UNIVERSITY OF EDUCATION, WINNEBA

EXAMINING THE EFFECT OF PHYSICS EDUCATION TECHNOLOGY (PhET) SIMULATION ON SENIOR HIGH SCHOOL STUDENTS' ACADEMIC PERFORMANCE IN ELECTRONICS AT LEKLEBI SENIOR HIGH SCHOOL

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DECLARATION

Student's Declaration

I, Francis Kafui Aidoo declare that this thesis, with the exception of quotations and references contained in published works which have been identified and duly acknowledged, is entirely my own work, and it has not been submitted either in part or whole for another degree elsewhere.

SIGNATURE: …….............……………….

DATE: …….........……...…………………

Supervisors' Declaration

I hereby declare that the preparation and presentation of this work was supervised in accordance with the guidelines for supervision of Thesis as laid down by the University of Education, Winneba.

SUPERVISOR: DR. NELLY ADJOA SAKYI-HAGAN

SIGNATURE: …….............……………….

DATE: …….........……...…………………

DEDICATION

This work is dedicated to my uncle and family in recognition of their unwavering support, encouragement, and sacrifices throughout my academic journey.

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I am profoundly grateful to God Almighty for His wisdom, strength, and guidance throughout this academic journey.

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ABSTRACT

The study examined the effect of Physics Education Technology (PhET) simulations on the academic performance of Senior High School students in Electronics at Leklebi Senior High School in the Afadjato South District of the Volta Region of Ghana. Specifically, the study determined baseline differences in performance between experimental and control groups, assessed the effect of PhET simulations on students' academic performance, compared simulation-based instruction with conventional teaching methods, and explored students' perceptions of the use of PhET simulations in learning Electronics. A quantitative quasi-experimental design, using a non-equivalent control group pre-test–post-test approach, was adopted. Two intact Form Two classes were purposively selected, comprising an experimental group taught using PhET simulation-based instruction and a control group taught using traditional lecture-based methods. Data were collected using structured achievement tests administered before and after the intervention, as well as a Likert-scale questionnaire administered to the experimental group. Data were analysed using descriptive statistics and inferential statistical techniques, including independent samples *t*-tests and paired samples *t*-tests. The findings revealed no statistically significant difference in pre-test performance between the experimental and control groups, indicating baseline equivalence. However, results showed a statistically significant improvement in the academic performance of students exposed to PhET simulations. Comparative analysis further indicated that the experimental group significantly outperformed the control group in post-test assessments. In addition, students expressed overwhelmingly positive perceptions of PhET simulations, reporting improved understanding of abstract Electronics concepts, increased engagement, enhanced confidence, and greater enjoyment of lessons. The study concludes that PhET simulations are an effective instructional strategy for improving students' academic performance and learning experiences in Electronics. It is recommended that PhET simulations be integrated into Integrated Science instruction in Senior High Schools, supported by teacher professional development and improved access to ICT resources, particularly in resource-constrained school contexts.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter presents the background to the study, statement of the problem, purpose of the study, and objectives of the study. It also includes the research questions, hypothesis, significance of the study, delimitations, limitations, definition of terms, and the organisation of the study.

1.1 Background to the Study

Electronics, a core component of modern science and engineering, focuses on the behaviour and movement of electrons in different media and underpins the design of circuits, devices, and systems essential to communication, computation, automation, and energy management. Its applications span smartphones, medical equipment, renewable energy, and intelligent systems, making proficiency in electronics essential for national development, industrial growth, and solving real-world problems (Singh & Tiwari, 2023).

At the Senior High School (SHS) level in Ghana, electronics is taught as part of the Integrated Science curriculum. The inclusion of electronics in the curriculum is intended to lay a foundational understanding for students to pursue science, technology, engineering, and mathematics (STEM)-related fields in tertiary education. This early exposure is crucial for developing scientific literacy and fostering innovation. Studies have emphasised that strengthening STEM education, particularly electronics, at the SHS level enhances critical thinking, problem-solving abilities, and students' readiness for future careers (World Bank, 2022; UNESCO, 2023).

Despite its significance, teaching electronics at the SHS level presents various challenges. Research in Ghana and other African countries has consistently shown that science, especially physics under which electronics is often taught, is perceived by students as abstract, difficult, and unrelatable (Azure, 2018; Buabeng et al., 2016; Ndihokubwayo et al., 2020). These perceptions stem from multiple factors, including a lack of practical exposure due to insufficient laboratory equipment (Kibiwott & Wanjiru, 2024), overreliance on traditional lecture-based instruction (Ramaila, 2022), low student engagement and interactivity in classrooms (Agyei & Agyei, 2021), the mathematical complexity of the subject matter (Taale, 2019), and inadequate teacher preparedness in the use of modern pedagogical tools (Murphy, 2022).

To overcome these challenges, educational technology has emerged as a promising solution. One such innovation is the Physics Education Technology (PhET) simulation developed by the University of Colorado Boulder. These are interactive, research-based simulations designed to teach complex science concepts in an engaging and visual format (Wieman et al., 2021). PhET simulations allow students to conduct virtual experiments, manipulate variables, and visualise phenomena that would otherwise be constrained by limited physical resources.

Globally, the integration of PhET simulations has proven effective in enhancing students' understanding of abstract scientific concepts, particularly in topics such as electronics, waves, and energy (Toma et al., 2024; Álvarez-Siordia, 2025). They have been adopted in countries including the United States, Indonesia, and Brazil to support inquiry-based learning, improve conceptual understanding, and foster interest in STEM disciplines (Pereira Gomes, 2023; Pranata, 2024). These documented benefits have drawn the attention of educational stakeholders in Africa, where resource limitations often hinder effective science teaching.

In Africa, particularly in sub-Saharan regions, studies have examined the effectiveness of PhET simulations in improving conceptual understanding and student engagement (Ndihokubwayo et al., 2020; Banda & Nzabahimana, 2022). In Ghana, several initiatives supported by the Ghana Education Service and educational non-governmental organisations have promoted the use of PhET simulations in secondary schools (Agyei & Agyei, 2021). These interventions aim to supplement theoretical instruction, address logistical limitations in science laboratories, and ultimately improve performance in science-related subjects.

However, while these simulations have shown promise in general physics instruction, limited research exists on their specific application to the teaching of electronics at the SHS level in Ghana. Most existing studies focus broadly on physics or STEM integration without a detailed examination of electronics as a distinct topic (Bani Yassin, 2022; Bastos, 2020). Furthermore, there is a paucity of empirical evidence on the effectiveness of PhET simulations in improving academic performance in electronics, particularly among Form Two students who are at a critical stage in their science education.

There is a clear research gap in this area. International studies have reported positive effects of PhET simulations on students’ learning outcomes. Some African countries have also begun to adopt these tools in science instruction. However, context specific evidence from Ghanaian senior high schools remains limited. In particular, little is known about how experiential tools such as PhET simulations influence students’ academic performance in electronics.

In addition, several instructional challenges persist in Ghanaian classrooms. These include limited opportunities for hands on practice, inadequate teaching aids, and low student engagement. These challenges further justify the need to explore more interactive and technology supported teaching approaches.

This study therefore investigates the impact of PhET simulations on students' academic performance in electronics among Form Two students at Leklebi Senior High School in the Afadjato South District. It seeks to fill the identified empirical gap by assessing whether these tools can enhance conceptual understanding, engagement, and performance in electronics, thereby contributing to ongoing educational reforms aimed at strengthening STEM learning outcomes in Ghana.

1.2 Statement of the Problem

The effective teaching and learning of Integrated Science, particularly its physics-related topics, present significant challenges at the Senior High School (SHS) level in Ghana. Among these topics, electronics is often regarded by students as very abstract and difficult to understand due to the limited availability of laboratory equipment and the continued reliance on teacher-centred instructional methods (Azure, 2018; Kibiwott & Wanjiru, 2024). These challenges negatively affect students' interest and performance in electronics.

The Chief Examiner's Report (WAEC, 2022) notes that many SHS candidates either avoid or perform poorly in questions related to electronics during the West African Senior School Certificate Examination (WASSCE). This pattern indicates deep-rooted conceptual difficulties and instructional inefficiencies in the delivery of electronics education at the SHS level.

To address such instructional gaps, tools such as Physics Education Technology (PhET) simulations have gained attention in science education globally. These simulations provide students with interactive, visual experiences of abstract concepts, allowing them to manipulate virtual circuits and observe phenomena that would otherwise be difficult to access through traditional classroom teaching alone (Wieman et al., 2021; Toma et al., 2024). While international studies highlight the effectiveness of PhET simulations in enhancing conceptual understanding and student engagement, there is limited empirical evidence in Ghana about their impact, particularly in the teaching of electronics.

In Ghana, some schools have begun incorporating PhET simulations into science instruction, but research on their use remains sparse and largely focused on broader physics concepts. Little is known about their specific effectiveness in improving students' academic performance in electronics within the context of SHSs such as Leklebi Senior High School, where students often face challenges typical of rural and resource-constrained settings.

This study, therefore, seeks to examine the impact of PhET simulations on the academic performance of Form Two students in electronics at Leklebi SHS. By addressing this gap, the study aims to contribute to ongoing efforts to enhance STEM education through experiential and technology-supported learning approaches in Ghanaian high schools.

1.3 Purpose of the Study

The purpose of this study is to examine the effect of using PhET simulations in teaching electronics on the academic performance of Form Two Senior High School students of Leklebi SHS in the Volta Region of Ghana.

1.4 Objectives of the Study

The study sought to:

1. Determine differences in the performance of the experimental and control groups in electronics prior to exposure to PhET simulations.

2. Investigate the effect of PhET simulations on the performance of the experimental group in electronics.
3. Compare the performance outcomes of students exposed to PhET simulations with those taught using conventional teaching methods.
4. Explore the perceptions of students in the experimental group about the use of PhET simulations in teaching electronics.

1.5 Research Questions

1. What is the difference in performance between the experimental and control groups before exposure to PhET simulations?
2. What is the effect of PhET simulations on the performance of the experimental group in electronics?
3. What is the effect of PhET simulations on student performance in electronics compared to conventional teaching methods?
4. What are students' perceptions of the use of PhET simulations in learning electronics?

1.6 Research Hypotheses

H_{01}: There is no significant difference in the pre-test performance in electronics between the experimental and control groups at Leklebi SHS.

H_{02}: The use of PhET simulations has no significant effect on the post-test performance of the experimental group in electronics.

H_{03}: There is no significant difference in the post-test performance in electronics between students taught with PhET simulations and those taught using only conventional teaching methods.

1.7 Delimitations of the Study

The study involved only students of Leklebi Senior High School in the Afadjato South District of the Volta Region of Ghana. The study was restricted to an aspect of the SHS Integrated Science syllabus that focuses on electronics. The second-year General Arts students and Visual Arts students, who study Integrated Science as a core subject, were selected for the study. All other students, including those in other year groups or academic programmes, were excluded from the study.

1.8 Limitations of the Study

The researcher encountered several challenges during the study. Some students were absent during parts of the intervention period, which may have influenced the consistency of the data. In addition, the level of student commitment and motivation to engage fully in the learning activities during instructional periods may have affected the outcomes. Finally, other research instruments such as classroom observations and personal interviews, which could have provided more comprehensive insights, were not employed in this study.

1.9 Significance of the Study

The study would help address the persistent difficulties students face in understanding and performing well in electronics, a component of Integrated Science, at Leklebi Senior High School. The study would also help schools facing similar challenges to adopt the PhET simulation approach rather than relying solely on traditional teaching methods commonly used in schools across the Afadjato South District.

It is hoped that the outcome of this research would motivate Integrated Science teachers to incorporate PhET simulations into their teaching, thereby improving the teaching and learning of electronics at Leklebi Senior High School. Finally, the outcome of the study would serve as a foundation for organising in-service training workshops for Integrated Science teachers in Senior High Schools within the Afadjato South District.

1.10 Definition of Terms

PhET Simulations: These refer to interactive, computer-based simulations developed by the PhET Interactive Simulations Project at the University of Colorado Boulder. They are used in science and mathematics education to visually demonstrate abstract concepts through real-time models and manipulation (Wiemanet al., 2008).

Computer-Assisted Instruction (CAI): A teaching approach that involves the use of computer technology to deliver instructional content, assess student performance, and provide feedback. In this study, CAI includes the use of PhET simulations to teach the topic of Electronics in Integrated Science.

Integrated Science: A subject taught at the senior high school level in Ghana that combines concepts from various branches of science including physics, chemistry, biology, and earth science to develop scientific knowledge and practical skills relevant to everyday life.

