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Improving Secondary School Students' Learning of Electricity through Inquiry-Based Strategy Blended with PhET Simulation: A Design-Based Study in Bahir Dar City

A Thesis Submitted for the Requirements of Master of Education in Teaching Sciences (Physics)

By:

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Advisor: Asheshim Mengstu (Ph.D.)

Bahir Dar, Ethiopia

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DECLARATION

I declare that this thesis is my original work and all the sources that I have cited or quoted herein have been duly acknowledged and referenced.

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Date: 05/10/2018 E.C

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Date: 05/10/2018 E.C

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Abstract

this study aimed to improve secondary school students' conceptual understanding in the learning of electricity by addressing misconceptions through guided inquiry-based learning integrated with PhET simulations at Bahir Dar, Ethiopia. A pragmatic paradigm followed with mixed-methods approach guided the study. A one-on-one design-based research design guided iterative cycles of design, implementation, evaluation, and refinement of an inquiry-based intervention supported by PhET simulations. A total of 35 Grade 10 students were participated in the study. Data were collected through administration of standardized Electricity Conceptual Understanding test (ECUT), classroom observations, worksheet analysis, and focus group discussions. Quantitative data were analyzed using descriptive statstics and one sample and paired sample t tests, while qualitative data were analyzed thematically. Baseline results revealed widespread misconceptions about current, voltage distribution, resistance, and circuit behavior, indicating low conceptual understanding. Findings show that integrating guided inquiry-based learning with PhET simulations improved students' conceptual understanding of electricity and reduces misconceptions significantly. To conclude, guided inquiry with PhET simulations is an effective and an alternative instruction for teaching abstract electricity concepts.

Keywords: *Conceptual Understanding, Electricity, Guided Inquiry-based learning, Misconceptions, PhET Simulations*

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Abbreviation or Acronyms

CI: Conventional Instruction

CUT: Conceptual Understanding Test

DBR: Design-Based Research

DC: Direct Current

ECUT: Electricity Conceptual Understanding Test

EM: Electromagnetic

ESDP: Education Sector Development Program

FGD: Focus Group Discussion

GIBL: Guided Inquiry-Based Learning

IBL: Inquiry-Based Learning

MCQ: Multiple Choice Question(s)

PER: Physics Education Research

PhET: Physics Education Technology

TMC: Total Misconceptions

ZPD: Zone of Proximal Development

Chapter One: Introduction

1.1 Background of the Study

Physics provides the foundation for understanding natural phenomena and contributed a lot of significant roles for technology advancements that shape modern society (Lederman, 2007; Osborne, 2010). The fundamental laws of physics describe natural phenomena has an implication to advance the use of technologies across various sectors including engineering, healthcare, communication, and energy (Serway & Jewett, 2014). Research findings claimed that the lifestyle of modern society is highly dependent on electric power (Zohuri & McDaniel, 2019).

However, many of the concepts of electricity are abstract by their nature and these concepts are designed in the physics curriculum where students are expected to learn at school (J. P. Burde & Wilhelm, 2020). Because of its abstract nature, learning electricity concepts need visualized instructional strategies that facilitate students learning(Aida et al., 2025). Multiple studies suggested that inquiry-based instruction helps students understand better the abstract concepts of electricity (Baptista & Martins, 2023). Several studies show that inquiry-based learning (IBL) can help students overcome persistent alternative conceptions in electricity and build more accurate scientific understanding (Erlina et al., 2018; Sanches., et al., 2018). Research in direct current electricity education has consistently found that students often enter instruction with misconceptions about current, voltage, and electric circuits, and that these misconceptions may persist after traditional teaching methods (D. Shipstone, 1988). However, when learners engage in inquiry-based activities where they generate hypotheses, conduct experiments, and interpret results there is clear evidence of conceptual gains (Hmelo-Silver et al., 2007; Sanches., et al., 2018). IBL had positive effects in fostering students' conceptual understanding of basic electricity concepts and in reducing misconceptions related to electric circuits and the roles of circuit components, such as the belief that a battery is a constant current source (Godwin. et al 2018).

In this modern era, teaching many of the concepts of electricity demand the applications of technology assisted instruction to foster students learning in the physics classroom(Abdullai Abukari et al., 2023a). A number of research findings showed that technology assisted instruction enhance students' learning of abstract concepts in physics in general, electricity domain of physics in particular(Agyei & Agyei, 2021). In addition, study findings also claimed that PhET simulation is one of a technology assisted instruction plat form that helps students to visualize abstract contents of electricity (Abdullai Abukari et al., 2023).

Even though many efforts are still employed in improving physics classroom teaching instructions across the globe, students perceived that electricity concepts are the most difficult and challenging domain of physics to understand (Mbonyiryivuze et al., 2019 & Guisasola et al., 2023).

From the Ethiopian school context, efforts are continuing in improvising teacher's way of teaching in physics classroom (Worku & Alemu, 2021b). Studies in Ethiopia indicate that secondary school students often struggle with electricity concepts such as current, voltage, resistance, and electric circuits, retaining misconceptions even after formal instruction (Dega et al., 2013). In Ethiopia, students still face learning difficulties in understanding the abstract concepts in electricity and many misconceptions were perceived on the side of learners in electricity concepts (Eshetu & Alemu, 2018).

Moreover, previous studies have indicated that effective classroom instruction remains an important area for further investigation to improve students' learning of physics, particularly in electricity topics. Therefore, this study aimed to design and implement a Guided Inquiry-Based Learning (GIBL) model integrated with PhET simulation in an actual classroom setting. The study sought to address students' misconceptions and enhance their conceptual understanding of electricity among Grade 10 students in Bahir Dar City, Ethiopia.

1.2 Statement of the Problem

There are multiple studies that came up with possible factors that hinder students' physics learning. One of these factors is students' misconceptions towards to physics concepts. Research in physics education consistently shows that students experience persistent difficulties in understanding core physics concepts across multiple domains. Studies showed that learners struggle with abstract ideas in electricity and electronics such as electric current and circuit elements (Hestenes et al., 1992; Singh, 2001; Engelhardt & Beichner, 2004). Evidence from classroom studies and conceptual assessments indicates that these difficulties often persist even after instruction, suggesting that students retain fragmented knowledge and misconceptions rather than developing coherent conceptual understanding (Maloney et al., 2001; Kock et al., 2011). For example, in electricity, students often believe that current is consumed by components (Engelhardt & Beichner, 2004); a battery is a constant current source (Shipstone, 1984), Electric current travelling in one direction decreases gradually due to consumption of current by devices (McDermott & Shaffer, 1992; Peşman & Eryilmaz, 2010; Sencar & Eryilmaz, 2004; D. Shipstone, 1988). Current flows within a wire like water flow in a pipe; most of the current goes straight and less amounts of it goes from the wire which is not straight(Peşman & Eryilmaz, 2010). The bulb which is farther away from the power supply is dimmer than the closer bulbs (Heller & Finley, 1992; Peşman & Eryilmaz, 2010; Sencar & Eryilmaz, 2004). Electric current is shared equally by devices within the circuit (Sencar & Eryilmaz, 2004; D. Shipstone, 1988).

These alternative conceptions are deep-rooted, stable, and resistant to change, even after conventional instruction (Engelhardt & Beichner, 2004). These misconceptions in electricity are universal across educational contexts across the globe (D. Shipstone, 1988; McDermott & Shaffer, 1992; Duit & Treagust, 2003).

Studies in physics education attribute these persistent difficulties to several interconnected factors. Many learners enter classrooms with pre-existing ideas and misconceptions that conflict with scientific explanations, which are resistant to change (Neidorf et al., 2020). Students also often rely on memorization rather than conceptual understanding, making abstract concepts difficult to grasp (Achor et al., 2022). Additionally, traditional teaching methodologies that emphasize lecture-based or procedural instruction over active, conceptual learning contribute to these difficulties (Achor et al., 2022). Together, these factors hinder the development of coherent understanding and meaningful application of physics concepts.

In the Ethiopian situation, secondary school education has long faced problems related to quality (Awayehu, 2017; ESDP, 2003; Eshetu, 2014; Goshu & Woldeamanuel, 2019). As a result, Ethiopian secondary school students' achievement in physics has been very low and not encouraging (Goshu & Woldeamanuel, 2019; Hamelo, 2016; MoE, 2017). In addition, multiple studies and national reports have indicated that students experience learning difficulties across different content domains of physics (Aragaw et al., 2022).

Evidence from national learning assessments further supports this concern. The first and second National Learning Assessment reports indicated that Ethiopian Grade 10 students' achievement in physics was very low and far below the minimum learning competency level of 50% set by the Ministry of Education (MoE, 2017; NLA, 2013; NLA, 2017).

In line with these findings, the mean scores of grades 10 students in physics were 35.94% in the first National Learning Assessment, declined to 29.43% in the second assessment, and further dropped to 4.6% in the third assessment. This shows that the trend of Grade 10 students' achievement in physics was decreasing over time. Moreover, analysis of the second National Learning Assessment report based on physics content domains indicated that Grade 10 students scored about 31.16% in electricity and magnetism, which clearly suggests that students have learning difficulties in this area of physics(Aragaw et al., 2022). The study also claimed that students' low academic achievement is strongly correlated with low conceptual understanding in many domains of physics subject.

Similarly, the achievement levels of physics content domains for Grades 10 and 12 showed that performance in electronics (34.22%), wave, motion, and sound (33.42%), and electricity and magnetism (31.16%) were far below the minimum learning competency level of 50% set by the Ministry of Education(Aragaw et al., 2022).

In response to these challenges, a number of studies have been conducted to identify factors that hinder students' learning of physics in general, electricity in particular at different school levels (Agbele et al., 2020; Bao & Koenig, 2019; Beyessa, 2014; Burkholder et al., 2020; De Rijdt et al., 2013). These studies identified several factors that reduce students' Conceptual understanding and aggravate misconceptions in electricity concepts, including the lack of effective teaching methods, shortage of facilities and laboratory equipment to support physics learning, and limitations in teachers' physics content knowledge(Aragaw et al., 2022).

Furthermore, many of these studies indicated that the use of inappropriate teaching methods is one of the major factors impairing students' physics learning and leading to low academic performance(Tolulope Agbele et al., 2020). In particular, different studies reported that the dominant teaching approach in secondary school physics classrooms is the traditional teaching method, which does not sufficiently enhance students' physics learning or improve their achievement in the subject (Gunta & Ousman, 2015; Higueras-Herbada et al., 2019; Hussain et al., 2011; Kunkle & Allen, 2016; Negassa, 2014; Sbhatu, 2021; Selcuk et al., 2011; Sulisworo & Suryani, 2014).

As noted by Bekalo and Welford (1999) and Bekele and Melesse (2010), physics teaching in Ethiopia tends to rely heavily on lecture-based methods, which have been shown globally to be insufficient for promoting conceptual understanding in electricity (McDermott, 2001; eltzer & Thornton, 2012).

Evidence suggests that conventional instruction has minimal impact on enhancing conceptual understanding and conceptual changes in electricity, even when teachers are knowledgeable and classrooms are well-managed (Engelhardt & Beichner, 2004; McDermott, 2004).

Given the persistent and universal nature of misconceptions in electricity, physics instruction requires pedagogical strategies that actively engage students, support conceptual conflict, encourage prediction and testing, and make invisible processes more observable (Duit & Treagust, 2003; McDermott & Shaffer, 1992). Inquiry-based environments especially those supported by interactive simulations are widely recognized as effective platforms for fostering conceptual change (Zacharia & Anderson, 2003; Podolefsky et al., 2010).

