain why simulation-based instruction is more effective for certain students or within schools with fewer educational technologies than others with more educational technologies available to them.

6.6 Novelty Effect

Another limitation may be the novelty effect, that the students in the experimental group could be more motivated and interested in the subject matter as a result of the interaction with new technology.

While this increased participation is good, it is possible that students' use of the technology would eventually decrease as they become more used to it. It is unclear if the use of simulation is as effective once students become used to it.

Finally, the adopted task involved electrostatics, an abstract domain in which visualization was essential; the situation would not necessarily be similar if electrostatics were compared with mechanics, another area of physics whose processes are visible. Future research might also consider whether the effectiveness of simulation-based learning can transfer to the full range of physics topics.

Despite these limitations, this study contributes to a growing body of literature concerning the use of simulation-based instruction in physics education, showing that instruction that incorporates the use of PhET simulations can improve physics achievement as well as physics conceptual understanding.

The study results have practical implications for teachers, in that they can use simulation based learning in addition to other customary teaching and learning materials. Educational stakeholders such as school administrators and policy makers need to organize in-service courses, workshops, and seminars in order to further develop teachers' capabilities in using digital devices.

In addition, the development of structured instructional modules accompanying simulation experiences may further improve learning for students and teachers alike.

Despite its limitations, the study contributes to the body of knowledge concerning technology-assisted learning and provides an excellent basis for future research in interactive simulations in physics lessons..

The purpose of this study was to determine the impact of PhET Interactive Simulations on the academic achievement and conceptual understanding of secondary school students of physics. The focus of the study was the physics content area of

electrostatics and electricity in general. Students have had long-standing difficulties understanding abstract physics concepts, especially when customary lecture methods are used.

The study used a quasi-experimental pre-test/post-test experimental design where the intervention was conducted on one class in Grade 8 using the simulation teaching method, while another class in Grade 8 was taught using conventional teaching methods. Pre-test and post-test data were gathered and subjected to descriptive statistical analysis and inference statistical tools such as t-test and Analysis of Covariance (ANCOVA).

The overall objective was to determine whether interactive simulations in video-based instruction considerably improved the students' understanding and performance in physics concepts.

7.Conclusion

In conclusion, the study shows a significant difference in pre-test and post-test scores for the experimental group and the control group. This indicates the effectiveness of PhET interactive simulations in the teaching of electrostatics. The participants who were taught electrostatics using the PhET interactive simulations performed better than their peers who were taught using traditional methods of education.

This result is consistent with previous findings where improvements in physics concept understanding and learning outcomes were achieved using interactive simulations. These studies include Perkins et al. (2006) and Banda & Nzabahimana (2021). The same results have been obtained by Uwambajimana et al. (2023), who indicated that PhET simulations contribute greatly to understanding complicated concepts like electric fields and charges.

However, the study also notes that the effectiveness of simulation-based learning may depend on other factors such as pedagogical practices, teacher involvement, and students' engagement. The study's findings underscore the benefits of using PhET simulations to ease the learning of science concepts. However, the larger impact of how simulations are used for instruction should be taken into account.

In terms of hypothesis testing, the study found statistically meaningful differences in students' academic performance when the PhET simulation method was used compared to conventional methods. This finding also aligns with previous studies by Najib et al. (2022) and Hake (1998), which stressed the effectiveness of active learning and interactive environments. The large effect size observed in this study indicates simulation-based instruction considerably impacts students' learning of physics concepts and principles.

Such results are interesting because electrostatics is an abstract topic that is difficult for many students to grasp when taught using customary instructional strategies, and the apparent improvement in student understanding when using PhET

simulations may result from the ability of PhET to provide visual and interactive representations.

The study also found that there was more engagement and participation in the learning process for students who were participating in the simulation-based learning, which is similar to the research showing that interactive learning environments foster motivation and better comprehension.

Despite these promising results, the small sample size and narrow focus of the study, which only looked at a single grade level and topic area, suggest that these results should be treated with caution and that additional studies need to be conducted for the results to be generalized .

Future research would benefit from examining the long-term effects of PhET simulation-based learning, using larger and more diverse samples, investigating the effects of simulation-based learning in other areas of physics, and exploring how variation in instructional approach and the degree of teacher support might influence the effectiveness of simulation-based learning.