Electronics: A topic within the Integrated Science curriculum that deals with the flow and control of electric current through components such as resistors, capacitors, and diodes. This study focuses on how students understand basic electronic concepts through simulation-based teaching.

Academic Performance: This refers to students' level of achievement as measured by their scores in standardised tests. In this study, it specifically relates to their pretest and posttest scores on topics in Electronics.

Control Group: A group of students who received traditional instruction using conventional teaching methods such as lecture, chalkboard illustrations, and textbook reading, without the use of PhET simulations.

Experimental Group: A group of students who received instruction using PhET simulations as part of computer-assisted instruction to enhance learning in the topic of Electronics.

Pretest: An assessment given to both groups before the intervention to evaluate their initial knowledge of Electronics.

Posttest: An assessment administered after the intervention to measure the students' learning outcomes and improvement in the topic of Electronics.

Perception: The opinions or attitudes of students toward the use of PhET simulations in learning science concepts. In this study, it refers to how students in the experimental group view the effectiveness and usefulness of the simulations.

Conventional teaching: refers to the teacher centred, lecture based approach commonly used in teaching Electronics, characterised by board explanation, textbook exercises, and limited use of interactive digital tools.

1.11 Organisation of the Study

This study is organised into five chapters that systematically present the research process, findings, and implications. Chapter One provides an overview of the study, including the background to the problem, statement of the problem, research objectives, research questions, significance, scope, and delimitations. Chapter Two reviews relevant literature related to the study, beginning with key concepts and theoretical perspectives on teaching Electronics in Integrated Science. It further discusses the Cognitive Theory of Multimedia

Learning and examines empirical studies on the use of PhET simulations and other instructional approaches. The chapter also identifies research gaps, particularly in the Ghanaian context, and concludes with a summary. Chapter Three describes the research methodology employed for the study. It outlines the research design, population, sampling procedures, data collection instruments, and how validity and reliability were established. The chapter also explains the procedures for data collection, implementation of the intervention, data analysis, and ethical considerations. Chapter Four presents and discusses the research findings. It includes the results from both the quantitative and qualitative data collected, analyses the performance of the experimental and control groups, and integrates student perceptions with their performance outcomes. The final chapter, Chapter Five, summarises the key findings of the study, draws conclusions based on the research objectives, and offers recommendations for stakeholders such as teachers, school leaders, and educational policymakers. It also suggests possible directions for future research.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter reviews literature on the use of PhET simulations in teaching Electronics. It focuses on their influence on student engagement, conceptual understanding, and academic performance. The chapter examines relevant learning theories, instructional approaches, empirical evidence, and the role of technology in science education. It concludes with the conceptual framework that guides the study.

2.1 Introduction

This chapter critically reviews literature relevant to the use of PhET simulations in teaching Electronics at the Senior High School level. The review examines theoretical perspectives that explain how simulation based learning influences cognitive engagement and academic performance. It also analyses empirical studies that have evaluated the effectiveness of PhET simulations across science disciplines.

Although international research reports positive outcomes associated with simulation based instruction, context specific evidence within Ghanaian Senior High Schools remains limited, particularly in relation to Electronics. Given persistent instructional challenges in visualising abstract electrical concepts, a critical examination of existing scholarship is necessary to establish the relevance of PhET simulations in this context.

The chapter therefore synthesises theoretical foundations, empirical findings, instructional approaches, and technological considerations before presenting the conceptual framework that guides the study. This structure provides a coherent basis for examining the impact of PhET simulations on students' academic performance and perceptions in Electronics.

2.2 Theoretical Framework

This study is primarily grounded in Kolb's Experiential Learning Theory. The theory posits that learning occurs through a cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation. In the context of Electronics education, PhET simulations provide learners with opportunities to manipulate variables, observe outcomes, and test ideas in a virtual environment. These processes reflect experiential learning principles and support deeper conceptual understanding.

The study also draws on the Cognitive Theory of Multimedia Learning, which suggests that students learn more effectively when verbal and visual information are integrated appropriately. PhET simulations combine animations, graphical representations, and interactive elements that engage dual channels of processing. When properly structured, this integration can enhance understanding and academic performance.

In addition, Constructivist theory underpins the interactive nature of simulations. It assumes that learners actively construct knowledge through engagement with tasks and tools. PhET simulations allow students to explore electronic concepts actively rather than passively receiving instruction.

Together, these theories explain how exposure to PhET simulations may influence students' academic performance and perceptions. Experiential Learning Theory provides the central explanatory lens, while Multimedia Learning and Constructivism offer complementary perspectives on how learning occurs within simulation based environments.

2.3 PhET Simulations in Science Education

PhET simulations are interactive digital tools developed by the University of Colorado Boulder to support science teaching and learning. They are widely used in physics, chemistry, biology, and earth science to help students visualise scientific processes that are not easily observed in traditional classroom settings (Wieman et al., 2021). The simulations allow learners to manipulate variables, test relationships, and observe immediate feedback.

In science education, abstract concepts often present learning difficulties. Topics such as electric circuits, force interactions, molecular motion, and energy transfer require learners to understand relationships that are not directly visible. PhET simulations provide dynamic visual representations that support exploration and experimentation. In electronics, for example, students can construct circuits, adjust voltage or resistance, and observe the resulting changes in current flow. This immediate feedback helps students connect theoretical explanations to observable outcomes.

Empirical studies report that simulation based instruction can improve students' conceptual understanding and engagement in science subjects. Perkins et al. (2019) found that students who used PhET simulations demonstrated stronger conceptual gains compared with those who relied solely on traditional instruction. Similarly, Pereira Gomes (2023) reported improved academic performance when simulations were integrated into science lessons alongside teacher guidance. These findings suggest that digital simulations can enhance learning when they complement structured instruction.

Despite growing global evidence, research on the use of PhET simulations in Ghanaian Senior High Schools remains limited. Science teaching in many Ghanaian schools continues to face constraints related to laboratory access, instructional materials, and large class sizes. Under such conditions, digital simulations may offer an alternative means of supporting experimentation and visualisation. However, their effectiveness depends on availability of technological infrastructure and the teacher’s ability to integrate them meaningfully into instruction (Kibiwott & Wanjiru, 2024).

PhET simulations have gained recognition as practical tools for supporting science instruction. Their relevance to electronics teaching lies in their capacity to provide interactive representations of circuit behaviour and electrical relationships, thereby strengthening students’ conceptual understanding.

2.4 Empirical Studies on the Use of PhET in Science Education

PhET simulations have been implemented worldwide, with substantial evidence supporting their effectiveness in improving students’ engagement and understanding of complex scientific concepts.

A study conducted by Perkins et al., (2019) in the United States evaluated the use of PhET simulations in high school physics classrooms. The results demonstrated that students who used PhET simulations showed significantly greater improvement in conceptual understanding compared to those taught using traditional methods.

Pranata (2024) explored how PhET simulations affected students’ understanding of physics. The research revealed that students exposed to PhET simulations performed better on post-tests in comparison to those who only received traditional instruction.

Toma, et al., (2024) examined the impact of PhET simulations on high school chemistry education. The findings suggested that PhET simulations improved students' ability to visualise and understand chemical reactions, atomic structure, and molecular dynamics.

In physics, PhET simulations are widely used to teach topics such as force, motion, electricity, and magnetism. Wieman et al., (2021) showed that PhET simulations enhanced students' ability to grasp fundamental physics concepts, particularly those related to kinematics and thermodynamics. This finding aligns with Mayer's (2021) Cognitive Theory of Multimedia Learning.

In chemistry, Bastos (2020) conducted a study in Portugal where PhET simulations were used in teaching high school chemistry. The research highlighted that students exposed to PhET simulations performed better in tests and connected theoretical knowledge with practical applications.

In biology, Davis and Gernsbacher (2023) demonstrated that PhET simulations helped students understand biological processes such as protein synthesis and ecosystem interactions.

In Ghana, Agyei and Agyei (2021) explored the integration of PhET simulations in teaching Integrated Science at the SHS level. The research found that simulations improved student engagement and conceptual understanding, though implementation was hindered by limited resources and teacher expertise.

Ndihokubwayor et al (2020) assessed the effectiveness of PhET simulations in several sub-Saharan African countries, including Ghana. The study highlighted positive effects in teaching abstract concepts such as waves and electricity, but noted challenges with infrastructure and teacher preparedness.

2.5 Instructional Approaches in Teaching Electronics

Effective instruction in Electronics at the Senior High School (SHS) level requires pedagogical strategies that address the subject's abstract nature while promoting a meaningful understanding of its concepts. Traditional methods, particularly the lecture-based approach, have long been the dominant instructional strategy in Ghanaian classrooms, including those for Integrated Science subjects like Electronics (Buabeng et al., 2016). However, these teacher-centred approaches tend to emphasise rote learning and memorisation, often leaving students with fragmented conceptual understanding and low engagement, especially in complex topics such as current, voltage, resistance, and circuit design (Taale, 2019).

Electronics, as a field rooted in both practical application and abstract reasoning, demands instructional methods that facilitate active student engagement with the content. Conventional teaching methods alone often fail to make intangible concepts, such as the flow of current or the functioning of transistors, accessible to students. This gap in understanding has contributed to the poor performance of SHS students in Electronics-related questions on the West African Senior School Certificate Examination (WASSCE), as highlighted in the WAEC Chief Examiner's Report (2022).

In response to these challenges, constructivist approaches, such as inquiry-based learning, cooperative learning, and the use of simulations, have been introduced across educational settings to improve students' understanding of Electronics (Gambari, Shittu, & Adegun, 2022). Constructivist models emphasise active student participation, collaboration, and the construction of knowledge through exploration and discovery. These methods have proven effective, particularly in STEM education, where learners benefit from engaging with content in diverse ways (Yusuf et al., 2023).

Among the most promising instructional strategies for teaching abstract science topics like Electronics is the integration of Computer-Assisted Instruction (CAI), including interactive simulations such as PhET. CAI methods use technology to provide real-time feedback, allow students to experiment with variables, and visualise abstract concepts, all of which are essential for Electronics education (Finkelstein et al., 2005). PhET simulations, in particular, have been shown to enhance students' understanding of circuit behaviour, Ohm's Law, and the principles of electric power.

For example, Ndihokubwayo, Uwamahoro, and Ndayambaje (2020) found that high school students taught electronics with PhET simulations outperformed their peers taught using traditional methods in post-test assessments. Similarly, Pranata (2024) observed that simulation-based instruction not only led to higher test scores but also improved students' problem-solving and critical thinking abilities.

In the Ghanaian context, the challenge of inadequate laboratory resources in many public SHSs limits teachers' ability to conduct hands-on experiments in Electronics. As a result, students often rely heavily on textbook explanations and blackboard diagrams, which are insufficient for developing a deep understanding of complex concepts (Agyei & Agyei, 2021). The introduction of simulations into instructional practice can help bridge this gap by offering virtual laboratories where students can build circuits, modify components, and measure outputs, thereby reinforcing theoretical knowledge with practical insights (Murphy, 2022).

Experiential learning is another important instructional strategy in Electronics education, where learners actively engage in hands-on tasks such as assembling simple circuits or testing components like batteries and resistors. Kolb's Experiential Learning Theory (1984) highlights the value of learning through concrete experience, reflection, and experimentation principles that align closely with the demands of teaching Electronics. When PhET simulations are integrated into an experiential learning framework, they offer a substitute for physical labs and enhance learning, particularly in resource-constrained schools like Leklebi SHS (Morrison & Collins, 2023).

Despite the advantages of these alternative approaches, challenges remain. Many teachers lack the necessary training to effectively use simulations in the classroom. Additionally, inconsistent electricity supply, limited access to computers, and large class sizes can hinder the successful implementation of technology-enhanced instructional strategies (Banda & Nzabahimana, 2022).

2.6 The Role of Technology in Science Education

Technology has increasingly become a pivotal component in modern science education, transforming traditional teaching practices and expanding opportunities for active, student-centred learning. Educational technologies, including interactive simulations, virtual laboratories, and multimedia tools, have the potential to enhance conceptual understanding, improve engagement, and foster higher-order cognitive skills among learners (Finkelstein et al., 2005; Mayer, 2021). In particular, tools such as PhET simulations provide a dynamic platform for exploring complex scientific phenomena, enabling learners to visualise and manipulate variables in ways that are often impractical or unsafe in traditional classroom settings (Ndihokubwayo et al., 2020; Pranata, 2024).