PhET simulations, in particular, provide dynamic visualizations of current, voltage, and circuit behavior that allow students to explore causal relationships actively and test predictions safely(E. Wieman, 2008). On the contrary, other studies claimed that using technology assisted instruction has a negative effect on students understanding of concepts in physics(Liu et al., 2022; Richter et al., 2022). These studies reported that students usually focus on the technology rather than using technology for transfer of learning that ultimately hinders students learning.

To this end, this study was tried to integrate effective teaching strategies blended with technology to visualize abstractions by taking the advantage of inquiry-based learning and technology assisted instruction plat form. Thus, the present study seeks to fill the identified gap by designing and implementing of guided inquiry-based learning integrated with PhET simulations, to solve students' classroom learning real problems in particular to minimizing Grade 10 students' misconceptions and improving their conceptual understanding of abstract electricity concepts such as electric circuits and current, voltage and Ohm's law in secondary schools in Bahir Dar, Ethiopia, context.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this study was to design, and implement a guided inquiry-based learning integrated with PhET simulation instruction to reduce students’ misconception and improve their conceptual understanding of electricity in Bahir Dar City, Ethiopia.

1.3.2. Specific Objectives

1. To identify Grade 10 students’ misconceptions about the different contents of electricity before the intervention.
2. To design a guided inquiry-based learning integrated with PhET simulations to address the topics of electricity.
3. To implement a guided inquiry-based learning integrated with PhET simulations to reduce students’ misconceptions about the topics of electricity.
4. Examining level of reducing students’ misconceptions about the topics of electricity through the use of guided inquiry-based learning integrated with PhET simulations.
5. To examine the effects of guided inquiry-based learning integrated with PhET simulation on students’ conceptual understanding of electricity.

1.4. Research Questions

This study is guided by the following research questions:

1. What are the misconceptions students’ holds about topics of electricity prior to the interventions?

2. How does guided inquiry-based learning integrated with PhET simulations instruction is designed to address topics of electricity?

3. How does guided inquiry-based learning integrated with PhET simulations instruction is implemented to reduce students’ misconceptions about the topics of electricity?

4. To what extent does guided inquiry-based learning integrated with PhET simulation reduce level of students’ misconceptions of electricity topics?

5. What are the effects of guided inquiry-based learning integrated with PhET simulation on students' conceptual understanding of electricity topics?

1.5. Significance of the Study

This study is significant for several reasons. First, it addresses the persistent conceptual difficulties students face in learning electric circuits, a core topic in Grade 10 physics. Research shows that misconceptions about current, voltage, resistance, and circuit behavior remain stable and resistant to traditional instruction. By designing and testing an inquiry based PhET simulation intervention, the study contributes a practical approach for helping students build more accurate scientific understanding.

Second, the study adds value to the Ethiopian physics education context, where classroom instruction is often dominated by teacher-centered approaches and where schools face limitations in laboratory resources. The PhET-based intervention offers a low cost yet effective alternative that allows students to explore electric circuit behavior interactively, even in settings with limited equipment.

1.6. Context and Scope of the Study

This study will be takes place in Bahir Dar city secondary school, Ethiopia. The schools follow the national curriculum, which introduces students about the basic components of an electric circuit and how these components are arranged in a simple series circuit. Although students are introduced to basic components of an electric circuit in Grade 8, research reports suggests that many students enter Grade 10 with fragmented or incorrect conceptions due to instruction that relies heavily on lectures, limited experimentation, and minimal interactive resources (McDermott & Shaffer, 1992; Duit & Treagust, 2003).

In Grade 10 Physics, electric circuits become more conceptually demanding and require students to explain how current, voltage, and resistance interact in different circuit configurations. Research in physics education shows that students often struggle with these concepts due to their abstract nature and the difficulty of visualizing electric processes (Duit et al., 2007; Psillos & Niedderer, 2002). Ethiopian classroom practices tend to emphasize theory and rote problem-solving, which further restrict opportunities for inquiry-based exploration and conceptual development (Eshetu., et al 2018).

Given this context, the study focuses on designing and implementing an inquiry-based instructional intervention supported by PhET simulations to strengthen Grade 10 students' conceptual understanding of DC electric circuits.

The scope of the study is restricted to one Grade 10 class at Millennium Progress Academy. The researcher will follow a design-based research approach that links classroom practice with continuous design improvement. The study concentrates specifically on students' conceptual understanding of DC electric circuits; therefore, outcomes such as attitudes and motivation are outside the intended scope.

1.7. Operational Definitions of Terms

Conceptual Understanding: The ability of students to correctly explain and apply scientific principles of electricity, beyond rote memorization.

Electricity: The set of physics concepts and practical skills that include electric circuits**,** current, voltage, and ohm's Law, combinations of resistors and measuring current and voltage.

Guided Inquiry based learning Integrated with PhET Simulation: A teaching approach where students learn electricity concepts through guided inquiry activities supported by PhET simulations.

Measuring Current and Voltage: Students' practical skill in correctly using ammeters and voltmeters to measure current and potential difference in a circuit.

Misconceptions: Students' incorrect or incomplete understandings of electricity.

PhET Simulations: Interactive computer-based tools developed by the University of Colorado Boulder that allow students to visually explore electricity.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1. Introduction

Physics education research (PER) has long focused on understanding how students learn fundamental physics concepts. Within this body of research, electricity has consistently been identified as one of the most conceptually challenging topics for secondary school students (McDermott & Shaffer, 1992).

Students' understanding of electricity is often shaped by intuitive reasoning based on everyday experiences, which frequently conflicts with scientifically accepted models. These ideas are highly persistent and commonly survive traditional instruction, limiting students' ability to develop a coherent understanding of electrical phenomena (Duit, 2009). Longitudinal research by(McDermott & Shaffer, 1992) examining learners with different levels of physics experience revealed that students' difficulties related to electricity vary in both frequency and complexity. While some difficulties diminish following instruction, others persist and continue to hinder learning of more advanced topics.

Research categorizes students' difficulties in electricity into several broad areas, including failure to apply formal concepts, difficulty interpreting symbolic and diagrammatic representations, and limited ability to reason qualitatively about electrical phenomena (Fernando et al., 2010). Many learners rely on analogies such as water flow or familiar battery-powered devices to explain electrical behavior. Although these analogies may support initial understanding, they often lead to oversimplified reasoning that restricts deeper conceptual development (D. M. Shipstone, 1984).

Traditional lecture-based instruction, which often emphasizes formula manipulation over conceptual understanding, has been shown to be insufficient for addressing students' alternative conceptions in electricity (Redish & Burciaga, 2004). As a result, PER increasingly emphasizes instructional approaches that actively engage learners, elicit their ideas, and support conceptual change (Meltzer & Thornton, 2012).

In response to these challenges, technology-enhanced instructional strategies have gained attention. PhET interactive simulations provide opportunities for students to explore and visualize electrical phenomena, supporting experimentation and conceptual reasoning (Nufus et al., 2020). The PhET project offers freely accessible, research-based simulations designed to support the teaching and learning of physics concepts, including electricity (K. Perkins et al., 2006). When carefully aligned with instructional goals and integrated within inquiry-based learning environments, such technologies can significantly enhance students’ understanding of electricity (Adrianus Nasar, 2025; Anselmo et al., 2024).

This chapter reviews literature relevant to the present study, focusing on students’ learning of electricity, documented conceptual difficulties, and instructional approaches particularly inquiry-based learning supported by PhET simulations that inform the design of the current study.

2.2 Theoretical Framework of the Study

The theoretical framework for improving secondary school students' understanding of electricity through inquiry-based PhET simulations is predominantly anchored in constructivism, social constructivism, and cognitive load theory.

Constructivism and Social Constructivism: At its core, inquiry-based learning aligns strongly with constructivist principles, where learners actively construct their own knowledge rather than passively receiving it(Antypas et al., 2025; Apedoe & Reeves, 2006). This perspective emphasizes that knowledge is built upon prior experiences and understanding (Ainsworth et al., 2011). In the context of electricity education, students often hold non-scientific preconceptions about electric current, as it is an invisible phenomenon (J. Lee et al., 2015a). Inquiry-based activities, particularly when supported by interactive simulations like PhET, allow students to challenge these preconceptions by observing phenomena, formulating hypotheses, and testing them in a controlled environment (Lee et al., 2015; Sari et al., 2024)

Vygotsky's social constructivism further enriches this framework by highlighting the role of social interaction and collaboration in learning (Şimşek & Kabapinar, 2010). When students engage in inquiry-based learning with PhET simulations, they often work in teams, discussing their predictions, interpreting results, and constructing explanations together(Bouchée et al., 2024). This collaborative aspect facilitates the co-construction of knowledge and allows for peer-assisted learning within the Zone of Proximal Development (ZPD) (Fan et al., 2018). The ZPD represents the gap between a learner's initial understanding and a more refined conception, which can be bridged through structured inquiry and teacher guidance (Fan et al., 2018a). This approach is particularly relevant given the challenges students often face in understanding abstract scientific concepts like electricity (Lee et al., 2015; Ainsworth et al., 2011).

Cognitive Load Theory: This theory emphasizes the limitations of working memory and suggests instructional strategies should manage cognitive load to optimize learning (Chiu et al., 2015). PhET simulations can reduce extraneous cognitive load by providing interactive, visual representations of abstract concepts, thereby making complex ideas more accessible (Chiu et al., 2015; Lee et al., 2015). By allowing students to manipulate variables and observe immediate feedback, PhET simulations enable a more intuitive understanding of electrical phenomena that are otherwise difficult to visualize or experiment with in a physical laboratory setting (James et al., 2022). For instance, students can visualize the flow of electric charge, which is otherwise invisible, helping them overcome non-scientific conceptions (J. Lee et al., 2015a).

2.3. Empirical Studies on Students' Conceptual understanding of Electricity

Few discoveries have had such an impact on our civilization as the discovery of electricity. Despite its cultural and technological importance, electricity remains one of the most challenging domains in physics education, with persistent learning difficulties observed across global educational systems. The abstract nature of electrical concepts contributes significantly to students' conceptual struggles(Mulhall et al., 2001a). These challenges are not confined to a particular region, but manifest universally among learners from primary school through university, indicating deep-rooted cognitive barriers that transcend cultural and curricular boundaries (Turgut et al., 2011). Most students have only a very vague understanding of its core quantities such as voltage, resistance, and current and their mutual relationship in simple circuits when they leave middle school (J. P. Burde & Wilhelm, 2020b). Electric circuit concepts in physics are abstract in nature and students find it difficult to comprehend (Tenzin D et al., 2024). Concepts involved in the teaching and learning of electric circuits can be problematic to understand as these are highly abstract and complex(Mulhall et al., 2001b). Students believe that current is "used up" as it passes through components, leading to the idea that bulbs farther from the battery glow dimmer (Quezada-Espinoza M et al., 2023; McDermott & Shaffer, 1992). Students also struggle to predict how adding or removing a resistor affects current and voltage in the circuit, frequently assuming that changes occur only locally rather than throughout the entire circuit(Engelhardt & Beichner, 2004).

Despite teachers' best efforts in the classroom, so-called "alternative conceptions" often prevail after traditional instruction. In particular, voltage has proven to be a difficult concept to teach--many students erroneously think of voltage as a property of electric current. Furthermore, a battery is often considered to be a source of constant current rather than constant voltage (Burde J et al., 2022).