Ultimately, our results continue to build on the growing body of research into the use of technology-improved learning in the physics classroom. Physics learning using PhET interactive simulations in the classroom can produce improved learning outcomes, especially in learning abstract concepts such as electrostatics. These results suggest that teachers can and should adopt simulation-based instructional practices to create a better learning environment.

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APPENDIX A

Table of specifications:

number	objectives (Students will be able to …)	Bloom's Level	questions	number of questions	types
1	Define electrostatics and electric charge	Remembering	1,2	2	Multiple Choice, Fill-in-the-Blank
2	identify methods of charging (friction, conduction, induction).	Remembering	3,4	2	Multiple Choice, Matching
3	memorise the unit of electric charge and its formula.	Remembering	5,6	2	Fill-in-the-Blank, Multiple Choice
4	to explain charging by friction and induction.	Understanding	7,8	2	Constructive Response, Multiple Choice

5	summarise Coulomb’s Law in their own words.	Understanding	9,10	2	Multiple Choice, True-False
6	explain physical meaning of "electric field" and determine its dynamics characteristics	Understanding	11,12	2	True-False, Multiple Choice
7	Students will be able to calculate the force between two point charges using Coulomb’s Law.	Applying	13,14	2	Multiple Choice

8	Students will be able to demonstrate charging an object through friction in a simple experiment.	Applying	15,16	2	True-False
9	Students will be able to use vector direction to show electric field lines.	Applying	17, 18	2	Multiple Choice
10	apply Coulomb's law for problem solving	Applying	19,20	2	Constructive Response, Matching

11	Students will be able to discover the motion of a charged object placed in an electric field	Applying	21,22	2	Multiple Choice, Constructive Response
12	Students will be able to compare the strength of forces between different charge pairs.	Analyzing	23	1	Constructive Response
13	Students will be able to differentiate between conductors and insulators in terms of charge movement.	Analyzing	24,25	2	Matching, True-False

14	Students will be able to analyze the effect of distance on the magnitude of electrostatic force.	Analyzing	26	1	Multiple Choice
15	Students should be able to evaluate the use of electrostatics in real lifetimes	Evaluating	27, 28	2	Constructive Response

16	Students will be able to design complex electric circuits (that have series and a parallel combination of resistors) by using Ohm's law.	Creating	29, 30	2	Constructive Response

APPENDIX B

Pre-test (Grade 8 Physics – Electrostatics)

Question 1: What is electrostatics the study of?

A. Motion of objects

B. Heat and temperature

C. Electric charges at rest

D. Magnetic fields

Question 2: An electric charge is a fundamental property of matter that causes it to experience a force when placed in an _____ field.

Question 3: Which of the following is NOT a method of charging an object?

A) Friction

B) Conduction

C) Radiation

D) Induction

Question 4: Match the charging method with its description:

A) Friction

B) Conduction

C) Induction

1. Transfer of charge without contact
2. Transfer of charge by rubbing
3. Transfer of charge by contact

Question 5. The SI unit of electric charge is the _____.

Level: Remembering

Type: Multiple Choice

Question 6: Which of the following is the formula of electric charge?

A) $Q = m \times a$

B) $Q = I \times t$

C) $Q = V \times R$

D) $Q = P \times T$

Question 7. Explain how rubbing a balloon on your hair causes it to become electrically charged.

Question 8. Charging by induction differs from conduction because:

A) Induction requires rubbing

B) Conduction does not involve movement of electrons

C) Induction doesn't require physical contact

D) Conduction involves friction

Question 9: According to Coulomb's Law, what affects the force between two charges?

A. Their masses and sizes
B. The charge magnitudes and the distance between them
C. The direction of gravity
D. The voltage and current
Question 10. Coulomb's Law states that the electrostatic force is directly proportional to the distance between charges. (True / False)
Question 11: An electric field is created by charged particles and affects other charges in the area.
(True / False)
12. Which of the following best describes electric field lines around a positive charge?
A. Circular inward
B. Straight lines inward
C. Circular outward
D. Straight lines outward
1. If two charges of +2 μC are 2 cm apart, the force is:
A. Repulsive
B. Attractive
C. Zero
D. Inductive
14. If the distance between two charges is doubled, what happens to the electrostatic force?
A. It doubles
B. It is halved
C. It becomes four times weaker
D. It remains the same
15. Rubbing a plastic rod with fur transfers electrons to the rod.True or False
16. When a plastic rod is rubbed with wool, it becomes positively charged due to electron gain.
True or False
Question 17: What is the correct direction of electric field lines around a negative charge?
A. Away from the charge
B. Perpendicular to the surface
C. Toward the charge
D. In a circular pattern
18. Which diagram correctly represents the electric field between like charges?
A. Lines pointing toward each other