The integration of technology in science education is grounded in cognitive and constructivist theories, which emphasise active engagement, exploration, and knowledge construction. Through interactive simulations, students can engage in experimentation, hypothesis testing, and observation of outcomes, promoting inquiry-based learning and critical thinking (Wang, et al., 2022; Gulikers, et al., 2022). Moreover, multimedia tools cater to diverse learning styles by combining visual, auditory, and interactive modalities, thereby facilitating deeper cognitive processing and long-term retention of complex concepts (Mayer, 2021; Yusuf et al., 2023).

PhET simulations, specifically, exemplify how technology can support abstract learning in science subjects such as physics, chemistry, and electronics. By providing virtual experiments, students can explore otherwise inaccessible concepts, such as electric circuit behaviour, molecular interactions, or energy transformations, in a safe and engaging environment. This approach addresses the challenges of traditional laboratory-based teaching, where resource constraints, safety concerns, and limited equipment often restrict experiential learning (Agyei & Agyei, 2021; Murphy, 2022). Furthermore, simulations offer immediate feedback and allow for repeated experimentation, which enhances learning through reflection and iterative problem-solving, consistent with Kolb's Experiential Learning Theory (Kolb, 1984; Morrison & Collins, 2023).

Despite these advantages, integrating technology into science education also presents significant challenges, particularly in resource-constrained environments. Schools in many developing countries, including Ghana, often face limitations in infrastructure, such as inadequate access to electricity, insufficient computing devices, and poor internet connectivity (Banda & Nzabahimana, 2022; Ndihokubwayo et al., 2020). Additionally, teachers may lack the requisite training or technological competence to effectively incorporate simulations into their instructional practice, reducing the potential benefits of these tools (Chai, Koh, & Tsai, 2020).

Despite these barriers, evidence indicates that even minimal integration of technology, when strategically implemented, can significantly enhance students' learning experiences. Research demonstrates that the use of PhET simulations improves student engagement, facilitates conceptual understanding of complex topics, and fosters motivation for science learning (Pranata, 2024; Pereira Gomes, 2023; Finkelstein et al., 2005).

2.7 Use of PhET Simulations in Teaching Electronics

The teaching of electronics at the Senior High School (SHS) level is particularly challenging due to its reliance on abstract concepts and complex theoretical models. Traditional teaching methods, such as lectures and textbook explanations, often fail to provide students with the hands-on experience necessary to fully grasp the principles of electronics. PhET simulations, as an educational tool, offer a promising solution by providing interactive, visual, and immersive learning experiences that enhance students' understanding of electronic concepts (Finkelstein et al., 2005; Pranata, 2024).

PhET simulations make abstract scientific concepts accessible and comprehensible by allowing students to interact with virtual models of electrical circuits, manipulate variables, and visualise phenomena such as the flow of electric current, voltage, resistance, and the behaviour of components like resistors, capacitors, and transistors (Ndihokubwayo et al.,2020; Pereira Gomes, 2023). Through these simulations, students can observe the immediate effects of their actions on the circuit, which helps them connect theory with practical application. The interactive nature of these simulations encourages active learning, promotes exploration, and supports problem-solving. Students are able to experiment with variables, test hypotheses, and see the consequences of their actions in real-time, thereby reinforcing conceptual understanding (Gulikers et al., 2022; Yusuf et al., 2023).

The challenges in teaching electronics are significant. Many concepts, such as the flow of current or the functioning of transistors, are inherently abstract and difficult for students to visualise (Taale, 2019). Limited practical exposure in schools without sufficient laboratory facilities prevents learners from experiencing hands-on experimentation. Traditional, teacher-centred instruction often results in passive learning, rote memorisation, and low engagement, leaving students with fragmented knowledge (Buabeng et al., 2016). Furthermore, inadequate teacher training in technology integration and large class sizes pose additional barriers to effective instruction (Banda & Nzabahimana, 2022).

PhET simulations address these challenges by providing a virtual, low-risk environment where students can explore and experiment freely. The simulations allow learners to visualise abstract processes, manipulate circuit components, and receive immediate feedback on their actions (Finkelstein et al., 2005). This promotes self-directed learning, reduces anxiety associated with complex concepts, and encourages students to engage in inquiry-based exploration (Wanget al., 2022).

In Ghana, the lack of laboratory resources in many public SHSs often forces teachers to rely heavily on textbooks and blackboard diagrams, which are insufficient for building deep understanding of electronics (Agyei & Agyei, 2021). PhET simulations provide an accessible alternative, enabling students to construct circuits, modify components, and measure outputs in a virtual environment. This hands-on engagement reinforces theoretical knowledge and aligns with Kolb's Experiential Learning Theory (Kolb, 1984; Morrison & Collins, 2023).

Empirical studies demonstrate the effectiveness of PhET simulations in enhancing learning outcomes. Ndihokubwayo et al. (2020) reported that Rwandan high school students taught electronics using PhET simulations performed significantly better in post-tests than peers taught through traditional methods. Similarly, Pranata (2024) observed that simulation-supported instruction improved not only test scores but also students' problem-solving and critical thinking skills. These studies highlight that simulations allow learners to experiment safely, make mistakes, and learn from them, fostering a more engaging and effective learning process (Perkinset al., 2019; Toma et al., 2024).

2.8 Challenges in Teaching Electronics and How PhET Simulations Address Them

Teaching Electronics at the Senior High School (SHS) level is fraught with multiple challenges that hinder student understanding, engagement, and performance. These challenges arise from the abstract nature of the subject, limited resources, and traditional teaching approaches that dominate many Ghanaian classrooms. Electronics involves concepts such as current, voltage, resistance, and circuit design, which are inherently abstract and often difficult for students to visualise (Taale, 2019). The lack of practical exposure further exacerbates this difficulty, as many schools, particularly in resource-constrained areas, do not have fully equipped laboratories. Consequently, students frequently rely on textbooks and blackboard diagrams, which are insufficient for developing a robust conceptual understanding of electronic principles (Agyei & Agyei, 2021).

Another challenge is the predominance of teacher-centred instruction. Traditional lecture methods emphasise rote learning and memorisation rather than critical engagement with the material, resulting in low student participation and poor conceptual retention (Buabeng et al., 2016). Students may memorise formulas without understanding their practical applications, leaving them unprepared for both examination tasks and real-world applications. The WAEC Chief Examiner’s Report (2022) highlights that many SHS candidates either avoid or poorly attempt questions on Electronics in the WASSCE due to insufficient practical understanding and conceptual clarity.

Inadequate teacher preparation and limited training in integrating technology into instruction further compound these issues. Teachers may lack the technical skills necessary to implement simulation-based learning effectively, and even when resources such as computers or electricity are available, large class sizes and insufficient guidance can hinder successful implementation (Banda & Nzabahimana, 2022).

PhET simulations offer a strategic solution to these challenges by providing an interactive, visual, and experiential learning environment. These simulations allow students to manipulate circuit components, adjust variables such as resistance and voltage, and immediately observe the outcomes of their actions, making previously invisible concepts tangible (Ndihokubwayo et al., 2020; Pereira Gomes, 2023). Through this interactive engagement, students can experiment safely, test hypotheses, and explore scientific principles in a low-risk environment, which encourages self-directed learning and reduces anxiety associated with complex topics (Pranata, 2024).

Moreover, PhET simulations support inquiry-based and constructivist pedagogical approaches. By encouraging learners to pose questions, explore alternatives, and actively participate in the learning process, simulations foster deeper understanding and critical thinking (Wang et al., 2022; Yusuf, et al., 2023). Students are able to see the immediate consequences of their actions within virtual circuits, linking theoretical concepts to observable outcomes. This approach aligns with Kolb's Experiential Learning Theory (1984), which emphasises the importance of learning through concrete experience, reflection, and experimentation (Morrison & Collins, 2023).

PhET simulations also provide an alternative to physical laboratories, which are often limited or unavailable in Ghanaian SHSs. Virtual labs enable students to construct circuits, modify components, and measure outputs without the constraints of physical materials or safety risks. This accessibility ensures that all students, regardless of their school's resource level, can engage in meaningful experimentation, reinforcing theoretical learning with practical insights (Murphy, 2022).

Finally, PhET simulations enhance teacher effectiveness by offering a tool to visualise complex electronic phenomena that might otherwise be challenging to demonstrate in class. Simulations enable teachers to illustrate abstract principles dynamically, providing students with real-time feedback on their understanding and allowing for more formative assessment (Finkelstein et al., 2005). However, successful implementation requires teachers to receive appropriate training in simulation use and classroom integration, highlighting the need for professional development programmes and investment in ICT infrastructure (Banda & Nzabahimana, 2022).

2.9 Students' Perceptions of PhET Simulations in Science Education

Students' perceptions of instructional strategies form an important dimension of contemporary science education research. Perception influences motivation, engagement, self-efficacy, and sustained interest in scientific learning. In technology supported classrooms, how students interpret the usefulness, clarity, and relevance of digital tools often shapes the extent to which those tools contribute to meaningful learning outcomes.

Recent studies indicate that students generally report favourable perceptions of simulation based learning in science subjects. For example, Ndihokubwayo et al. (2020) found that secondary school students perceived PhET supported instruction as clearer as and more engaging than conventional teaching methods. Students reported improved confidence in understanding abstract scientific concepts after interacting with simulations. The study further observed that learners appreciated the opportunity to manipulate variables and observe immediate feedback, which they associated with deeper understanding.

Similarly, Wang et al. (2022) examined simulation supported inquiry learning in secondary science classrooms and reported that students perceived the learning environment as more interactive and intellectually stimulating. Participants indicated that simulations enhanced their ability to test ideas and visualise scientific relationships. The authors concluded that positive perceptions were linked to higher levels of cognitive engagement and improved conceptual reasoning.

More recently, Pereira Gomes (2023) investigated students’ responses to simulation based instruction in physics and reported that learners expressed strong perceptions of usefulness and clarity. Students indicated that simulations reduced confusion around abstract principles and allowed them to connect theoretical explanations with observable outcomes. Importantly, the study found a relationship between positive perceptions and improved academic performance.

Research has also explored students’ attitudes towards digital learning tools in sub Saharan African contexts. Yusuf et al. (2023) reported that senior secondary school students demonstrated favourable attitudes towards simulation supported science lessons, particularly where simulations complemented teacher explanation. However, the study noted that students’ perceptions were influenced by the level of guidance provided and access to reliable technological infrastructure.

Although many students express positive views of simulation based learning, the literature also emphasises that perception is shaped by instructional design. Gulikers et al. (2022) argue that digital tools are most effective when embedded within structured tasks and supported by clear pedagogical guidance. Without such structure, students may engage superficially with the simulation rather than focusing on conceptual understanding.

Within the Ghanaian Senior High School context, empirical research on students’ perceptions of PhET simulations remains limited. Given existing challenges in science education, including limited laboratory resources and teacher centred instruction, it is important to examine whether students perceive simulation-based teaching as beneficial, understandable, and relevant to their learning needs. Understanding students' perceptions will therefore provide insight into the acceptability and practical value of PhET simulations in teaching Electronics.

Recent literature suggests that students tend to perceive simulation-based science instruction positively, particularly in relation to clarity, engagement, and conceptual support. However, context specific evidence remains insufficient. This justifies the present study's focus on exploring students' perceptions of PhET simulations in Senior High School Electronics.

2.10 Conceptual Framework

The conceptual framework for this study specifies the instructional method as the independent variable and students' academic performance in Electronics as the dependent variable. The instructional method comprises two approaches: PhET simulation based instruction and traditional teacher centred instruction. Academic performance is measured through pretest and post test scores in Electronics.

The framework is grounded primarily in Mayer's Cognitive Theory of Multimedia Learning, which posits that learning improves when information is presented through coordinated verbal and visual channels (Mayer, 2021). PhET simulations integrate animations, visual representations, and interactive features that support dual channel processing and deeper cognitive organisation. When properly structured, such multimedia environments enhance conceptual understanding and retention.