Parallel circuits bring a new set of conceptual challenges. Students often fail to notice that voltage across parallel branches is the same, wrongly believing that it falls along branches (McDermott & Shaffer, 1992). Any increase in the number of parallel resistors increases the total resistance (a resistor is always an obstacle to current flow) (Peşman & Eryilmaz, 2010;Sencar & Eryilmaz, 2004; Taşlıdere & Taşlıdere, 2013). Misunderstandings about current division are also common; learners frequently assume that current splits equally regardless of the resistance in each branch, revealing a lack of understanding of Ohm’s law in parallel arrangements (Engelhardt & Beichner, 2004).

Students also struggle to integrate knowledge of series and parallel circuits in mixed configurations, often applying rules from one type of circuit incorrectly to another(Quezada-Espinoza et al., 2023).

In Ethiopia, research confirms that these global patterns of misunderstanding are present and often exacerbated by contextual factors (Dega et al., 2013). Despite formal instruction, many students retain fragmented mental models that hinder coherent understanding.

Contributing factors in the Ethiopian context include limited access to laboratory equipment, lack of hands-on experimentation, teacher-centered pedagogy emphasizing rote memorization, and insufficient training in diagnostic teaching methods (Dega et al., 2013).

Collectively, the literature underscores that overcoming students’ difficulties in electricity requires moving beyond transmission-mode instruction toward active, inquiry-based learning environments that explicitly confront misconceptions with evidence, promote metacognitive reflection, and integrate multimodal representations to make abstract processes tangible.

2.4. Inquiry- Based Learning and PhET Simulations as a Pedagogical Strategy

Inquiry-based learning (IBL) is a pedagogical approach that promotes student engagement in scientific practices by shifting classroom activity from teacher-dominated instruction toward student-centered reasoning, questioning, and problem-solving (García-Carmona, 2020; Bevins & Price, 2016; Kang, 2020). Defining inquiry in a single, fixed way is difficult because its implementation varies across educational contexts, learning goals, and classroom cultures(Teig, 2021; Bevins & Price, 2016). Despite this variability, science education research commonly characterizes inquiry as a process in which students identify problems, evaluate and critique evidence, compare alternative explanations, plan and conduct investigations, test conjectures, seek relevant information, construct models, engage in argumentation, and justify their conclusions(Teig, 2021). According to(Pedaste et al., 2015) . Conceptual framing of inquiry as an instructional approach is expressed in the fig 1 below.

M. Pedante et al./Educational Research Review 14 (2015) 47–61

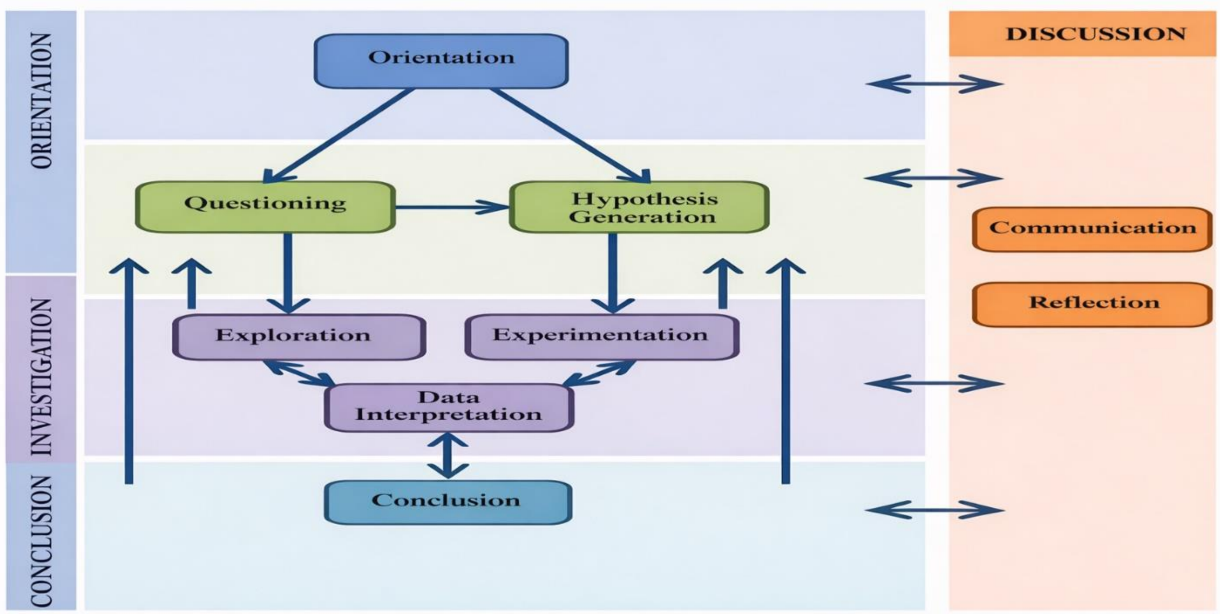


Fig. 1. Inquiry-based learning framework (general phases, sub-phases, and their relations).

Fig 1: Conceptual framing of inquiry as an instructional approach

Within this framework, the teacher's role is not to transmit knowledge directly but to guide students' sense-making by posing questions, providing scaffolds, and supporting reflection (Lee, 2012; Pedaste et al., 2015). Effective inquiry-based lessons therefore emphasize meaningful questions, collaborative learning, peer discussion, and active engagement that build on students' prior knowledge (Herranen & Aksela, 2019; Kang, 2020).

Inquiry-based instruction is best understood as a continuum defined by the degree of structure and guidance provided by the teacher (Wang et al., 2022). At one end of this continuum is open inquiry, in which students are responsible for generating questions, designing procedures, and interpreting results, while at the other end is confirmatory inquiry, where students verify known principles using prescribed questions, methods, and expected outcomes(Toma, 2022; Suduc et al., 2015). Between these extremes are structured inquiry, in which students are given the research question and procedure but develop their own explanations, and guided inquiry, where students are provided with the research question but determine how the investigation should be conducted(Bunterm et al., 2014; Arslan, 2014; Brata & Suriani, 2020).

Table 1. Four-Level Model of Inquiry (adapted from Bell et.al)

Level of inquiry	Question	Method	Solution
Confirmation Inq (1)	Given	Given	Given
Structured Inq.(2)	Given	Given	Open
Guided Inq (3)	Given	Open	Open
Open Inq.(4)	Open	Open	Open

The selection of guided inquiry as a pedagogical strategy is supported by substantial empirical evidence. Guided inquiry offers an effective balance between student autonomy and instructional support, enabling meaningful conceptual learning while avoiding the challenges associated with fully open inquiry (Bunterm et al., 2014; Lee, 2012). Research indicates that secondary school students engaged in guided inquiry often achieve stronger conceptual understanding and report higher levels of enjoyment compared to those experiencing open inquiry, even though open inquiry may better reflect authentic scientific practice(Bunterm et al., 2014). Guided inquiry has been shown to be particularly effective for teaching foundational physics topics, including direct current electric circuits, where students commonly hold persistent misconceptions (Kock et al., 2015). From a cognitive perspective, novice learner's benefit from structured guidance, as unguided exploration can lead to cognitive overload and fragmented understanding (Lee, 2012; Baur & Emden, 2021). Moreover, guided inquiry environments support conceptual change by explicitly eliciting, challenging, and reconstructing students' pre-existing idea (Menia et al., 2017). These characteristics make guided inquiry well suited for instructional interventions targeting complex and abstract physics concepts like electric circuits.

PhET simulations further strengthen guided inquiry by providing interactive, visual, and easily manipulable environments in which students can test ideas, revise predictions, and explore relationships that are difficult to observe using traditional laboratory equipment (Perkins et al., 2010; Peffer et al., 2015; Fan et al., 2018). These simulations are intentionally designed to promote sense-making, encourage exploration, and draw students' attention to key scientific relationships (Perkins et al., 2010). When integrated with guided-inquiry worksheets or teacher prompts, PhET simulations create a scaffolded learning environment that supports prediction, exploration, explanation, and reflection without overwhelming learners (Peffer et al., 2015; Yulianti et al., 2021). Physics education research has consistently shown that combining guided inquiry with interactive simulations leads to greater conceptual gains than traditional instruction and supports more accurate understanding of physics concepts, including electricity(Yulianti et al., 2021). In resource-limited educational contexts, such as many Ethiopian classrooms, PhET simulations also provide a practical and accessible alternative to expensive laboratory equipment while maintaining the integrity of inquiry-based investigation (Perkins et al., 2010; Diab et al., 2024a; Crowell & Geller, 2016).

The integration of technology, particularly PhET simulations, within guided inquiry has been shown to enhance student engagement, comprehension, and active participation in learning (Perkins et al., 2010; Crowell & Geller, 2016; Chen & Chen, 2025). Multiple studies have demonstrated that guided inquiry supported by PhET simulations significantly improves students' critical thinking abilities and conceptual understanding across physics topics(Bunterm et al., 2014; Yulianti et al., 2021; Fan et al., 2018). Together, these findings highlight the pedagogical value of combining guided inquiry with interactive simulations as a powerful strategy for enhancing both conceptual understanding and essential scientific skills in science education.

2.5. Inquiry- Based Methods and PhET Simulations for Conceptual Understanding of Electricity

The conceptual understanding of electricity presents a significant challenge for students globally due to its abstract nature (Mohammed, 2019). To address this, various pedagogical approaches and technological tools have been explored, with inquiry-based learning (IBL) and PhET simulations emerging as prominent strategies (Banda & Nzabahimana, 2021; Korganci et al., 2015; Tenzin et al., 2024).

2.5.1. Effectiveness of Inquiry-Based Learning in Electricity Concepts

Inquiry-based learning emphasizes active student engagement in scientific processes, promoting critical thinking and deeper conceptual understanding rather than rote memorization (Sari et al., 2024). Studies have consistently demonstrated the positive impact of IBL on students' conceptual understanding of electricity. IBL encourages students to formulate problems, generate hypotheses, conduct experiments, gather data, and analyze results, thereby fostering critical thinking skills essential for complex subjects like electricity (Sari et al., 2024). Research on physics education students, utilizing a mixed-methods approach, investigated students' conceptual application in solving electrical circuit problems through inquiry-based learning, demonstrating its role in addressing application errors (Cicyn Riantoni1, 2024).

However, implementing IBL can present challenges, particularly in contexts where a lack of experimental resources, activities and educational technologies can hinder effective teaching (Mohammed, 2019). Despite these challenges, the theoretical underpinnings and empirical findings support IBL as a promising approach for teaching and learning science concepts (Berie et al., 2022).

2.5.2. Effectiveness of PhET Simulations in Learning of Electricity Concepts

PhET (Physics Education Technology) interactive simulations offer a virtual laboratory environment that allows students to experiment and visualize abstract physics concepts, including electricity (Dheeraj Kumar, 2024; Villarreal Villarreal, 2024). Numerous studies have validated the effectiveness of PhET simulations in enhancing conceptual understanding. A comprehensive review of 31 quasi- or experimental research studies over the past decade found robust evidence that PhET simulations significantly enhance students' conceptual understanding of physics(Banda & Nzabahimana, 2021). These simulations can replace or supplement real laboratories, providing interactive and engaging learning experiences (Ernita et al., 2021; Studi et al., 2018).

Specifically in electricity education, PhET simulations have proven beneficial. A study aimed to assess the impact of PhET simulations on the conceptual understanding of electrostatics among secondary school students, concluding that PhET positively influenced understanding (Uwambajimana et al., 2023). Another study proved that PhET simulations improved engagement, satisfaction, and academic achievement in direct current electric circuit concepts among ninth-grade students (Dorji et al., 2024a).