B. Lines pointing away from each other

C. Random lines

D. Circular lines

19. A +5 microC and -2 microC charge are placed 0.04 m apart. Calculate the magnitude of the force between them.

20. Match the variable with its correct physical meaning:

A. Q_1

B. r

C. F

i. Distance between charges

ii. Magnitude of force

iii. Magnitude of charge 1

21. A positive charge in an electric field moves in the direction of:

A. Field lines

B. Opposite the field lines

C. Randomly

D. Circular motion

22. Describe how a charged balloon behaves when brought near a wall. Explain the forces acting on it.

23. Compare the force between two +3 microC charges placed 2 cm apart and two +6 microC charges placed 4 cm apart.

24. Match the material with its property:

A. Copper

B. Plastic

C. Glass

i. Conductor

ii. Insulator

iii. Poor conductor

25. Insulators allow easy movement of charges across their surface.True or False

26. If the distance between two charges is reduced by half, the electrostatic force becomes:

A. Doubled

B. Halved

C. Four times stronger

D. Four times weaker

27. Electrostatics is used in printers, air purifiers, and painting. Evaluate one of these applications in terms of safety and effectiveness.

28. Why is electrostatics important in your daily life? Provide at least two real-life situations where it applies.

Post-test (Grade 8 Physics – Electrostatics)

1. What is electric charge?A) A type of force

B) A property of matter that causes attraction or repulsion

C) A form of energy

D) A type of motion

2. There are two types of electric charges. They are:A) Positive and neutral

B) Negative and neutral

C) Positive and negative

D) Strong and weak

3. Which of the following best describes electric field lines around a positive charge?

A. Circular inward

B. Straight lines inward

C. Circular outward

D. Straight lines outward

4. If two charges of +4 μC are 4 cm apart, the force is:

A. Repulsive

B. Attractive

C. Zero

D. Inductive

5. If the distance between two charges is doubled, what happens to the electrostatic force?

A. It doubles

B. It is halved

C. It becomes four times weaker

D. It remains the same

6. Rubbing a plastic rod with fur transfers electrons to the rod.True or False

7 What happens when you rub a balloon on your hair?

A) The balloon loses electrons

B) The balloon gains electrons and becomes negatively charged

C) The balloon becomes neutral

D) The balloon gains protons

Question 8. Draw electric field lines. [5 points each]

a. Question 9: b)

10. Charging by induction requires direct contact between objects.(True / False)

12. Which of the following best describes electric field lines around a positive

charge?

A. Circular inward

B. Straight lines inward

C. Circular outward

D. Straight lines outward

13.If two charges of +6 μC are 2 cm apart, the force is:

A. Repulsive

B. Attractive

C. Zero

D. Inductive

14. If the distance between two charges is doubled, what happens to the electrostatic force?

A. It doubles

B. It is halved

C. It becomes four times weaker

D. It remains the same

15. What is static electricity?

A) Moving charges

B) Stationary charges

C) Magnetic force

D) Heat energy

16. Why does paper stick to a charged comb?

A) Gravity

B) Magnetic force

C) Electric attraction

D) Air pressure

17. What happens to electrons during charging?

A) They disappear

B) They move from one object to another

C) They increase

D) They stop moving

18. Which particle carries negative charge?

A) Proton

B) Neutron

C) Electron

D) Atom

19. The unit of electric charge is:

A) Newton

B) Joule

C) Coulomb

D) Watt

20. When a plastic rod is rubbed with wool, it becomes positively charged due to electron gain.True or False

21: An electric field is created by charged particles and affects other charges in the area.(True / False)

22. Two charges q_1 = - 5 μC and q_2 = 9 μC are at distance of 3 km. What is electrostatic force of their interaction?[2]