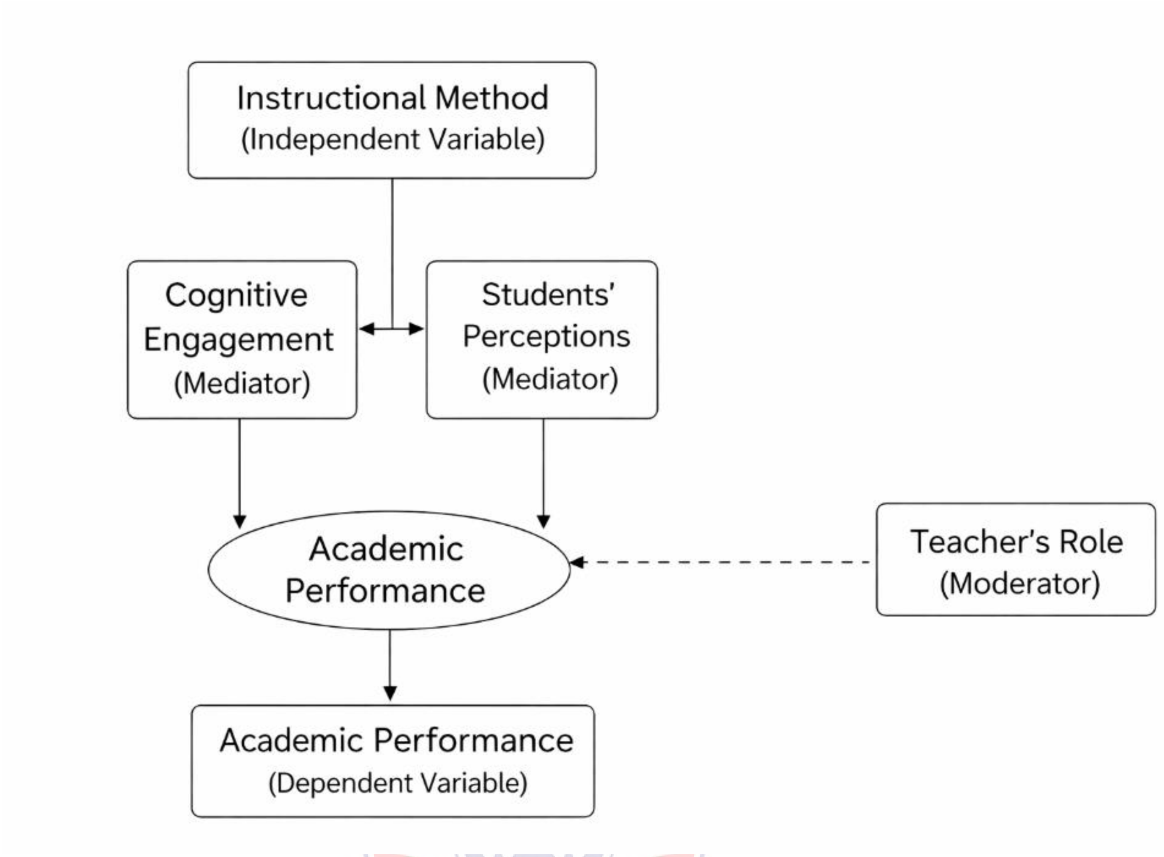
The relationship between instructional method and academic performance is mediated by students' cognitive engagement and students' perceptions. Cognitive engagement refers to the degree of active involvement in learning tasks, including attention, effort, and meaningful processing of content. Interactive simulations allow learners to manipulate variables, observe outcomes, and test conceptual relationships in real time, which can strengthen engagement and conceptual change (Ndihokubwayo et al., 2020; Wang et al., 2022). Increased engagement is expected to contribute to improved performance outcomes.

Students' perceptions constitute a second mediating variable. Perceptions of usefulness, clarity, relevance, and enjoyment influence motivation and willingness to invest effort in learning tasks. Positive perceptions of simulation based instruction have been associated with improved learning outcomes and sustained interest in science subjects (Gulikers et al., 2022; Yusuf et al., 2023). In this study, students' perceptions help explain how exposure to PhET simulations may translate into measurable academic gains.

The teacher's role operates as a moderating variable. Teachers guide instructional delivery, provide scaffolding, and ensure comparable content coverage across experimental and control groups. Effective facilitation may strengthen the impact of the instructional method on engagement and performance, whereas inadequate guidance may reduce its effectiveness (Banda & Nzabahimana, 2022; Morrison & Collins, 2023).

Overall, the framework proposes a directional relationship in which instructional method influences cognitive engagement and students' perceptions, which in turn affect academic performance in Electronics. By clearly distinguishing the independent, dependent, mediating, and moderating variables, the framework provides a structured basis for examining differences between students exposed to PhET simulations and those taught using conventional teaching method.

Figure 1: Conceptual framework



CHAPTER THREE

METHODOLOGY

3.0 Overview

This chapter outlines the research design employed in the study, detailing the target population, sample size, sampling procedures, and the instruments used for data collection. It further explains how the validity and reliability of the primary instruments were ensured, describes the treatment process, and discusses the procedures for collecting and analysing the data.

3.1 Research Design

This study employed a quasi-experimental design, specifically the non-equivalent control group pre-test–post-test design, to examine the impact of experiential learning on students' academic performance in the topic of Electronics. This design is widely used in educational research where random assignment is not feasible, as it allows for comparison between groups while accommodating the realities of classroom settings (Creswell & Creswell, 2018).

The non-equivalent nature of the design refers to the fact that the groups were not randomly assigned but were instead selected from existing classroom populations. According to Fraenkel, et al., (2019), this approach is appropriate in school-based research where practical constraints prevent randomisation, yet rigorous comparison is still desired.

This design was suitable for the current study because it enabled the researcher to investigate cause-and-effect relationships under natural classroom conditions, using pre- and post-intervention data to measure the effect of the teaching strategy on academic outcomes. As Gay et al., (2012) explain, pre-test–post-test control group designs are particularly useful for evaluating instructional innovations in real-life educational contexts.

3.2 Research Approach

The study adopted a quantitative research approach because the purpose was to measure the effect of PhET simulations on students' academic performance in Electronics using numerical data. A quantitative approach provides a systematic and objective means of examining relationships between variables and enables the researcher to draw valid conclusions based on statistical evidence. As Creswell and Creswell (2018) explain, quantitative methods are appropriate when the intention is to test hypotheses, evaluate interventions, and determine the extent to which changes in outcomes can be attributed to specific treatments.

The research approach was grounded in the principles of objectivity, measurement, and replicability. By employing structured instruments such as pre-tests, post-tests, and a Likert-scale questionnaire, the study ensured consistency in data collection across both the experimental and control groups. This approach also allowed for the use of inferential statistics, including independent samples t-tests and paired samples t-tests, to determine whether observed differences in performance were statistically significant.

The choice of a quantitative approach was particularly relevant to this study because it aimed to examine cause-and-effect relationships in a classroom environment. As Fraenkel et al., (2019) note, quantitative designs are suitable for educational research where researchers seek to evaluate the impact of instructional strategies on learning outcomes. Through systematic analysis of test scores, the research approach enabled a clear comparison between traditional instruction and PhET-based teaching, strengthening the validity of conclusions drawn about the effectiveness of the intervention.

In addition, the quantitative approach enhanced the reliability of the study by reducing researcher bias. The use of numerical data allowed for transparent interpretation and enabled other researchers to replicate the study under similar conditions. Overall, the research approach provided a structured, rigorous framework for assessing the effectiveness of PhET simulations in improving students' understanding and performance in Electronics.

3.3 The Research Population

A research population refers to a well-defined group of individuals or elements that share common characteristics relevant to a particular study (Creswell & Creswell, 2018). In this study, the target population comprised all second-year students offering Integrated Science at Leklebi Senior High School within the Volta Region of Ghana. The accessible population consisted of all Form Two General Arts and Visual Arts students at Leklebi Senior High School.

Leklebi Senior High School was purposively chosen due to the researcher's teaching role at the school, which provided easy access to students and institutional cooperation. As an Integrated Science teacher, the researcher was able to coordinate instructional activities, implement the PhET simulation intervention effectively, and observe the learning process closely factors that contributed to the smooth execution of the research (Fraenkel et al., 2019).

These two groups were selected because both General Arts and Visual Arts students are enrolled in the Integrated Science course, and the topic of Electronics is taught in the second year as part of the approved curriculum. Including both groups ensured diversity and enhanced the generalisability of the findings to a wider range of non-Science elective students.

3.4 Sample and Sampling Technique

A purposive sampling technique was employed to select the classes used for the study. This non-probability method was considered appropriate because it enabled the researcher to deliberately select groups that had already been taught the relevant Integrated Science content, were accessible, and were willing to participate in the research (Palinkas et al., 2015). Given the school-based nature of the study, purposive sampling ensured that the chosen participants were suitable for the intervention and aligned with the research objectives.

The selection process began with the administration of a pre-test to all Form Two General Arts and Visual Arts students at Leklebi Senior High School. The purpose of this preliminary assessment was to determine whether any significant differences existed in the academic performance of the classes prior to the intervention. After the pre-test results were analysed, two intact classes were identified as academically comparable.

In total, eighty-nine (89) students participated in the study: 46 students from General Arts 1 and 43 students from Visual Arts 1. Statistical analysis confirmed that there was no significant difference between the mean scores of the two groups, thereby validating their suitability for a quasi-experimental comparison.

Following this equivalence check, General Arts 1 (n = 46) was designated as the experimental group, while Visual Arts 1 (n = 43) served as the control group. The decision to assign General Arts 1 as the experimental group was informed by practical considerations: the researcher was the Integrated Science teacher for this class during the 2024/2025 academic year, which made it possible to supervise the PhET simulation activities more effectively and to ensure consistent implementation of the intervention. In contrast, Visual Arts 1, serving as the control group, received instruction through the conventional teaching methods. Both groups were taught the same Integrated Science content on Electronics, ensuring that the instructional method was the only substantive difference between them.

Form Two students were purposively selected because Electronics is taught at the second year level within the Integrated Science syllabus for Ghanaian Senior High Schools. This ensured that the content addressed during the intervention was relevant, appropriate for their level, and aligned with curricular expectations. The researcher's teaching role at Leklebi Senior High School further facilitated access to the participants, enhanced cooperation, and supported the smooth execution of the study (Fraenkel et al., 2019).

3.5 Research Instruments

This study employed two main instruments for data collection: a test and a questionnaire. Two equivalent tests were used to gather quantitative data from both the experimental and control groups, while the questionnaire was designed to collect qualitative data from the experimental group regarding their perceptions of the PhET simulation-based instructional method used in teaching the topic of Electronics.

3.5.1 Test

The study employed two structured achievement tests to measure students' knowledge and performance in Electronics. The pre-test was labelled as the Student Knowledge Test on Electronics (SKTE), while the post-test was referred to as the Student Achievement Test on Electronics (SATE). Both instruments were developed in alignment with the Integrated Science curriculum, specifically the topic of Electronics, which is part of the second-year syllabus for Senior High Schools in Ghana.

The SKTE (see Appendix A) was administered one week prior to the commencement of the treatment to establish baseline knowledge and identify areas of difficulty in students' understanding of basic Electronics concepts. Following the instructional intervention with PhET simulations, the SATE (see Appendix B) was administered to measure students' performance, conceptual understanding, and knowledge retention in Electronics.

Each test comprised twenty (20) items, consisting of ten (10) multiple-choice questions and ten (10) true-or-false questions. A standardised marking guide was developed for both instruments (see Appendices C and D), with each test carrying a total score of twenty (20) marks. Students were given thirty (30) minutes to complete each test under supervised conditions.

The scores from both the experimental group (General Arts 1) and the control group (Visual Arts 1) were collected, analysed, and documented in Appendices E and F. These appendices present the raw data for each group, confirming the comparability of the classes at baseline and the subsequent differences in achievement after the intervention.

By combining the SKTE and SATE with standardised marking guides and detailed score tables, the study ensured transparency, consistency, and reliability in the measurement of learning outcomes. This comprehensive documentation of instruments and results strengthens the validity of the findings and provides a clear framework for replication in similar educational contexts.

3.5.2 Questionnaire

The questionnaire used in the study was administered to the experimental group to gather their feedback on the effectiveness and user experience of the PhET simulation tool. The items were carefully structured to capture students' attitudes, engagement, and perceived learning benefits associated with the intervention.

The questionnaire consisted of ten (10) items designed using a five-point Likert scale format. The response options included: Strongly Agree (SA), Agree (A), Uncertain (U), Disagree (D), and Strongly Disagree (SD). Students were instructed to indicate their level of agreement with each statement by ticking the most appropriate option. The aim was to understand students' levels of engagement, interest, and perceived benefits associated with the use of PhET simulations during instruction. The full questionnaire is included in Appendix E.

v Trial Testing of the Instruments

A pilot test was conducted to assess the clarity, reliability, and suitability of the pre test and post test instruments developed for the study. The purpose of the trial testing was to identify ambiguous items, assess item difficulty, and evaluate the overall internal consistency of the instruments before their use in the main study.

The pilot was conducted with twenty Form Two Visual Arts students at Leklebi Senior High School who were not included in the final experimental or control groups. Although the pilot was conducted within the same school, several measures were taken to minimise potential influence on the main study.