PhET's ability to visualize invisible phenomena, such as the flow of electric charge, is particularly valuable for students who often struggle with non-scientific conceptions of electric current(J. Lee et al., 2015b). PhET simulations positively impacted students' academic performance and motivation in Basic Science and Technology (Olugbade et al., 2024). The use of PhET simulations with a discovery learning model also enhanced the understanding of dynamic electricity concepts (Anisa & Astriani, 2022). Furthermore, PhET simulations are seen as a game-based learning tool that enhances engagement and understanding (Danika Pranata, 2024).

While PhET simulations are widely recognized for their benefits in science education, particularly in enhancing conceptual understanding and engagement, some criticisms and limitations regarding their effectiveness have been noted in the literature. These criticisms often revolve around the conditions of implementation, the potential for superficial learning, and the necessity for integration with sound pedagogical approaches.

One challenge arises when PhET simulations are used without proper pedagogical guidance or within an inadequate instructional framework. Simply providing students with simulations does not automatically guarantee improved learning outcomes; the effectiveness is highly dependent on how these simulations are integrated into the teaching and learning process (Banda & Nzabahimana, 2021). For example, a comprehensive review of PhET simulations in physics education highlighted that the "best ways to use PhET simulations to enhance conceptual understanding of physics" is a critical question, implying that misuse or suboptimal application can diminish their impact (Banda & Nzabahimana, 2021). If not guided appropriately, students might engage in trial-and-error without forming deep conceptual connections, leading to a superficial understanding rather than true conceptual change (Fan, Geelan, Gillies, et al., 2018).

Moreover, while PhET simulations are praised for promoting engagement and motivation(Banda & Nzabahimana, 2021c; Dorji et al., 2024b; Olugbade et al., 2024), these benefits do not automatically translate to deeper conceptual understanding without thoughtful integration.

The appeal of simulations as "game-based learning tools (Danika Pranata, 2024) can be engaging, but educators must ensure that this engagement is directed towards scientific inquiry and conceptual development rather than just entertainment. Without explicit guidance on how to formulate problems, generate hypotheses, conduct virtual experiments, and analyze data, the full potential of PhET in fostering critical thinking and conceptual change may not be realized (Sari et al., 2024).

2.5.3. Effectiveness of Integrated Approaches (IBL and PhET Simulations)

The combination of inquiry-based learning (IBL) with PhET simulations offers a synergistic approach that leverages the strengths of both methods, where IBL provides the pedagogical framework for active exploration, and PhET simulations offer interactive tools to facilitate that exploration, particularly for abstract concepts like electricity(Fan, Geelan, Gillies, et al., 2018; Godwin Kwame Aboagye, 2018a). Studies have shown that integrating these two approaches can lead to enhanced learning outcomes (Drastisianti et al., 2024; Fan et al., 2018; Godwin et al., 2018).

One study investigated the effectiveness of using PhET simulations with inquiry learning models to increase students' conceptual understanding of static electricity, finding it to be effective(Drastisianti et al., 2024). This combined approach trains students to formulate problems, generate hypotheses, conduct experiments, gather data, and analyze through virtual practical simulation principles (Sari et al., 2024). Combining inquiry-based and computer simulation methods with cooperative learning was found to have the potential to improve students' learning outcomes in electric circuits (Godwin et al., 2018).

A novel inquiry-based instructional sequence using interactive simulations (like PhET) was investigated, showing effectiveness in supporting students' development of conceptual understanding, inquiry process skills, and confidence (Fan et al., 2018).

A comparative study focusing on electric circuit concepts found that a combined strategy of simulation and hands-on activities was effective in enhancing conceptual understanding (Tenzin et al., 2024c). This suggests that while PhET simulations are powerful, their integration with other strategies can yield superior results.

2.5.4. Effectiveness of Inquiry-Based Learning in Electricity Education in Ethiopia

Inquiry-based learning emphasizes active student engagement in scientific processes, fostering critical thinking and deeper conceptual understanding. Research within Ethiopia has acknowledged the potential benefits of IBL in science education generally(Berie et al., 2022). For instance, a guided inquiry teaching method was found to significantly improve grade eight students' conceptual understanding of photosynthesis (Dagnew & Mekonnen, 2020). The broader literature from 2010 to 2021 also supports the thesis that IBL is promising for teaching and learning, deserving further development (Berie et al., 2022).

2.5.5. Effectiveness of PhET Simulations in Electricity Education in Ethiopia

PhET (Physics Education Technology) interactive simulations offer a virtual laboratory environment that allows students to experiment with and visualize abstract physics concepts. While studies outside of Ethiopia have extensively demonstrated the effectiveness of PhET simulations in enhancing conceptual understanding in various physics topics, including electricity (Anisa et al., 2023), direct research on the impact of PhET simulations specifically for electricity education within Ethiopia is limited.

However, there are indications of technology-enhanced learning approaches being explored. For example, research aimed at improving high school students' conceptual understanding of electricity and magnetism utilized scaffold analogy instructions, which involved simulated analogical teaching models (Mengistu et al., 2022).

2.5.6. Effectiveness of Integrated Approaches (IBL and PhET Simulations) in Ethiopia

The combination of IBL with PhET simulations offers a synergistic approach where IBL provides the pedagogical framework for active exploration, and PhET simulations offer interactive tools to facilitate that exploration, particularly for abstract concepts like electricity. Globally, studies have shown that integrating these two approaches can lead to enhanced learning outcomes (Fan et al., 2018). Such combined strategies have been found to improve students' learning outcomes in electric circuits (Godwin et al., 2018). An inquiry-based instructional sequence using interactive simulations has also been shown to be effective in supporting students' development of conceptual understanding, inquiry process skills, and confidence (Fan et al., 2018).

2.6 Conceptual Framework of the Study

The conceptual framework integrates inquiry-based learning with PhET simulations to enhance secondary school students' conceptual understanding and reduce misconceptions of electricity. This framework hypothesizes that an intentionally designed learning environment, combining the active learning principles of IBL with the interactive visualization capabilities of PhET, will lead to improved learning outcomes.

The conceptual framework of this study is expressed as an interaction between inquiry-based learning processes and PhET simulations, where students actively explore electrical phenomena, generate predictions, conduct virtual experiments, analyze results, and construct explanations under teacher guidance, leading to improved conceptual understanding of electricity and reduction of misconceptions among secondary school students. The conceptual frame work of this study is summarized in the Fig 2 below.

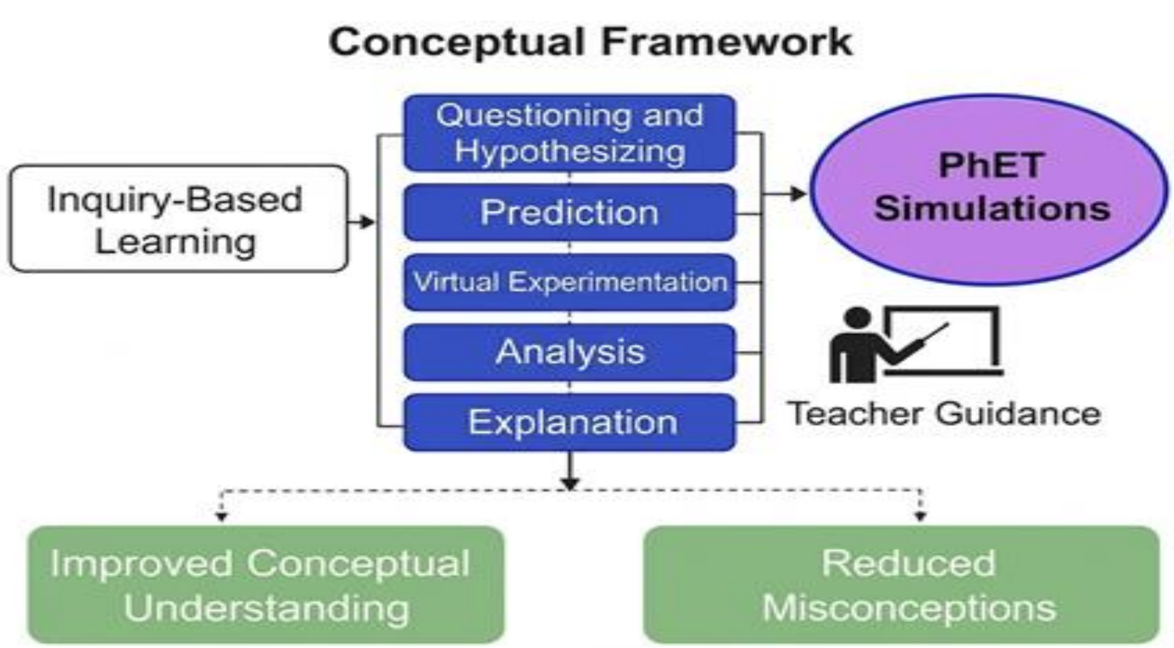


Fig 2: Conceptual frame work of the study

Overall, this conceptual framework posits that by combining the active, student-centered nature of inquiry-based learning with the powerful visualization and interactive capabilities of PhET simulations, secondary school students can achieve a deeper and more robust conceptual understanding of electricity, overcoming common learning difficulties associated with its abstract nature.

2.7. Summary and Implications

The reviewed literature demonstrates that students experience persistent difficulties in learning electricity, particularly in understanding abstract concepts such as current, voltage, energy transfer, and electrical interactions. These difficulties are widely reported across different educational contexts and often remain unresolved after traditional instruction(Duit, 2009; McDermott & Shaffer, 1992; D. M. Shipstone, 1984). Students' reliance on intuitive reasoning and everyday analogies, while common, frequently conflicts with scientific explanations and limits meaningful understanding.

Physics education research highlights the limitations of lecture-based and formula-centered instruction in promoting conceptual understanding of electricity(Redish & Burciaga, 2004). In contrast, inquiry-oriented instructional approaches are shown to be more effective in engaging students' thinking, revealing their ideas, and supporting conceptual change(Meltzer & Thornton, 2012). Interactive technologies, particularly PhET simulations, further support learning by making invisible electrical processes observable and allowing learners to test and refine their ideas through exploration(Nufus Choirum Masruroh Amelya Vivianti, 2020; K. Perkins et al., 2006).

Recent studies indicate that integrating inquiry-based learning with PhET simulations enhances students' conceptual understanding of electricity and promotes higher-order thinking skills(Adrianus Nasar1, 2025; Anselmo et al., 2024).However, most of this evidence comes from studies conducted outside the Ethiopian context. Local research remains limited, particularly studies that focus on inquiry-oriented, simulation-based approaches to teaching electricity.

Research Gap

Despite the global evidence supporting the effectiveness of inquiry-based learning and PhET simulations, and some research within Ethiopia focusing on IBL or certain educational technologies, there is a discernible gap in the specific integration and rigorous evaluation of inquiry-based learning with PhET simulations for conceptual understanding of electricity within the Ethiopian educational system. While analogy instructions involving simulated models have been explored(Mengistu et al., 2022), the direct impact of PhET interactive simulations, as widely studied elsewhere(Anisa & Astriani, 2022; Tenzin et al., 2024; Uwambajimana et al., 2023), remains underexplored in conjunction with IBL for electricity concepts in Ethiopia.