First, the pilot participants were drawn from a different intact class that did not participate in the quasi-experimental comparison. Second, the test items were reviewed and modified after the pilot phase to improve clarity and structure. Some items were reworded, rearranged, or replaced. This reduced the likelihood that the exact pilot instrument would reappear in the main administration. Third, the pilot group was not exposed to the instructional intervention used in the main study, and no discussion of the test content was encouraged beyond the pilot session.

To further reduce test sensitisation effects, the time interval between the pilot test and the main data collection was sufficient to minimise recall of specific items. These measures helped to ensure that conducting the pilot in the same school did not compromise the internal validity of the study.

The pilot data were also used to compute reliability coefficients using Cronbach's alpha to determine internal consistency. Items with low discrimination or poor performance were revised or removed prior to the main administration. This process strengthened the overall quality and dependability of the instruments.

3.6 Validity of the Instruments

Validity refers to the extent to which an instrument truly measures the concept it is intended to assess. According to Fraenkel, Wallen, and Hyun (2019), establishing validity ensures that the inferences drawn from test results are appropriate and relevant to the purpose of the study.

In this research, emphasis was placed on content validity, which considers whether the items included in the instruments thoroughly reflect the subject matter under investigation. The test and questionnaire items were carefully designed to align with the Integrated Science syllabus, standard textbooks used in Ghanaian senior high schools, and past WASSCE questions, all of which focused on the topic of Electronics.

To ensure that the items were valid in terms of content, the instruments were submitted for expert review. The review panel included seasoned Integrated Science educators, the Head of the Science Department at Leklebi Senior High School, and the researcher's academic supervisor. These individuals assessed the instruments for clarity, scientific accuracy, relevance to the curriculum, and appropriateness for the cognitive level of Form Two students.

Constructive feedback from the panel led to the revision of some items to enhance their alignment with instructional goals and student comprehension levels. This comprehensive validation process played a crucial role in confirming that the instruments were capable of accurately measuring students' knowledge and perceptions related to Electronics.

3.7 Reliability of the Instruments

Reliability refers to the consistency or stability of an instrument in measuring what it is intended to measure over time. According to Fraenkel, Wallen, and Hyun (2012), an instrument is said to be reliable if it yields the same results under consistent conditions. A reliable instrument ensures that the data collected are dependable and reproducible.

In this study, reliability was established for both the test and the questionnaire through a pilot testing process. The trial-testing was conducted using a group of 20 second-year Visual Arts students from Ve Senior High School, who were not part of the actual sample. This was done to determine the internal consistency of the instruments.

The reliability coefficient for the achievement test was calculated using the Kuder-Richardson Formula 20 (KR-20), which is appropriate for items with dichotomous responses such as multiple-choice and true/false. The questionnaire, which employed a Likert scale format, was analysed using Cronbach's alpha to measure internal consistency.

The KR-20 reliability coefficient for the pre-test and post-test was found to be 0.78, indicating acceptable reliability (Gay et al., 2011). Similarly, the Cronbach's alpha coefficient for the questionnaire was 0.81, suggesting a high level of internal consistency among the questionnaire items (George & Mallery, 2003). These results confirmed that the instruments were sufficiently reliable for use in the main study.

3.8 Data Collection Procedure

An introductory letter was secured from the Head of Department, Science Education, University of Education, Winneba (UEW). This letter was presented to the Headmaster and the Head of Science Department of Leklebi Senior High School to seek official permission to conduct the study. Once approval was granted, the data collection process began.

A pre-test was first administered to both the experimental and control groups to assess students' initial understanding of the selected electronics concepts. Following the pretest, students in the experimental group were taught using PhET-based computer-assisted instructional methods, while those in the control group received instruction through conventional teaching strategies such as lectures and demonstrations.

Upon completion of the instructional period, a post-test was administered to both groups. The researcher personally supervised the administration of all tests and the questionnaire to ensure strict adherence to the instructions, discourage cheating, and maintain the integrity of the responses. Students were not allowed to copy from one another, and adequate time was given for completion.

The completed scripts were collected immediately, marked, and the results recorded. Feedback was then provided to the students by returning the marked scripts after the post-test. These pretest and post-test instruments provided the quantitative data needed for measuring the academic performance of students before and after the intervention.

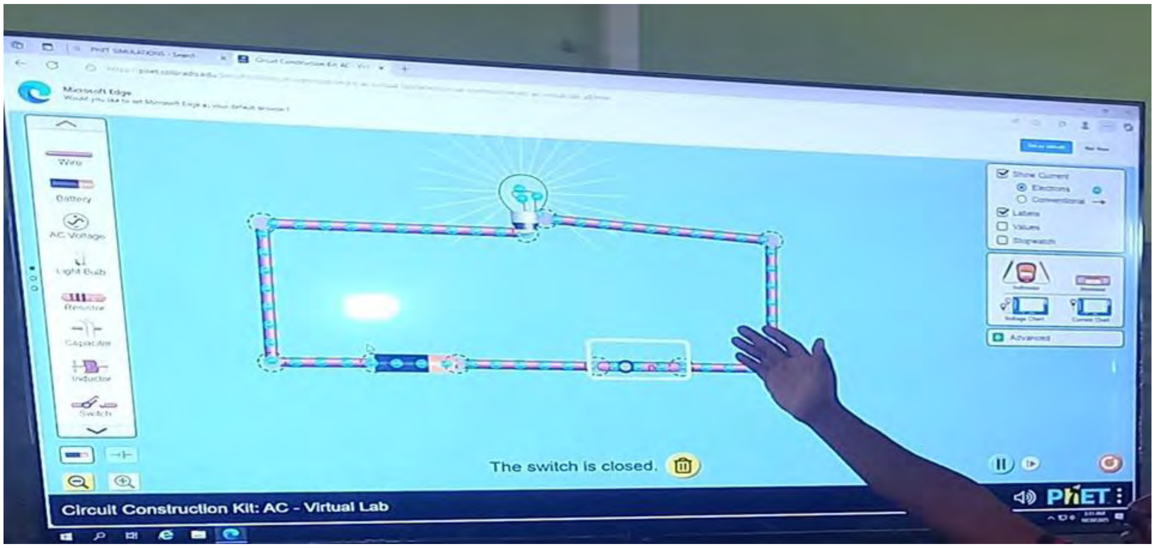
In addition to the tests, a questionnaire was given to the experimental group after the post-test to gather qualitative data on their perceptions and experiences with the use of PhET simulations in learning Electronics. This helped the researcher evaluate the effectiveness and student reception of the computer-assisted instructional approach.

3.9 Intervention Implementation

The intervention was conducted over five weeks during the first semester of the 2024/2025 academic year at Leklebi Senior High School. Two Form Two classes participated: General Arts, designated as the experimental group, and Visual Arts, designated as the control group. Both groups were exposed to the same Integrated Science content on Electronics, but the instructional approaches differed. The experimental group received computer-assisted instruction using PhET simulations, while the control group was taught using conventional teaching methods.

Week 1: Concept Review

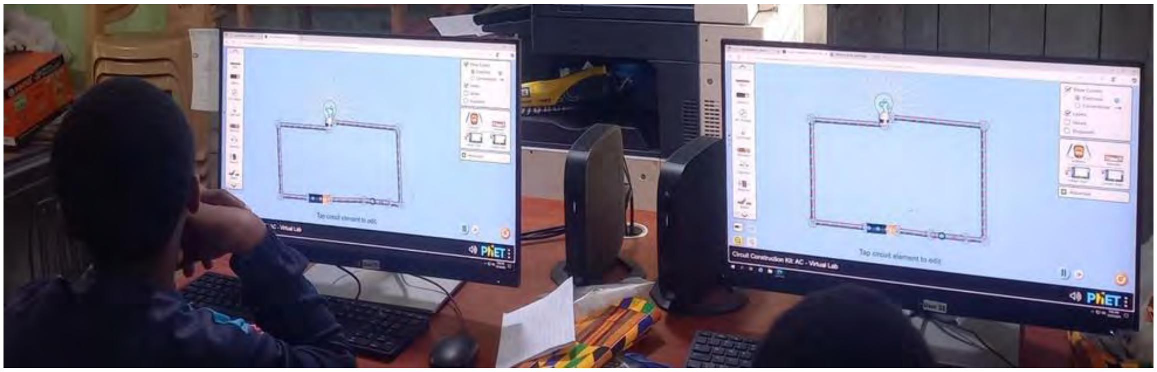
The researcher began by reviewing basic electronics concepts with the experimental group to establish a strong conceptual foundation. Key topics included current, voltage, resistance, series and parallel circuits, conductors, insulators, Ohm’s Law, and electrical energy. This review allowed students to consolidate prior knowledge and prepared them for interactive, simulation-based activities.



Screenshot of the PhET interface showing basic circuit simulations

Week 2: Exploring Electric Current

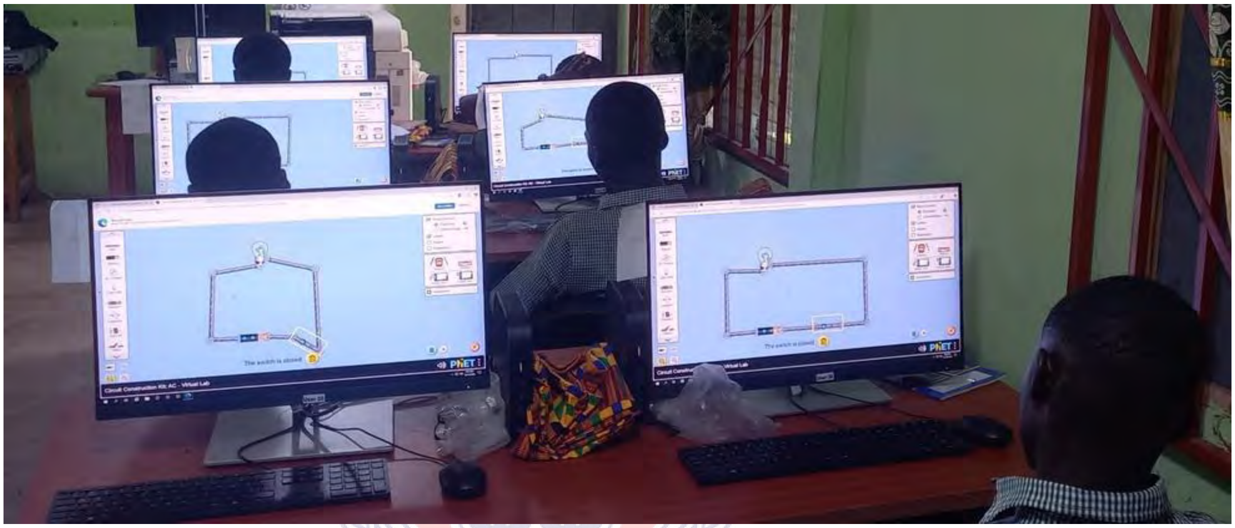
Students in the experimental group engaged with PhET simulations to observe the flow of electrical current through circuits. They constructed simple virtual circuits, experimenting with battery and bulb arrangements to visualise changes in brightness and current. The interactive tool enabled students to manipulate variables and observe outcomes in real time, fostering active learning and engagement.



Photograph of students constructing simple circuit on computers.

Week 3: Understanding Ohm’s Law

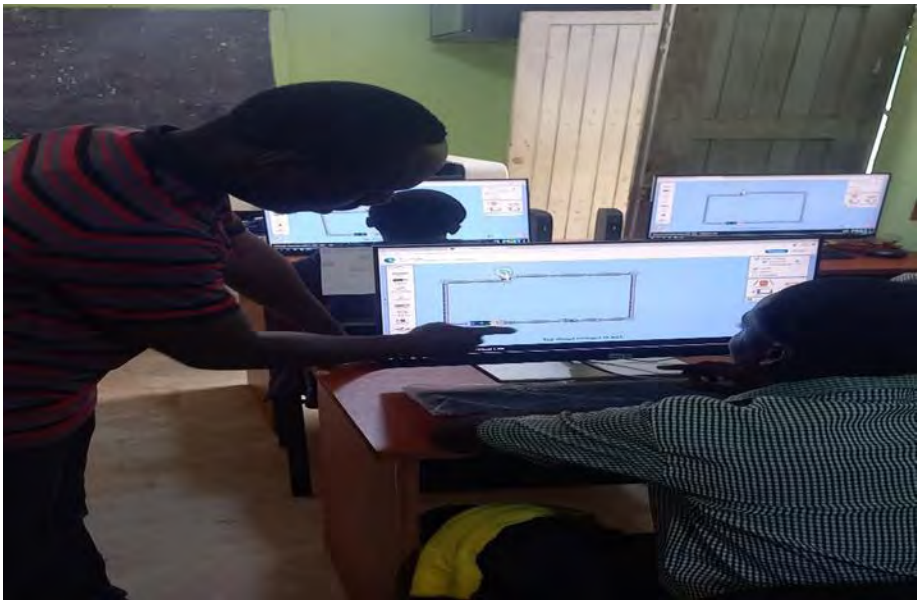
The focus of instruction shifted to Ohm’s Law, with students using PhET simulations to investigate the relationship between voltage, current, and resistance. By adjusting variables and observing changes in current, learners deepened their understanding through visual and interactive learning, which supported the construction of accurate mental models of the concepts.



Photograph of the Ohm’s Law simulation showing variable adjustments

Week 4: Series and Parallel Circuits

Students explored series and parallel circuits using the simulation. They compared how current and voltage behaved in each configuration, reinforcing theoretical knowledge through virtual experimentation. This interactive approach allowed learners to link abstract concepts with observable outcomes, enhancing comprehension and retention.



Photograph of facilitator guiding students on series and parallel circuits simulations

Week 5: Consolidation and Real-Life Applications

In the final week, students examined real-life applications of Electronics. They were organised into teams of five and engaged in practical exercises using the PhET tool to solve circuit-related problems. The researcher supplemented the simulations with PowerPoint presentations summarising and reinforcing key concepts. Collaborative problem-solving and discussion encouraged deeper engagement and applied understanding of Electronics.

Meanwhile, the control group (Visual Arts) received instruction using traditional methods. Teaching strategies included chalkboard illustrations, discussions, textbook references, questioning techniques, and note-taking. Students also participated in group exercises, working in teams of five to solve problems related to each week's topics. While content coverage was identical for both groups, the key distinction was the instructional approach: technology-enhanced, interactive simulations for the experimental group versus conventional teacher-led instruction for the control group.

3.10 Data Analysis Procedure

The data gathered from the pretest, post-test, and student perception questionnaire were analysed using quantitative methods, consistent with the design and instruments employed in the study. The analysis focused on numerical data generated from test scores and Likert-scale responses, allowing for objective interpretation and statistical comparison between the experimental and control groups.

To evaluate students' academic performance before and after the intervention, the pretest and post-test scores from both groups were entered into the Statistical Package for the Social Sciences (SPSS) version 26. Descriptive statistics, including means, standard deviations, and frequency distributions, were computed to describe trends in performance and provide an overview of students' levels of achievement.

Inferential statistics were used to determine whether the differences observed between the groups were statistically significant. An independent samples t-test was conducted to compare the pretest mean scores of the experimental and control groups, enabling the researcher to establish baseline equivalence prior to the intervention. A second independent samples t-test was used to compare post-test mean scores to assess the effectiveness of PhET simulation-based instruction relative to the traditional lecture method. In addition, a paired samples t-test was performed for the experimental group to determine the extent of improvement following the intervention.

The questionnaire administered to the experimental group also generated quantitative data. Responses on the five-point Likert scale were analysed using frequencies, percentages, means, and standard deviations. This analysis provided a numerical summary of students' perceptions of the PhET simulation-based approach, offering insight into their levels of engagement, confidence, and perceived understanding. Because the questionnaire consisted entirely of closed-ended items, the analysis remained strictly quantitative.

The use of descriptive and inferential statistics enabled a systematic and objective evaluation of both academic performance and student perceptions, ensuring that conclusions drawn about the effectiveness of PhET simulations were supported by clear empirical evidence.

3.11 Ethical Considerations

Ethical guidelines were strictly followed throughout the research process to ensure that the rights, privacy, and welfare of all participants were protected. Prior to the commencement of the study, an introductory letter was obtained from the Department of Science Education, University of Education, Winneba, and presented to the Headmaster and the Head of Science Department of Leklebi Senior High School to formally seek permission to conduct the research.

Upon approval, the purpose and procedures of the study were clearly explained to the participants. The researcher emphasised that participation was voluntary, and students were informed of their right to withdraw from the study at any stage without any negative consequences.

Informed consent was obtained verbally from all participating students. Since the participants were minors, the school authorities provided additional approval as gatekeepers. Participants were assured that the data collected would be used solely for academic purposes and that all responses would be kept confidential. To ensure anonymity, students were not required to write their names on any of the instruments.

Moreover, during the intervention and data collection stages, the researcher ensured that no student was placed at a disadvantage. Lessons delivered to both the control and experimental groups were based on the same Integrated Science syllabus, and identical learning objectives were addressed.

All ethical procedures adhered to the University of Education, Winneba's research ethics standards and were guided by the principles of respect, beneficence, and justice in educational research.

CHAPTER FOUR

PRESENTATION, ANALYSIS, AND DISCUSSION

4.0 Overview

This chapter presents and analyses the findings of the study on the effect of PhET simulations on the academic performance of Form Two students in Electronics at Leklebi Senior High School. The analysis is structured in line with the study's objectives and research questions to ensure that the results comprehensively address the main purpose of the investigation.

A comparative analysis is then conducted to determine the effect of the PhET simulation-based intervention relative to the traditional lecture method. In addition, the perceptions of the experimental group regarding the use of PhET simulations are presented, based on questionnaire responses. Finally, the findings are discussed in relation to existing literature, highlighting consistencies, divergences, and implications for science education in Ghana.

4.1 Pre-test Performance

Research Question 1: What is the difference in performance between the experimental and control groups before PhET simulations?

An independent samples *t* test was conducted to determine whether there was a statistically significant difference between the pre-test scores of the experimental and control groups prior to the intervention.

Table 4.1: *Independent Samples t-test for Pre-test Scores*

Group	N	Mean	SD	t	df	p-value
Experimental (Pre-test)	46	6.08	3.89	.75	87	.457
Control (Pre-test)	43	6.42	3.67			

Note. M = mean; *SD* = standard deviation.

An independent samples *t*-test was conducted to compare the pre-test scores of the experimental group (General Arts 1, *n* = 46) and the control group (Visual Arts 1, *n* = 43). Results indicated no statistically significant difference between the groups, *t*(87) = 0.75, *p* = .457. This confirms that the two groups were academically comparable before the intervention.

4.2 Effect of PhET Simulations on Experimental Group Performance

Research Question 2: What is the effect of PhET simulations on experimental group performance in Electronics?

A paired samples *t* test was conducted to determine whether there was a statistically significant difference between the pre-test and post-test scores of the experimental group following exposure to PhET simulations.

Table 4.2: Descriptive and Paired Samples t-test Results for Pre-test and Post-test Scores of the Experimental Group

Test	N	Mean	SD	Mean Difference	SD of Difference	t	df	p-value
Pre-test	46	6.08	3.89					< .001
Post-test	46	15.98	3.57	7.26	2.64	20.24	45	

Note. M = mean; SD = standard deviation.

Table 4.2 presents both the descriptive statistics and the paired samples *t*-test results for the experimental group's performance before and after the PhET simulation intervention. The mean pre-test score was 6.08 (SD = 3.89), while the mean post-test score increased to 15.98 (SD = 3.57). The paired samples *t*-test confirmed that this improvement was statistically significant, $t(45) = 20.24$, $p < .001$, with a mean difference of 7.26 (SD = 2.64). These results indicate that the PhET simulations had a strong positive effect on students' understanding of Electronics concepts.

4.3 Comparative Post-test Performance of Experimental and Control Groups

Research Question 3: What is the effect of PhET simulations on student performance in electronics compared to conventional teaching methods?

An independent samples *t*-test was conducted to compare the post-test scores of the experimental and control groups.

Table 4.3: ***Independent Samples t-test for Post-test Scores***

Group	N	Mean	SD	t	df	p-value
Experimental (Post-test)	46	15.98	3.57	12.45	87	< .001
Control (Post-test)	43	8.21	3.64			

Note. M = mean; SD = standard deviation.

Results indicated a statistically significant difference, $t(87) = 12.45$, $p < .001$, with the experimental group (M = 15.98, SD = 3.57) outperforming the control group (M = 8.21, SD = 3.64). This confirms that the PhET simulation-based intervention was more effective than the traditional lecture method in improving students' understanding of Electronics.

4.4 Student Perceptions of PhET Simulations

Research Question 4: What are students' perceptions of the use of PhET simulations in learning Electronics?

Descriptive statistics were used to analyse students' perceptions of PhET simulations. Responses were measured on a five point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

Table 4.4: *Students' Perceptions of PhET Simulations in Learning Electronics*

Item	Statement	1 n (%)	2 n (%)	3 n (%)	4 n (%)	5 n (%)
1	PhET helped me understand electronic concepts better	0 (0.0)	0 (0.0)	1 (2.2)	10 (21.7)	35 (76.1)
2	The visual and interactive nature of PhET improved my retention	0 (0.0)	0 (0.0)	2 (4.3)	12 (26.1)	32 (69.6)
3	PhET simulations should be used more often in Integrated Science lessons	0 (0.0)	0 (0.0)	1 (2.2)	11 (23.9)	34 (73.9)
4	I would recommend PhET simulations to other students	0 (0.0)	0 (0.0)	3 (6.5)	12 (26.1)	31 (67.4)
5	The lessons were more enjoyable when PhET simulations were used	0 (0.0)	0 (0.0)	2 (4.3)	11 (23.9)	33 (71.7)
6	Abstract concepts became clearer through the simulations	0 (0.0)	0 (0.0)	1 (2.2)	9 (19.6)	36 (78.3)
7	I prefer PhET-based lessons over traditional chalk-and-talk methods	0 (0.0)	0 (0.0)	2 (4.3)	10 (21.7)	34 (73.9)
8	My confidence in learning Electronics improved after using PhET	0 (0.0)	0 (0.0)	1 (2.2)	8 (17.4)	37 (80.4)
9	I was more active and engaged during PhET-based lessons	0 (0.0)	0 (0.0)	3 (6.5)	11 (23.9)	32 (69.6)
10	PhET simulations encouraged me to explore Electronics beyond the classroom	0 (0.0)	0 (0.0)	2 (4.3)	12 (26.1)	32 (69.6)
	Overall Mean = 1.47, Overall SD =0.68					

Source: Fieldwork, 2025 *Note. Response scale: 1 = Strongly Disagree, 2 = Disagree, 3 = Uncertain, 4 = Agree, 5 = Strongly Agree*

The results in Table 4.4 reveal overwhelmingly positive student perceptions of the use of PhET simulations in learning Electronics. Across all ten items, the majority of respondents selected “Strongly Agree” (SA), with percentages ranging from approximately 67% to over 80%. For example, 76.1% of students strongly agreed that PhET helped them understand electronic concepts better, while 80.4% strongly agreed that their confidence in learning Electronics improved after using PhET. Similarly, 73.9% strongly agreed that PhET-based lessons should be used more often in Integrated Science, and 69.6% strongly agreed that the simulations encouraged them to explore Electronics beyond the classroom.

Uncertain or negative responses (Disagree/Strongly Disagree) were virtually absent, with only a small proportion of students (2–6%) selecting “Uncertain” on a few items. The overall mean score of 1.47 (SD = 0.68) further confirms that students leaned strongly toward agreement with the positive statements.

Taken together, these findings indicate that students perceived PhET simulations as highly effective in enhancing their understanding, engagement, confidence, and enjoyment of Electronics lessons. The consistency of strong agreement across items underscores the pedagogical value of simulation-based learning in Integrated Science.

4.5 Discussion of Results

Research Question 1: What is the difference in performance between the experimental and control groups before PhET simulations?

The pre-test results (Table 4.1) indicated no statistically significant difference between the experimental group (M = 6.08, SD = 3.89) and the control group (M = 6.42, SD = 3.67), t(87) = 0.75, p = .457. This demonstrates that the groups were comparable at baseline, thereby establishing internal validity for the study.

This finding aligns with Creswell and Creswell (2018) and Fraenkel, Wallen, and Hyun (2019), who emphasise that establishing baseline equivalence is critical in quasi-experimental research to ensure that post-intervention differences can be attributed to the instructional treatment rather than pre-existing disparities.

The relatively low mean scores in both groups reflect persistent challenges in Electronics education, consistent with literature indicating that traditional, teacher-centred methods in Ghanaian SHSs often fail to adequately develop conceptual understanding in abstract topics such as current, voltage, and circuits (Buabeng et al., 2016; Taale, 2019). This confirms that subsequent improvements observed in the experimental group can be attributed to the PhET simulation intervention rather than differences in prior knowledge.