CHAPTER THREE: RESEARCH METHODOLOGIES

3.1 Research Paradigm and Approaches

This study was guided by the pragmatic research paradigm, which emphasizes addressing practical educational problems through the use of methods that best answer the research questions (Creswell & Plano Clark, 2018). Pragmatism supports the integration of quantitative and qualitative approaches, making it suitable for design-based research conducted in real classroom settings (Tashakkori & Teddlie, 2010). Besides, pragmatism as a paradigm would guide the present study on the context where the designed based research was aimed to tackle students' learning problems in real classroom practice and bring a model that works in the culture of that particular school. Accordingly, the pragmatic paradigm was appropriate for this study, as it focused on designing, implementing, and refining an inquiry-based PhET simulation strategy to improve secondary school students' learning of electricity topics in authentic school contexts in Bahir Dar City. This study adopted a concurrent embedded mixed-methods research approach, in which qualitative and quantitative data were collected during the same phase of the study and played complementary roles. This research design followed the embedded experimental model described by Creswell and Plano Clark (2018), as illustrated in the Fig 3 below.

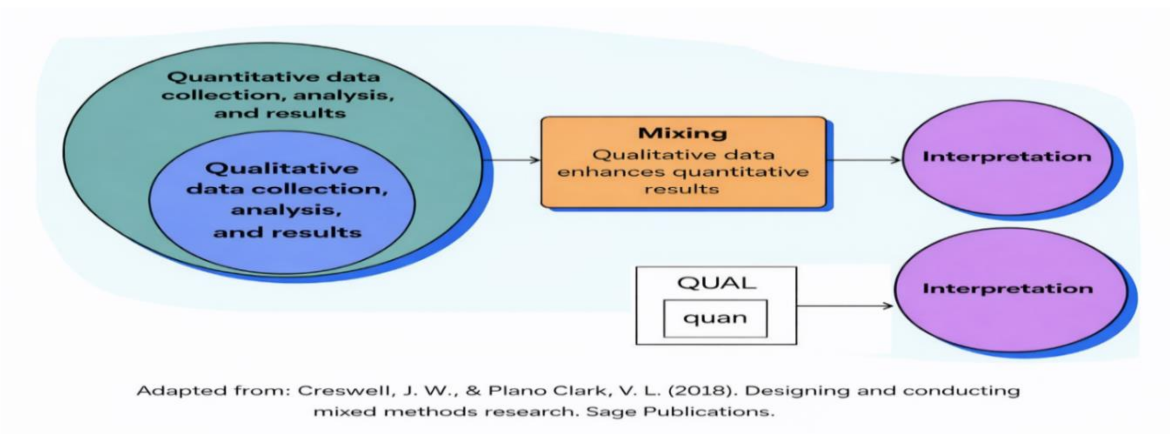


Fig 3: mixed method research design

3.2 Research Design

This study employed a one-on-one design-based research (DBR) approach to develop, implement, and refine an inquiry-based PhET simulation strategy aimed at improving secondary school students' learning of electricity topics in Bahir Dar City. Design-based research is appropriate for this study because it allows the researcher to design an instructional intervention, test it in a real classroom setting, and iteratively refine it based on continuous evidence from practice (Brown, 1992; The Design-Based Research Collective, 2003; Anderson & Shattuck, 2012). The "one-on-one" design refers to the close, focused interaction among the researcher, the teacher, and learners during implementation, allowing for detailed observation of students' learning processes, difficulties, and instructional challenges (Reeves, 2006; van den Akker et al., 2006). The study proceeded through iterative cycles of design, enactment, analysis, and redesign, with each cycle informed by both qualitative and quantitative data. Through this process, the research aimed to improve students' conceptual understanding of electricity and also to generate practical design principles for effectively integrating inquiry-based learning with PhET simulations in secondary school physics classroom.

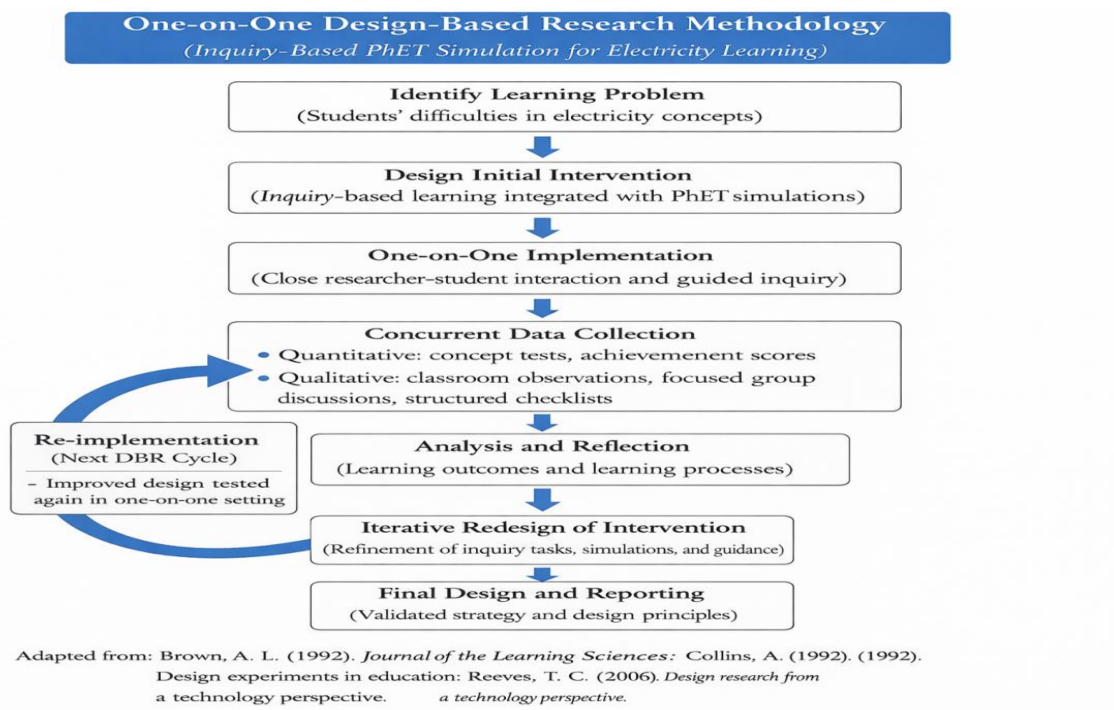


Fig 4: Design based research methodology

3.3 Sample and sampling Techniques

This research was conducted in one intact classroom with 35 students. Purposive sampling was used to select schools for the study, based on their access to adequate digital resources, including computers and internet connectivity, which were necessary for implementing the PhET simulation intervention. Within the selected schools, the participant intact class was randomly selected from Grade 10 physics classes covering the electricity unit to ensure fairness and reduce selection bias.

3.4 Data Collection Instruments

This study employed multiple data collection instruments to capture both the learning outcomes and learning processes associated with the inquiry-based PhET simulation intervention. Classroom observations and focus group discussions (FGDs) were conducted to gather in-depth qualitative insights into students' experiences, perceptions, learning progress, and challenges related to learning electricity topics through the intervention. In addition, standardized electricity tests (ECUT) were administered before and after the intervention to quantitatively measure changes in students' conceptual understanding and level of misconceptions about electricity topics. Together, these instruments provided complementary qualitative and quantitative evidence to support a comprehensive analysis of the effectiveness and refinement of the intervention.

3.5 Data Analysis Methods

Quantitative data obtained through standardized electricity tests were analyzed using descriptive and inferential statistics by evaluating to the required assumptions to answer the designed research questions.

Qualitative data collected through classroom observations, focus group discussions (FGDs) and students' responses on the worksheet were narratively analyzed. Descriptive analysis was employed to analyze qualitative data so as to support the quantitative data to see the effect of the inquiry-based blended with PhET simulation in reducing misconceptions and enhancing conceptual understanding of electricity topics. This involved identifying recurring patterns, categories, and themes in students' responses, behaviors, and interactions, and then narratively describing these findings to capture the depth and richness of the learning process (Braun & Clarke, 2006; Creswell & Plano Clark, 2018).

3.6 Participants and Context

The study was conducted at one of the secondary schools found at Bahir Dar City, Ethiopia, involving Grade 10 physics students studying the electricity unit. The participants were Grade 10 Section C students, with a total of 35 students (12 males and 23 females). Section C was selected randomly from the four Grade 10 sections (A–D). The participants were organized into small groups to support guided inquiry-based learning activities using PhET interactive simulations. The intervention was implemented in the school computer laboratory during regular instructional periods. The researcher designed, implemented, and facilitated the learning activities while collecting observational and assessment data.

3.7 Procedures

The researcher began by preparing a standardized electricity test, which was administered to diagnose students' prior understanding. Both quantitative and qualitative data obtained from this initial assessment were analyzed to identify learning gaps and misconceptions. Based on these findings, Cycle 1 of the DBR intervention was designed, implemented, and analyzed using inquiry-based PhET simulation activities aimed at addressing the identified gaps. After completing Cycle 1, the researcher reanalyzed the data to evaluate its effectiveness and further identified remaining learning difficulties. These findings were then used to refine the instructional design and implement Cycle 2 with improved scaffolding and learning activities. Finally, a post-test was administered to measure students' conceptual understanding after the full intervention, and the results were analyzed to determine overall learning improvements.

Data were collected across the iterative phases of the design-based research cycle to examine how the inquiry-based PhET simulation instruction supported students' conceptual understanding and reduced misconceptions about electricity topics. Qualitative data were collected using classroom observations and focus group discussions before the intervention and during the intervention. Quantitative data were collected using standardized electricity tests before the intervention and after each cycle of the research intervention.

3.8 Ethical Considerations

This study followed established ethical guidelines to protect the rights and well-being of all participants (American Psychological Association, 2017; Belmont Report, 1979). Approval was sought from the appropriate institutional review bodies before data collection began. Permission was also requested from the school administration where the study took place.

Participation was entirely voluntary. Students and their parents or guardians received clear information about the purpose of the study, the activities involved, the types of data collected, and their right to withdraw at any time without any negative consequences (Creswell & Creswell, 2018).

Confidentiality was maintained throughout the research process. No student names or identifying details appeared in the data files, transcripts, reports, or publications. Codes were used to label student responses (American Psychological Association, 2017). The intervention posed minimal risk, as it aligned with regular classroom activities and supported the Grade 10 physics curriculum. Care was taken to ensure that participation did not disrupt normal learning or disadvantage any student (Belmont Report, 1979).

CHAPTER FOUR: DATA ANALYSIS AND RESULTS

4.1. Demographic Data of Participants (Baseline Assessments)

In the study, 35 grade 10 students were involved in the study. 23 of them were females and 12 them were males. In the initial phase of the study, students' understanding of topics of electricity concepts was assessed using an Electricity Conceptual Understanding Test (ECUT) (see ECUT in appendix 1). The ECUT, consisting of 10 two-tier multiple-choice questions (MCQs), was designed to establish a baseline of students' conceptual understanding, and level of misconceptions in relation to the concepts of electricity were presented in table 2 below.

Table 2: Descriptive Statistics of ECUT Scores.