Research Question 2: What is the effect of PhET simulations on experimental group performance in Electronics?

The experimental group exhibited a substantial increase in performance from pre-test (M = 6.08, SD = 3.89) to post-test (M = 15.98, SD = 3.57), with a mean difference of 7.26 points, t(45) = 20.24, p < .001 (Table 4.2). This result demonstrates that PhET simulations significantly enhanced students’ understanding of Electronics concepts.

The findings corroborate Kolb’s Experiential Learning Theory (1984), which emphasises learning through a cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation. The interactive and visual nature of PhET simulations enabled students to manipulate virtual circuits, observe immediate outcomes, and engage in trial-and-error learning, effectively replicating the experiential learning cycle in a resource-constrained environment.

These results are consistent with empirical literature reviewed in Chapter Two. Perkins et al., Wieman (2019) and Wieman et a., (2021) emphasise that simulation-based learning promotes conceptual clarity, reduces misconceptions, and supports higher-order thinking skills in science. Similarly, Finkelstein et al. (2005) demonstrated that simulations in physics improved both understanding and retention in complex topics, while Ndihokubwayo et al.,(2020) found that Rwandan high school students benefited significantly from PhET in Electronics instruction.

This implies that simulation-based interventions can effectively address the conceptual difficulties identified in Ghanaian SHSs, particularly for abstract topics where physical laboratories are limited.

Research Question 3: What is the effect of PhET simulations on student performance in Electronics compared to conventional teaching methods?

Post-test comparison revealed that the experimental group (M = 15.98, SD = 3.57) significantly outperformed the control group (M = 8.21, SD = 3.64), t(87) = 12.45, $p < .001$ (Table 4.3). This confirms that PhET simulations are more effective than conventional teaching methods in improving students' academic performance in Electronics.

These findings align with empirical studies reviewed in Chapter Two. Gambari, Shittu, and Adegun (2022) and Pranata (2024) found that interactive, technology-enhanced approaches significantly improved learning outcomes in abstract science topics. Similarly, Pereira Gomes (2023) and Álvarez-Siordia et al. (2025) reported higher conceptual understanding and engagement when PhET simulations were integrated into physics and chemistry instruction.

From a theoretical perspective, the results support constructivist learning theory (Piaget, 1976; Vygotsky, 1978) and Mayer's (2021) Cognitive Theory of Multimedia Learning. Constructivism emphasises active knowledge construction, while multimedia learning theory posits that combining visual, interactive, and textual information enhances comprehension and retention. By enabling students to visualise electron flow, test hypotheses, and manipulate circuits in real time, PhET simulations provide a cognitively rich learning environment that conventional teaching methods cannot offer.

This implies that PhET simulations provide a pedagogical advantage for teaching Electronics, particularly in contexts with limited laboratory resources, by promoting active engagement, experimentation, and higher-order thinking.

Research Question 4: What are students' perceptions of PhET simulations in learning Electronics?

The findings indicate that students in the experimental group held strongly positive perceptions of PhET simulations. Most respondents agreed or strongly agreed that the simulations improved their understanding of electronic concepts, clarified abstract ideas, strengthened retention, and increased engagement and confidence. Importantly, there were no negative responses recorded across the perception items, suggesting broad acceptance of simulation-based instruction within the group.

These results are consistent with recent research in science education. Ndihokubwayo et al. (2020) reported that students perceived simulation supported physics lessons as clearer and more accessible than traditional instruction. Similarly, Wang et al. (2022) found that simulation-based inquiry environments enhanced students' engagement and conceptual reasoning. Pereira Gomes (2023) also observed that learners associated simulation use with improved clarity and confidence in solving subject related problems. The present findings therefore align with contemporary evidence that interactive digital tools are generally well received in science classrooms.

Beyond simple agreement, the perception data offer insight into how the intervention may have influenced academic performance. Students reported that abstract concepts became clearer and that they were more active during lessons. These responses suggest that the simulations promoted deeper cognitive engagement rather than superficial interaction. Gulikers et al. (2022) argue that when students perceive digital tools as useful and relevant, they are more likely to invest effort in learning tasks. In the present study, the positive perceptions observed may have strengthened engagement, which in turn contributed to the significant improvement in post test scores recorded for the experimental group.

The alignment between improved performance and favourable perceptions strengthens the interpretation of the intervention's effectiveness. The significant gain in academic achievement cannot be viewed in isolation from the students' reported experiences. Rather, the perception findings suggest that PhET simulations were not only effective in improving measurable outcomes but were also accepted as meaningful learning tools. This combination of cognitive gains and positive affective response supports the argument for integrating simulation based instruction into the teaching of Electronics at the Senior High School level.

4.7 Hypotheses Testing

To evaluate the effect of PhET simulations on students' performance in Electronics, three null hypotheses were formulated and tested:

Hypothesis 1 (H_{01})

There is no significant difference in the pre-test performance in Electronics between the experimental and control groups at Leklebi SHS.

Analysis of the pre-test scores showed that the experimental group had a mean score of 6.08 (SD = 3.89), while the control group achieved a mean of 6.42 (SD = 3.67). An independent samples t-test revealed no significant difference, t(87) = 0.75, $p = .457$.

Therefore, H_{01} was retained, indicating that both groups were equivalent at baseline. This confirms the methodological reliability of the study, ensuring that any observed post-intervention differences can be attributed to the instructional intervention rather than pre-existing disparities in knowledge or ability.

This finding aligns with Creswell and Creswell (2018) and Fraenkel et al., (2019), who emphasise the importance of establishing baseline equivalence in quasi-experimental designs. The relatively low mean scores also reflect persistent challenges in Electronics education, consistent with literature indicating that traditional, teacher-centred methods in Ghanaian SHSs often fail to adequately develop conceptual understanding in abstract topics such as current, voltage, and circuits (Buabeng et al., 2016; Taale, 2019).

Hypothesis 2 (H_{02})

The use of PhET simulations has no significant effect on the post-test performance of the experimental group in Electronics.

A paired samples t-test comparing the pre-test and post-test scores of the experimental group revealed a substantial increase from a mean of 6.08 (SD = 3.89) to 15.98 (SD = 3.57), with a mean difference of 7.26 points, t(45) = 20.24, $p < .001$.

Accordingly, H_{02} was rejected, providing strong evidence that PhET simulations significantly enhanced students' conceptual understanding, application skills, and knowledge retention in Electronics.

This improvement aligns with Kolb's Experiential Learning Theory (1984), which emphasises learning through concrete experience, reflective observation, abstract conceptualisation, and active experimentation. The interactive and visual nature of PhET simulations enabled students to manipulate virtual circuits, observe immediate outcomes, and engage in trial-and-error learning, effectively replicating the experiential learning cycle in a resource-constrained environment.

The findings also corroborate empirical studies reviewed in Chapter Two. Perkins, Adams, and Wieman (2019) and Wieman et al., (2021) demonstrated that simulation-based learning promotes conceptual clarity and supports higher-order thinking skills. Similarly, Finkelstein et al. (2005) found that simulations improved retention in physics, while Ndihokubwayo et al., (2020) reported significant gains in Electronics learning among Rwandan students.

Hypothesis 3 (H_{03})

There is no significant difference in the post-test performance in Electronics between students taught with PhET simulations and those taught using only conventional teaching methods.

Post-test analysis revealed that the experimental group (M = 15.98, SD = 3.57) significantly outperformed the control group (M = 8.21, SD = 3.64). An independent samples t-test confirmed this difference as highly significant, t(87) = 12.45, $p < .001$.

Consequently, H_{03} was rejected, demonstrating that PhET simulations offer a clear pedagogical advantage over traditional, lecture-based approaches in teaching Electronics.

These findings align with empirical studies such as Gambari et al.,(2022) and Pranata (2024), which found that interactive, technology-enhanced approaches significantly improved learning outcomes in abstract science topics. Similarly, Pereira Gomes (2023) and Álvarez-Siordia et al. (2025) reported higher conceptual understanding and engagement when PhET simulations were integrated into physics and chemistry instruction.

From a theoretical perspective, the results support constructivist learning theory (Piaget, 1976; Vygotsky, 1978) and Mayer's (2021) Cognitive Theory of Multimedia Learning. Constructivism emphasises active knowledge construction, while multimedia learning theory posits that combining visual, interactive, and textual information enhances comprehension and retention. By enabling students to visualise electron flow, test hypotheses, and manipulate circuits in real time, PhET simulations provide a cognitively rich learning environment that conventional methods cannot offer.

Retention of H_{01} validates baseline equivalence, while the rejection of H_{02} and H_{03} underscores the effectiveness of simulation-based instruction. Overall, the hypotheses testing confirms that PhET simulations significantly enhanced academic performance, engagement, and conceptual understanding in Electronics.

These findings provide robust evidence supporting the adoption of experiential and technology-enhanced learning approaches in resource-constrained senior high school contexts. They highlight the value of integrating multimedia tools with constructivist and experiential learning principles to improve STEM education outcomes, particularly in Ghanaian SHSs where laboratory resources are limited.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter presents a summary of the study, highlights the major findings derived from the analysis, draws conclusions, and provides recommendations for practice and future research. The study investigated the effect of PhET simulations on the academic performance of Form Two students in Electronics at Leklebi Senior High School. Specifically, it examined baseline performance, the impact of PhET simulations on the experimental group, comparative differences with the control group, and students' perceptions of simulation-based instruction.

5.1 Summary of Findings

The findings are discussed in relation to the four research questions that guided this investigation.For Research Question 1, which sought to determine students' performance in Electronics before the introduction of PhET-based experiential learning, the results indicated no statistically significant difference between the pretest scores of the experimental and control groups. This finding confirms that both groups were equivalent at baseline, possessing similar prior knowledge in Electronics. Establishing such equivalence was crucial to ensure that any post-intervention differences could be attributed to the instructional approach rather than pre-existing academic disparities.

Regarding Research Question 2, which examined the effect of PhET simulations on the experimental group, the findings demonstrated a substantial improvement in performance. The paired samples t-test showed that the mean score of the experimental group increased from 6.08 in the pretest to 15.98 in the posttest, representing a statistically significant and educationally meaningful gain. This indicates that the integration of PhET simulations into instruction positively influenced student achievement, enabling learners to better comprehend abstract Electronics concepts and apply them effectively in assessments.

Research Question 3 compared the post-test performance of the experimental and control groups. The results revealed a statistically significant difference, with the experimental group achieving higher mean scores than the control group. This indicates that students exposed to PhET simulations not only improved individually but also performed better than peers taught through conventional instruction. The findings suggest that integrating interactive, technology-supported strategies can enhance academic performance in Electronics when compared with traditional lecture-based approaches.

Finally, Research Question 4 explored students' perceptions of PhET simulations in learning Electronics. Analysis of the perception questionnaire revealed overwhelmingly positive responses, with mean scores ranging from 1.33 to 1.54 on a five-point Likert scale. These values indicate strong agreement with statements regarding the benefits of PhET simulations. Students reported that the simulations made lessons more engaging, clarified abstract concepts, encouraged active participation, and enhanced their confidence in responding to Electronics questions. Furthermore, students expressed a preference for PhET-based lessons over traditional methods and recommended broader use of the simulations in science instruction. This suggests not only cognitive benefits but also affective gains in terms of motivation, interest, and confidence.

The study established that both groups were equivalent at baseline that PhET simulations significantly enhanced performance in the experimental group, which subsequently outperformed the control group, and that students regarded PhET simulations as an engaging and effective learning tool. These findings provide strong evidence for the educational value of integrating PhET simulations into senior high school Electronics instruction.

5.2 Conclusions

The findings of this study lead to several important conclusions regarding the use of PhET simulations in teaching and learning Electronics at the senior high school level.

Firstly, the results confirm that the experimental and control groups were comparable in their baseline knowledge of Electronics. The absence of a statistically significant difference in pretest performance demonstrates that both groups were academically equivalent prior to the intervention, ensuring that observed post-intervention differences can be confidently attributed to the instructional method.

Secondly, the study concludes that integrating PhET simulations significantly enhances students’ performance in Electronics. The experimental group exhibited a marked improvement in mean scores between the pretest and posttest. By allowing students to visualise, manipulate, and experiment with virtual circuits and components, PhET simulations addressed common conceptual difficulties and supported deeper learning. This finding affirms the theoretical propositions of experiential and constructivist learning frameworks, which emphasise active engagement, practical exploration, and reflective observation as central to meaningful learning outcomes.

Thirdly, the comparative analysis demonstrated that students taught with PhET simulations significantly outperformed those taught through conventional teaching methods. This conclusion highlights the pedagogical advantage of interactive, technology-enhanced instruction over traditional, didactic approaches. The findings also indicate that challenges typically associated with conventional Electronics instructions such as overreliance on rote memorisation and limited access to functional laboratory equipment can be mitigated through the use of digital simulations.

Finally, the study concludes that students hold highly positive perceptions of PhET simulations. They consistently reported increased engagement, improved motivation, greater confidence, and preference for simulation-based lessons. These affective benefits are critical for sustained learning, as positive attitudes towards instructional methods are closely linked with higher motivation, persistence, and academic success.

Taken together, these conclusions demonstrate that PhET simulations represent a highly effective, learner-centred approach for teaching Electronics in senior high schools. They offer a feasible solution to challenges associated with abstract content delivery, limited laboratory resources, and student disengagement, and hold significant promise for improving STEM education in Ghana and comparable contexts.

5.3 Recommendations

Based on the findings of this study, the following recommendations are proposed for Leklebi Senior High School.

First, Integrated Science teachers at Leklebi Senior High School should incorporate PhET simulations into the teaching of Electronics. The results showed that students who were exposed to simulation-based instruction achieved significantly higher post test scores than those taught through conventional teacching methods. Simulation supported lessons should therefore complement traditional explanation in order to strengthen conceptual understanding.

Second, the management of Leklebi Senior High School should provide structured professional development to enable teachers to integrate simulations effectively into their lessons. Training should focus on guiding inquiry, facilitating discussion, and connecting virtual experiments to theoretical principles. Sustained performance gains will depend on the quality of instructional implementation.

Third, students of Leklebi Senior High School should be encouraged to engage actively with simulations rather than treating them as teacher demonstrations. The findings indicated that improved performance was associated with active manipulation of variables and exploration of relationships within the simulations. Students should therefore take responsibility for testing ideas, asking questions, and reflecting on outcomes during simulation-based lessons.

Fourth, students should be encouraged to collaborate during simulation activities. Structured group discussion and peer explanation can strengthen conceptual clarity and address misconceptions. Given the positive perceptions reported by students regarding interactive learning, collaborative engagement may enhance both understanding and motivation.

Fifth, students should be encouraged to revise Electronics concepts using available digital resources, including simulations, where access permits. Independent exploration beyond scheduled class time may reinforce understanding and improve retention.

Sixth, Integrated Science teachers at Leklebi Senior High School should provide timely feedback during and after simulation activities. Continuous monitoring and clarification of misconceptions will ensure that engagement leads to accurate conceptual understanding.

Finally, the leadership of Leklebi Senior High School should prioritise the allocation and scheduling of available technological resources to support simulation-based instruction.

Even with limited laboratory facilities, structured access to simulations can provide meaningful opportunities for experimentation and visualisation in Electronics lessons.

5.4 Suggestions for Further Studies

This study was conducted among Form Two Integrated Science students at Leklebi Senior High School using a quasi-experimental design. Future research may extend this work in several directions.

First, similar studies could be conducted in other Senior High Schools within the Volta Region and across different regions of Ghana. Expanding the geographical scope would enhance the generalisability of findings and determine whether the positive effects of PhET simulations are consistent across diverse school contexts.

Second, future studies could examine the long term effects of simulation based instruction. The present study measured performance over a relatively short intervention period. Longitudinal research could investigate whether the learning gains associated with PhET simulations are sustained over time.

Third, further research could explore the impact of PhET simulations on other science topics beyond Electronics, including Chemistry, Biology, and core Physics topics. This would help determine whether the effectiveness observed in Electronics is transferable across science disciplines.

Fourth, qualitative or mixed methods studies could investigate in greater depth how students experience simulation based learning. While this study measured perceptions quantitatively, interviews or focus group discussions could provide richer insight into how students interpret and interact with simulation tools.

Fifth, future research may examine the influence of teacher factors such as technological pedagogical competence, years of experience, or attitudes towards digital instruction on the effectiveness of PhET simulations. Such studies would clarify the role of teacher implementation in shaping learning outcomes.

Finally, comparative studies involving fully randomised experimental designs, where feasible, could strengthen causal inference and further validate the findings obtained through quasi experimental methods.

5.5 Chapter Summary

This chapter has presented a synthesis of the study's key findings, conclusions, and recommendations concerning the effect of PhET simulations on the academic performance of senior high school students in Electronics. The findings demonstrated that the experimental and control groups commenced the study at a comparable baseline, thereby establishing the internal validity of the analyses that followed. The use of PhET simulations was shown to significantly enhance the performance of students in the experimental group. Comparative analysis further revealed that these students outperformed their peers who received only conventional, teaching method. In addition, students reported overwhelmingly positive perceptions of the PhET approach, emphasising its ability to make lessons more engaging, interactive, and confidence-building.

The conclusions drawn from these findings confirm the pedagogical value of integrating PhET simulations into science instruction. Beyond improving academic achievement, the simulations fostered deeper conceptual understanding, increased student motivation, and addressed systemic challenges such as inadequate laboratory resources. These advantages highlight PhET simulations as a feasible and scalable instructional strategy for improving the quality of science education in resource-constrained contexts such as Ghana.

In light of these conclusions, the study recommends that teachers adopt blended pedagogical approaches that incorporate PhET simulations, that school administrators prioritise investment in ICT infrastructure and professional development, and that policymakers consider embedding simulation-based learning within the national curriculum. Furthermore, researchers are encouraged to explore the effectiveness of PhET simulations through longitudinal and multi-site studies to build a broader evidence base.

In summary, the study demonstrates that PhET simulations have the potential to transform the teaching and learning of Electronics by improving both academic performance and students' attitudes towards the subject. The chapter thus provides a coherent synthesis of the study's contributions and outlines practical steps for sustaining and scaling the impact of simulation-based instruction in senior high school science education.

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APPENDIX A

PRE-TEST: ELECTRONICS (FORM TWO)

Duration: 30 minutes

Total Marks: 20

Instructions: Answer all questions. For Multiple Choice, choose only one correct option. For True/False, circle the correct answer.

SECTION A: Multiple Choice Questions (10 Marks)

(Each question = 1 mark)

1. Which of the following is a component of an electric circuit?

   A. Light energy

   B. Copper rod

   C. Resistor

   D. Generator

2. The function of a diode in an electronic circuit is to:

   A. store charge

   B. amplify signals

   C. allow current to flow in one direction

   D. measure voltage

3. A capacitor is mainly used to:

   A. increase resistance

B. store electrical energy

C. convert AC to DC

D. block electric current

4. Which of the following is not a conductor?

A. Copper

B. Iron

C. Plastic

D. Aluminium

5. The unit of electric current is:

A. Volt

B. Ohm

C. Ampere

D. Watt

6. A transistor is mainly used to:

A. resist current

B. store electric charge

C. amplify signals

D. convert sound to current

7. What is the role of a resistor in a circuit?

A. Store charge

B. Produce electricity

C. Limit current flow

D. Generate heat

8. Which device is used to measure voltage?

A. Ammeter

B. Voltmeter

C. Galvanometer

D. Resistor

9. The energy source in a circuit is usually a:

A. Resistor

B. Capacitor

C. Battery

D. Fuse

10. Ohm’s law is represented by the formula:

A. V = IR

B. P = IV

C. R = V/I

D. E = PT

SECTION B: True / False Questions (10 Marks)

(Each question = 1 mark)

11. A fuse is used to protect electrical circuits from overload. **True / False**

12. An insulator allows electric current to flow easily. **True / False**

13. The symbol “Ω” stands for ohms, a unit of resistance. **True / False**

14. Capacitors are used to resist the flow of current in a circuit. **True / False**

15. Silicon is a common material used in semiconductors. **True / False**

16. Transistors can be used as switches in electronic devices. **True / False**

17. Voltage is the same as current. **True / False**

18. An ammeter is connected in parallel in a circuit. **True / False**

19. Diodes allow current to flow both ways. **True / False**

20. Resistors are used to reduce current flow. **True / False**

APPENDIX B

POST-TEST: ELECTRONICS (FORM TWO)

Duration: 30 minutes **Total Marks:** 20

Instructions: Answer all questions. For Multiple Choice, choose only one correct option. For True/False, circle the correct answer.

SECTION A: Multiple Choice Questions (10 Marks)

(Each question = 1 mark)

1. Which law explains the relationship between current, voltage, and resistance in a circuit? A. Ohm’s Law B. Newton’s Law C. Faraday’s Law D. Coulomb’s Law
2. A device that stores electrical energy in an electric field is called: A. Resistor B. Capacitor C. Diode D. Fuse
3. Which of the following components is used to protect circuits from excess current? A. Battery B. Fuse C. Capacitor D. Transistor
4. The unit of electrical power is: A. Watt B. Ampere C. Volt D. Ohm
5. A transistor can function as: A. A switch and amplifier B. A resistor C. A fuse D. A capacitor
6. Which instrument is used to measure electric current? A. Voltmeter B. Ammeter C. Galvanometer D. Wattmeter
7. The main function of a resistor in a circuit is to: A. Increase voltage B. Limit current flow C. Store charge D. Convert AC to DC

8. Which of the following is a semiconductor material? A. Copper B. Aluminium C. Silicon D. Iron

9. The energy supplied by a battery in a circuit is measured in: A. Joules B. Watts C. Volts D. Ohms

10. Which of the following best describes alternating current (AC)? A. Current flows in one direction only B. Current changes direction periodically C. Current is constant and steady D. Current flows through insulators

SECTION B: True / False Questions (10 Marks)

(Each question = 1 mark)

11. A diode allows current to flow in one direction only. **True / False**

12. Voltage is the force that drives current through a circuit. **True / False**

13. A capacitor can be used to smooth fluctuations in voltage. **True / False**

14. Resistors are measured in amperes. **True / False**

15. Transistors are essential components in modern electronic devices. **True / False**

16. A fuse automatically disconnects a circuit when current exceeds safe limits. **True / False**

17. Electric current is measured in volts. **True / False**

18. An ammeter must always be connected in series in a circuit. **True / False**

19. Silicon is widely used in the manufacture of diodes and transistors. **True / False**

20. Ohm’s Law states that V = IR. **True / False**

APPENDIX C

MARKING GUIDE FOR PRE-TEST: STUDENT KNOWLEDGE TEST ON ELECTRONICS (SKTE)

Total Marks: 20 **Duration:** 30 minutes

SECTION A: Multiple Choice Questions (10 Marks)

(Each correct answer = 1 mark)

1. C. Resistor
2. C. Allow current to flow in one direction
3. B. Store electrical energy
4. C. Plastic
5. C. Ampere
6. C. Amplify signals
7. C. Limit current flow
8. B. Voltmeter
9. C. Battery
10. A. V = IR

SECTION B: True / False Questions (10 Marks)

(Each correct answer = 1 mark)

11. True
12. False

13. True

14. False

15. True

16. True

17. False

18. False

19. False

20. True

APPENDIX D

MARKING GUIDE FOR POST-TEST: STUDENT ACHIEVEMENT TEST ON ELECTRONICS (SATE)

Total Marks: 20 **Duration:** 30 minutes

SECTION A: Multiple Choice Questions (10 Marks)

(Each correct answer = 1 mark)

1. A. Ohm's Law
2. B. Capacitor
3. B. Fuse
4. A. Watt
5. A. A switch and amplifier
6. B. Ammeter
7. B. Limit current flow
8. C. Silicon
9. A. Joules
10. B. Current changes direction periodically

SECTION B: True / False Questions (10 Marks)

(Each correct answer = 1 mark)

11. True
12. True

13. True

14. False

15. True

16. True

17. False

18. True

19. True

20. True

APPENDIX E

STUDENT PERCEPTION QUESTIONNAIRE

Instructions: Tick (✓) the response that best reflects your opinion.

Statement: **Strongly Agree (SA)** **Agree (A)** **Uncertain (U)** **Disagree (D)**

Strongly Disagree (SD)

	SA	A	N	D	SD
1. PhET simulations helped me understand electronic concepts better.					
2. The simulations made the lessons more interesting and enjoyable.					
3. Using PhET simulations made abstract concepts in electronics clearer.					
4. I was more active and engaged during lessons involving simulations.					
5. I prefer PhET-based lessons over traditional (chalk and talk) methods.					
6. PhET simulations encouraged me to explore topics beyond the classroom.					
7. The visual and interactive nature of PhET helped me retain information.					
8. PhET simulations should be used more often in Integrated Science lessons.					
9. I feel more confident answering questions on electronics after using PhET.					
10. I would recommend the use of PhET simulations to other students.					