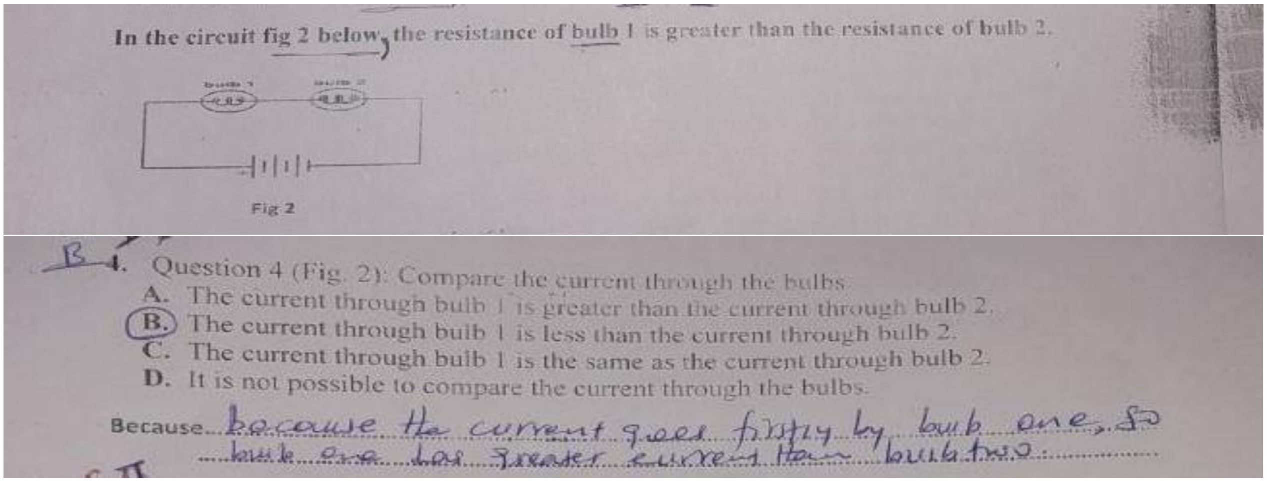
Variable	N	Mean	St. Dev.	Skewness	Kurtosis
Pre-ECUT	35	29.43	8.89	6.1	1.10
Post-EUCT	35	54.93	2.79	0.95	0.5

The result analysis in table 2 above showed that there is a mean score difference on students' electricity conceptual understanding within the group before and after intervention. Thus, to analyze whether this mean score difference was statistically significant or not, the presence of student's misconception, the designing of the guided inquiry-based learning integrated with PhET simulation, and its implementation, level of student's misconception before and after intervention were reported as follows.

4.2 Secondary School Students Misconception about Electricity Topics before the implementation

Qualitative analysis of student's responses about current distribution in series circuit revealed that some students stated that "bulb one gets more current because it is first connected," others explained that "bulb one consumes more current because it has larger resistance," and some said "bulb 2 gets less current because most of the current is consumed by bulb 1." These responses show that students reasoned locally about each bulb rather than viewing the circuit as a system, reflecting an incomplete application of Ohm's law.

Sample response of a student to current distribution in series circuit



In the circuit fig 2 below, the resistance of bulb 1 is greater than the resistance of bulb 2.

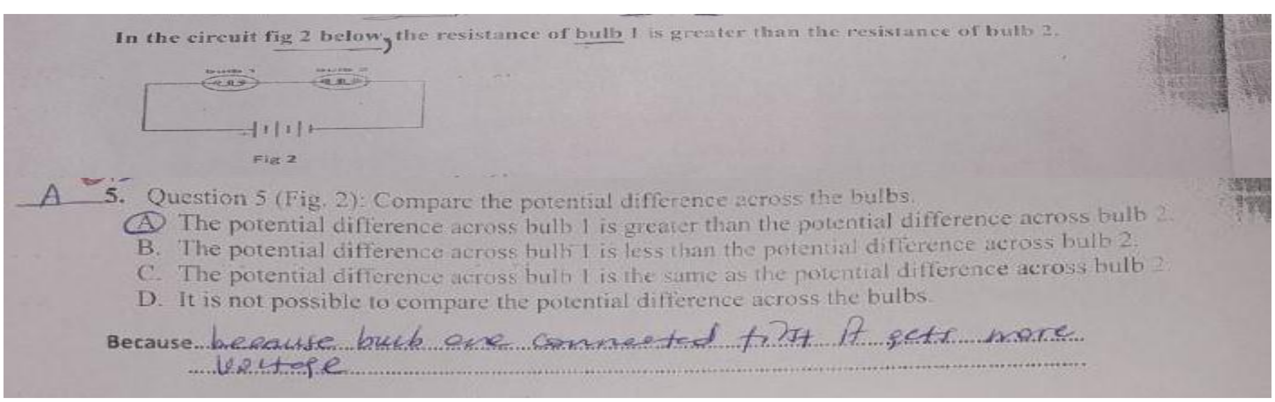
Fig 2

B 4. Question 4 (Fig. 2): Compare the current through the bulbs.
A. The current through bulb 1 is greater than the current through bulb 2.
B. The current through bulb 1 is less than the current through bulb 2.
C. The current through bulb 1 is the same as the current through bulb 2.
D. It is not possible to compare the current through the bulbs.

Because because the current goes firstly by bulb one, so bulb one has greater current than bulb two.

Qualitative analysis of student's responses about voltage distribution in series circuit highlighted common reasoning patterns among students. Some correctly noted that "*the bulb with higher resistance has a higher potential difference,*" demonstrating awareness of the proportional relationship between resistance and voltage in a series circuit. However, many students gave inaccurate explanations. For example, some stated that "*larger resistance bulb 1 has more voltage because when resistance increases, voltage also increases,*" without recognizing that current is the same for both bulbs**.** Others explained that "*bulb 1 has larger voltage because it is connected first and takes more voltage in the circuit.*" These responses show that many students reasoned locally about each bulb rather than considering the series circuit as a system, reflecting an incomplete or inappropriate application of Ohm's law.

Sample response of a student to voltage distributions in series circuit



In the circuit fig 2 below, the resistance of bulb 1 is greater than the resistance of bulb 2.

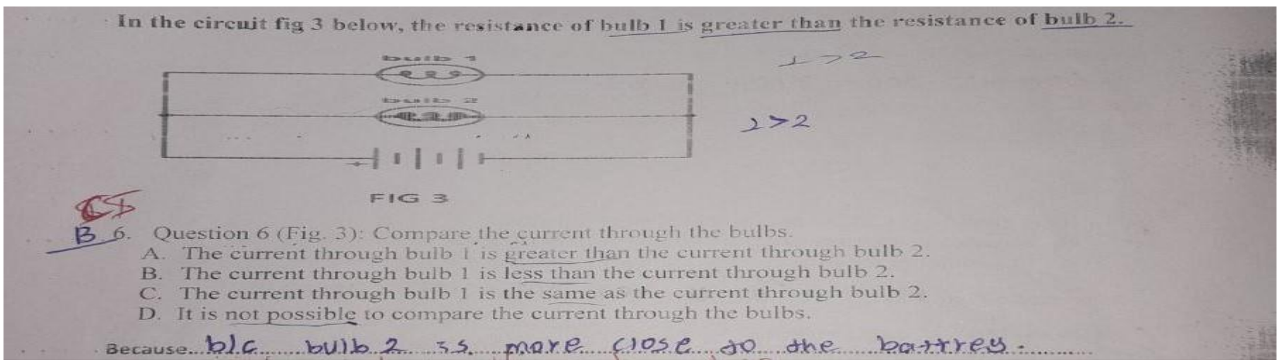
Fig 2

A 5. Question 5 (Fig. 2): Compare the potential difference across the bulbs.
A. The potential difference across bulb 1 is greater than the potential difference across bulb 2.
B. The potential difference across bulb 1 is less than the potential difference across bulb 2.
C. The potential difference across bulb 1 is the same as the potential difference across bulb 2.
D. It is not possible to compare the potential difference across the bulbs.

Because because bulb one connected first it gets more voltage

Qualitative analysis of students' explanations about current distributions in parallel circuit revealed common reasoning patterns and misunderstandings. A few students correctly noted that "*the branch with lower resistance has more current,*" demonstrating awareness of the inverse relationship between resistance and current in parallel circuits. However, many students gave inaccurate explanations. For example, some stated that "*bulb 2 has more current because it is connected first,*" others thought that "*bulb 1 has larger current because a large resistor consumes more current,*" and some believed that "*the current is shared equally between the bulbs.*" These responses indicate that many students reasoned locally about each component.

Sample response of a student to distribution of current in a parallel circuit


In the circuit fig 3 below, the resistance of bulb 1 is greater than the resistance of bulb 2.

1 > 2

1>2

FIG 3

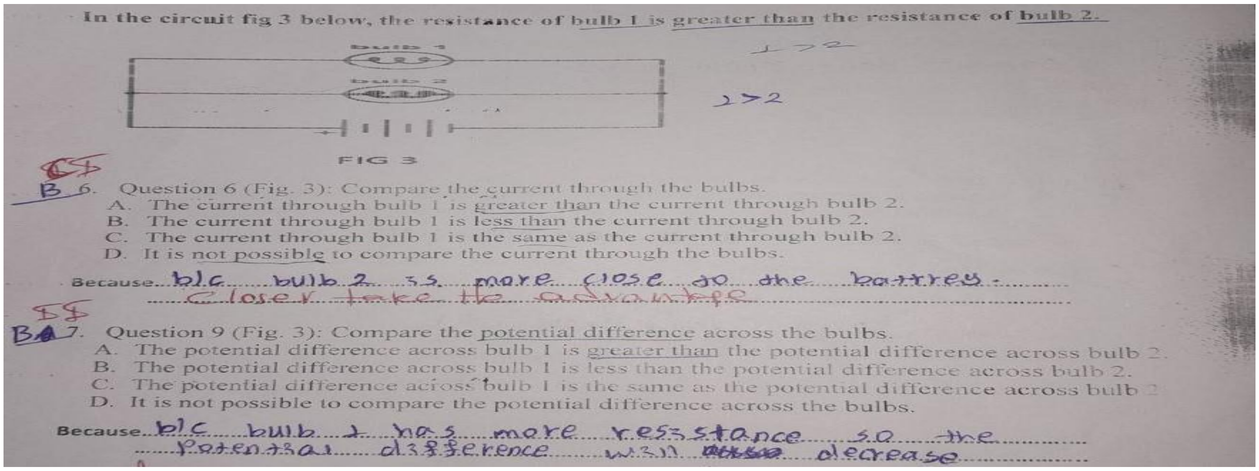
B 6. Question 6 (Fig. 3): Compare the current through the bulbs.

A. The current through bulb 1 is greater than the current through bulb 2.
B. The current through bulb 1 is less than the current through bulb 2.
C. The current through bulb 1 is the same as the current through bulb 2.
D. It is not possible to compare the current through the bulbs.

Because... b/c bulb 2 is more close to the battrey.

Qualitative analysis of students' explanations about voltage distribution in parallel circuit highlighted several common misunderstandings. While some correctly recognized that "*in a parallel circuit, the potential difference across all bulbs is the same,*" many students gave inaccurate reasoning. For example, some stated that "*bulb 1 has more voltage because it has higher resistance,*" others thought "*bulb 2 has less voltage because it is smaller,*" and some assumed "*the voltage is shared equally but depends on the size of the resistor.*" Additionally, a few students explained that "*bulb 2 has more voltage because it is near to the source.*" These responses showed that many students had confusion between series and parallel circuit.

Sample response of a student to voltage distribution in parallel circuit


In the circuit fig 3 below, the resistance of bulb 1 is greater than the resistance of bulb 2.

1 > 2

FIG 3

B 6. Question 6 (Fig. 3): Compare the current through the bulbs.

A. The current through bulb 1 is greater than the current through bulb 2.
B. The current through bulb 1 is less than the current through bulb 2.
C. The current through bulb 1 is the same as the current through bulb 2.
D. It is not possible to compare the current through the bulbs.

Because b/c bulb 2 is more close to the battrey. closer take the advantage

BA 7. Question 9 (Fig. 3): Compare the potential difference across the bulbs.

A. The potential difference across bulb 1 is greater than the potential difference across bulb 2.
B. The potential difference across bulb 1 is less than the potential difference across bulb 2.
C. The potential difference across bulb 1 is the same as the potential difference across bulb 2.
D. It is not possible to compare the potential difference across the bulbs.

Because b/c bulb 1 has more ressstance so the potentaial difference will decrease

Table 3: Frequency Distribution of Students' Pre-test Total Misconceptions

		Pre-test total misconceptions			
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	2.9	2.9	2.9
	2	2	5.7	5.7	8.6
	3	13	37.1	37.1	45.7
	4	10	28.6	28.6	74.3
	5	6	17.1	17.1	91.4
	6	3	8.6	8.6	100.0
	Total	35	100.0	100.0	

The result in Table 3 above shows that most students had a high level of misconceptions in the pre-test. The majority of students scored 3 misconceptions (37.1%), followed by 4 misconceptions (28.6%). In addition, 17.1% and 8.6% of the students scored 5 and 6 misconceptions respectively. Only 2.9% of the students had no misconception. This indicates that students had considerable misconceptions about electricity concepts before the intervention.

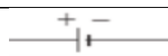
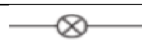
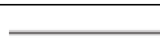
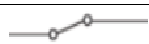
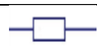
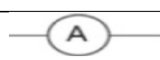
In general, from the pre-survey of the study, the participant students had misconceptions in many of the topics of electricity where the contents are still included in grade 10^{th} physics text book (MoE, 2023). The findings of this study revealed that students in this school context have misconceptions where changing the classroom instruction is essential to enhance their learning in a meaningful way. Thus, the presented study tried to tackle students' misconception by designing guided inquiry-based learning blended with PhET simulations.

4.3 Designing Guided Inquiry-Based Learning Integrated with PhET Simulation

To solve students' real learning difficulties and misconception identified in the learning of electricity topics, the researcher had selected instructional activities that targets the learning objectives designed in the physics curriculum at grade 10th level.

Learning Activities and Lesson Design

1. Table 1: Shows the electrical symbols of the elements of an electric circuit. First, define an electric circuit, and then write the picture, name, and usage of each element shown in table 1 below.

Electric circuit	Definition:		
Picture	Symbol	Name	Usage in the circuit
			
			
			
			
			
	 or 		
			
			

2. Using Circuit Construction Kit: DC PhET experiment to draw an open and a closed circuits and describe their differences based on the question given in the table 2 below

Table 2: Questions on drawing open and closed circuits and describing their differences

Connection with	Draw an open and a closed circuits and describe their differences	
	Series open circuit	Series closed circuit
2 bulbs with resistances 10Ω and 20Ω + 1 battery with 60V		
Differences		

3. Briefly explain current, voltage, and resistance and record your explanations in the table 3 below?

Terms	Explain current, voltage, and resistance
	Definition
current	
Voltage	
Resistance	

4. Please summarize the relationship between current and voltage values as the number of batteries increase as shown in the table 4 below. First draw the circuit diagrams using Circuit Construction Kit: DC PhET experiment and see the change in the brightness of the bulb.

Relationship between current and voltage values as the number of batteries increase			
I Circuit diagram	II Circuit diagram	III Circuit diagram	IV Circuit diagram
Voltage: 9.0 Volt Resistance: 10Ω bulb Current:	Voltage: 18.0 Volt Resistance: 10Ω bulb Current:	Voltage: 27.0 Volt Resistance: 10Ω bulb Current:	Voltage: 36.0 Volt Resistance:10Ω bulb Current:

Considering the change in voltage and current values in series circuits from the above table 4, draw voltage versus current graph and explain Ohm's law on the Table 5 below.

Graphical representation for Ohm's Law

No	Voltage	Resistance	Current	Graph (Voltage vs Current) and explain to Ohm's law
I	9.0 Volt	10Ω		
II	18.0 Volt	10Ω		
III	27.0 Volt	10Ω		
IV	36.0 Volt	10Ω		

5. In Table 6 below, the factors affecting the resistance of a given resistor (R) are listed. Using the "Resistance in a Wire" PhET simulation, determine whether the resistance of the wire increases or decreases when each factor is increased or decreased.

Factors affecting the resistance of a given wire		Resistance of the wire will be	From your observation write the formula to calculate resistance of a wire.
Length of the wire(L)	Length increased		
	Length decreased		
Cross sectional area of the wire(A)	Cross sectional area increased		
	Cross sectional area decreased		
Resistivity of the material(ρ)	Resistivity of the material increased		
	Resistivity of the material increased		

6. Answer the following questions and record your answers in Table 7 below.
   - Find the current value in total and over each bulb in each circuit?
   - Find the voltage value in total and over each bulb in each circuit?
   - Find the equivalent resistance in each circuit?

Table 7: Question to find the equivalent resistance the current through each bulb, the voltage drop across each bulb and the total current in each circuit.

Connection with	Draw the circuits and find the equivalent resistance, the current through each bulb, the voltage drop across each bulb and the total current in each circuit.	
	Series Circuit	Parallel Circuit
2 bulbs with resistances 10Ω and 20Ω + 1 battery with 60V		
Equivalent resistance: Current (total): Current (each bulb): Voltage (total): Voltage (each bulb):		
Compare the total current with the currents through each bulb		
Compare the total voltage with the voltages across each bulb		

7. Complete Table 8 below by stating what each instrument measures, how it is connected in a circuit, and providing reasons for its method of connection.

Instrument	Used to measure:	Connected in: Justify your answer by reasons
Ammeter		
Voltmeter		

8. Draw the circuits using **circuit construction PhET experiment** and measure the total current, the currents through each bulb using ammeter and measure the total voltage, the voltages across each bulb using voltmeter. And record your answers in the table 9 below

Connection with	Draw the circuits and measure the total current, the currents through each bulb using ammeter and measure the total voltage, the voltages across each bulb using voltmeter.	
	Series Circuit	Parallel Circuit
2 bulbs with resistances 10Ω and 20Ω + 1 battery with 60V		
Using ammeter Current (total): Current (each bulb):		
Using voltmeter Voltage (total): Voltage (each bulb):		
Compare the total current with the currents through each bulb		
Compare the total voltage with the voltages across each bulb		

4.4 Implementation of the Designed Guided Inquiry –based Learning Integrated with PhET Simulation

After selectively designing of GIBL integrated with PhET Simulation, the classroom teaching was carried out as follows.

Implementation Phase

The Lesson Tasks

The researcher aimed to use inquiry-based learning integrated with PhET simulation experiments to enhance students' conceptual understanding and reduce misconceptions about topics of electricity. The instructional activities were designed following an inquiry-based approach, where students actively explored concepts through simulation, discussion, and guided questioning.

The intervention was implemented with 35 Grade 10 students, of which 12 were male and 23 were female. During the lessons, students used computers to interact with PhET simulations and virtual laboratory activities, which allowed them to manipulate circuit variables, observe outcomes, and explain their findings.

The instructional process was conducted over four class sessions, with each session lasting 45 minutes. Throughout the activities, students worked collaboratively to perform virtual experiments, make predictions, record observations, and explain their reasoning. Students' responses were collected and analyzed to examine their conceptual understanding and identify possible misconceptions related to electricity concepts. Samples of student responses were provided. The lesson flow was presented below.

Cycle one

Lesson One

The teacher started the lesson by presenting Table 1 (see Table 1 in section 4.2), which showed the electrical symbols of the basic elements of an electric circuit. The teacher then asked the students, "What is an electric circuit?" and encouraged the students to explain their ideas based on their previous knowledge. The students were expected to understand that an electric circuit is a closed path through which electric charges flow from a power source through different components and back to the source.

After the discussion, the teacher asked students to observe the symbols of the circuit elements in table 1 and complete Table 1 on the worksheet. Students were required to identify the picture, name, and usage of each circuit element used in an electric circuit. The teacher guided the students to recognize common elements such as a battery, bulb, ammeter, voltmeter, resistor, switch, and connecting wires, and emphasized their roles in a circuit.

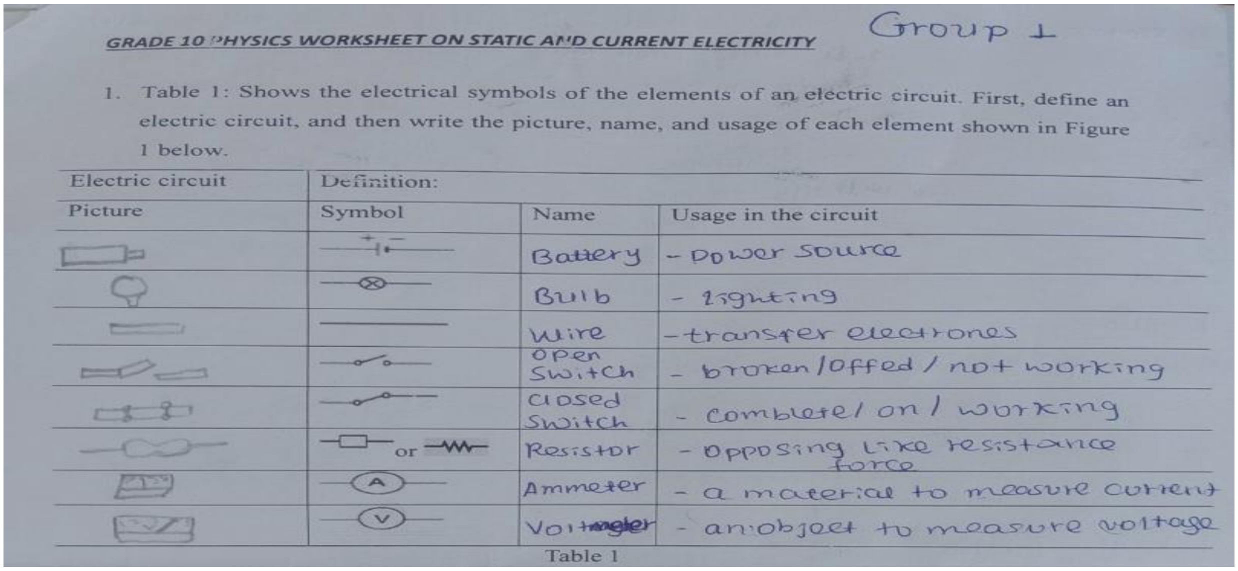
Next, the teacher introduced the computer simulation PhET Circuit Construction Kit: DC and explained how it could be used to construct electric circuits virtually. The teacher demonstrated how to select components such as a battery, bulbs, and wires and how to connect them in the simulation environment. The students were then instructed to use the simulation to construct two types of circuits using two bulbs with resistances of 10 Ω and 20 Ω and one battery of 60 V.

Students were asked to draw and observe both a series open circuit and a series closed circuit and record their work in Table 2 (see Table 2 in section 4.2). During the activity, the teacher asked guiding questions such as, "What happens to the bulbs when the circuit is open?" and "What changes when the circuit becomes closed?" Students were expected to observe that in an open circuit the path is incomplete and no current flows, so the bulbs do not light, while in a closed circuit the path is complete, allowing current to flow and the bulbs to light.

Finally, students were asked to describe the differences between open and closed circuits based on their observations. The teacher facilitated a short discussion in which students shared their findings and explanations, helping them clarify that a closed circuit allows electric charge to flow while an open circuit interrupts the flow of charge.

Sample student's responses are presented below.

Their responses regarding the picture, name, and function of each element in an electric circuit are attached below.



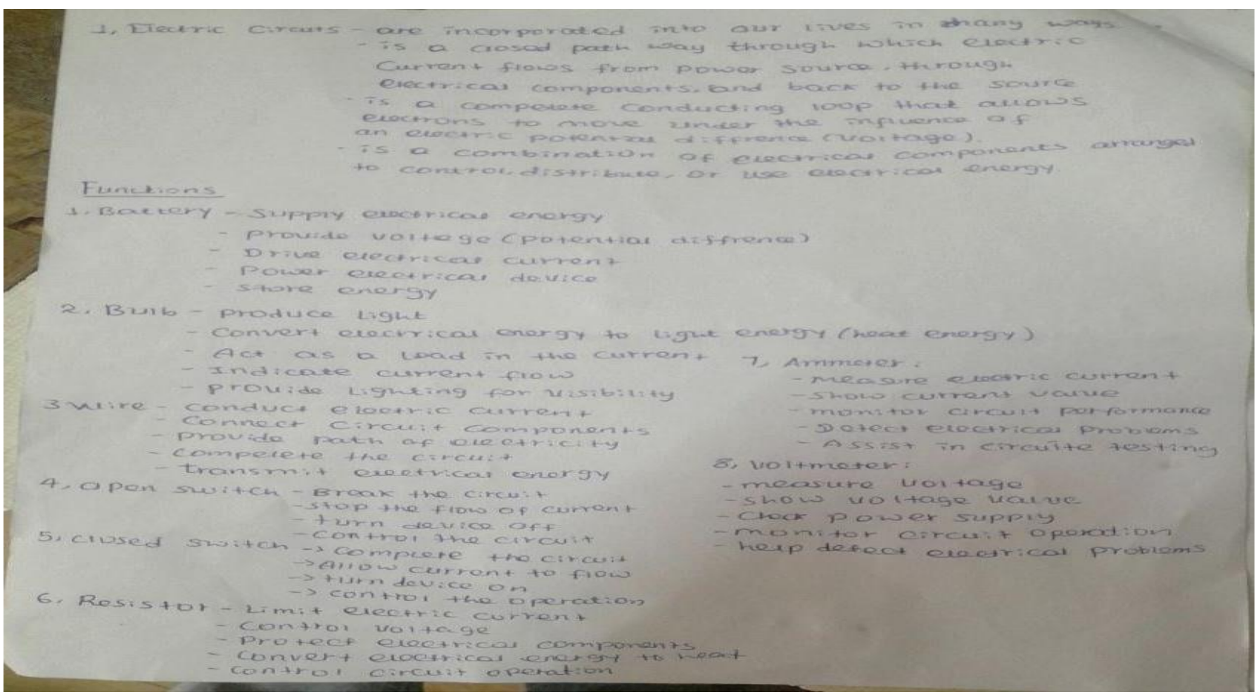
GRADE 10 PHYSICS WORKSHEET ON STATIC AND CURRENT ELECTRICITY Group 1

1. Table 1: Shows the electrical symbols of the elements of an electric circuit. First, define an electric circuit, and then write the picture, name, and usage of each element shown in Figure 1 below.

Electric circuit	Definition:		
Picture	Symbol	Name	Usage in the circuit
		Battery	- Power source
		Bulb	- lighting
		Wire	- transfer electrones
		Open Switch	- broken/offed / not working
		Closed Switch	- complete/ on / working
	or	Resistor	- opposing like resistance force
		Ammeter	- a material to measure current
		Voltmeter	- an object to measure voltage

Table 1

The students demonstrated a clear understanding of the components and functions of an electric circuit. Their responses after discussion attached as blow



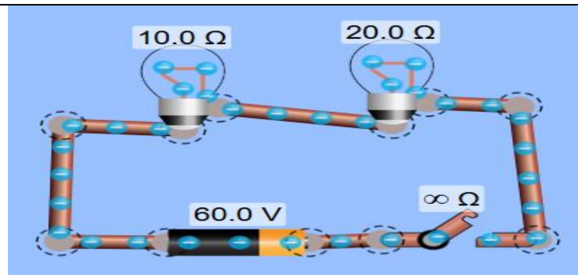
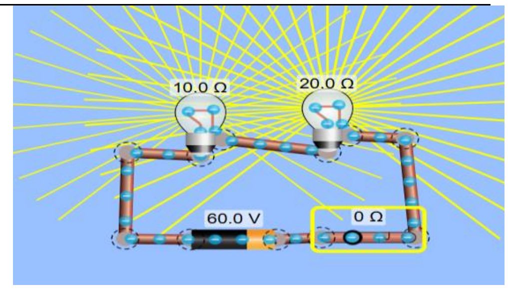
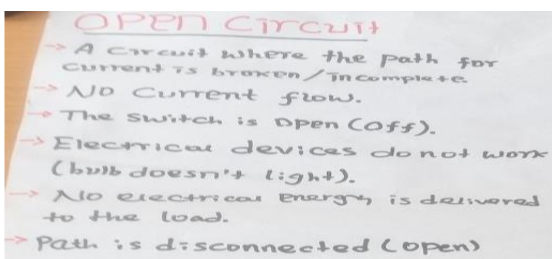
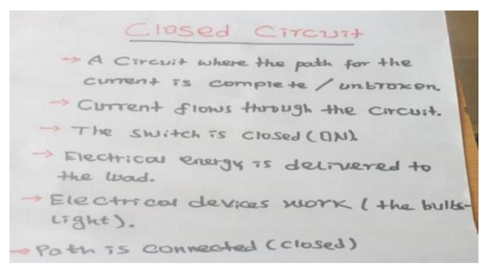
1, Electric Circuits - are incorporated into our lives in many ways.
- is a closed path way through which electric current flows from power source, through electrical components, and back to the source
- is a complete conducting loop that allows electrons to move under the influence of an electric potential diffrence (voltage).
- is a combination of electrical components arranged to control, distribute, or use electrical energy.

Functions
1. Battery - Supply electrical energy
- Provide voltage (potential diffrence)
- Drive electrical current
- Power electrical device
- Store energy
2. Bulb - produce light
- Convert electrical energy to light energy (heat energy)
- Act as a load in the current
- Indicate current flow
- Provide lighting for visibility
3 Wire - Conduct electric current
- Connect circuit components
- Provide path of electricity
- Complete the circuit
- transmit electrical energy
4, Open switch - Break the circuit
- stop the flow of current
- turn device off
- Control the circuit
5, closed switch -> Complete the circuit
-> Allow current to flow
-> turn device on
-> control the operation
6, Resistor - Limit electric current
- Control voltage
- Protect electrical components
- Convert electrical energy to heat
- Control circuit operation
7, Ammeter:
- measure electric current
- Show current value
- monitor circuit performance
- Detect electrical problems
- Assist in circuite testing
8, Voltmeter:
- measure voltage
- show voltage value
- Check power supply
- monitor circuit operation
- help detect electrical problems

After students discussed in groups and identified and understood the electrical symbols presented in **Table 1**, which shows the electrical symbols of the elements of an electric circuit, they were able to define an electric circuit as a closed path through which electric charge flows from a power source through different components and back to the source. They completed the table by identifying and writing the picture, name, and usage of each element. They also demonstrated their understanding of the functions of basic circuit components such as the battery, bulb, switch, ammeter, voltmeter, resistor, and connecting wires by, explaining the role of each component in the operation of an electric circuit. “Students described the battery as ‘*the source of electrical energy that provides voltage to the circuit,*’ the bulb as ‘*the device that converts electrical energy into light,*’ the switch as ‘*a component used to open and close the circuit to control the flow of electric charges*,’ the ammeter as ‘*an instrument used to measure electric current*,’ the voltmeter as ‘*a device used to measure the potential difference across components*,’ the resistor as ‘*a component that limits or controls the flow of electric charges,*’ and the connecting wires as ‘*conductors that provide a path for electric charges to move between the different components in the circuit.*’” Following this activity, the teacher guided students to apply their knowledge practically by introducing the Circuit Construction Kit: DC PhET simulation, where students constructed and observed both open and closed circuits. Students then used the simulation to draw an open circuit and a closed circuit and described their differences based on the questions provided in **Table 2** (see Table 2 in section 4.2),, helping them recognize that an open circuit prevents the flow of charge, while a closed circuit allows charge to flow and operate the connected components. Sample responses of students is attached below

Using Circuit Construction Kit: DC PhET experiment to draw an open and a closed circuits and describe their differences based on the question given in the table 2 below

Table 2: Questions on drawing open and closed circuits and describing their differences

<table>
<tr><td rowspan="2">Connection with</td><td colspan="2">Draw an open and a closed circuits and describe their differences</td></tr>
<tr><td>Series open circuit</td><td>Serial closed circuit</td></tr>
<tr><td>2 bulbs with resistances 10Ω and 20Ω 1 battery with 60V</td><td>
</td><td>
</td></tr>
<tr><td rowspan="2">Differences between open and closed circuit</td><td colspan="2">“Students discussed in groups and clearly described the differences between open and closed circuits.”</td></tr>
<tr><td>

Open Circuit
→ A Circuit where the Path for Current is broken/incomplete.
→ No Current flow.
→ The switch is open (off).
→ Electrical devices do not work (bulb doesn't light).
→ No electrical energy is delivered to the load.
→ Path is disconnected (open)</td><td>

Closed Circuit
→ A Circuit where the path for the current is complete/unbroken.
→ Current flows through the circuit.
→ The switch is closed (ON)
→ Electrical energy is delivered to the load.
→ Electrical devices work (the bulb light).
→ Path is connected (closed)</td></tr>
</table>

The lesson effectively supported students’ understanding of electric circuits by combining prior knowledge, guided instruction, and PhET simulation. Students were able to correctly define an electric circuit as a closed path for the flow of charges and successfully identified common circuit elements, including their symbols and functions, in Table 1. Through the use of the Circuit Construction Kit: DC, students actively constructed and observed both open and closed series circuits, which helped them clearly grasp the concept of charge flow. Their responses and discussions showed that they understood the difference between open and closed circuits particularly that a closed circuit allows charge to flow and light the bulbs, while an open circuit prevents it.

During the lesson, students experienced difficulties in understanding the roles of components in an electric circuit. Although they were familiar with the practical applications of components such as batteries, bulbs, switches, and wires in their homes, they struggled to connect this prior knowledge to the theoretical concepts being taught. A challenge widely reported in science education when students attempt to link everyday experiences with abstract scientific ideas (Vosniadou, 2013 Taber, 2013). Similarly, when discussing open and closed circuits, students faced observable learning difficulties. For example, some students incorrectly predicted that a bulb would still light when the switch was open, or believed that no charge could flow when the switch was closed. These misconceptions were influenced by their native language, as in Amharic the word “open” is often interpreted as a free path through which charges can flow, and “closed” is understood as a blocked path, reflecting how prior knowledge and language can shape students’ scientific understanding and lead to alternative conceptions (Spatz et al., 2020; Driver et al., 2014). To address these challenges, in lesson two, a practical analogy was introduced to help students better grasp the concepts of current, electron current, conventional current, voltage, and resistance, as outlined in Table 3 (see table 3 in section 4.2). The use of analogy as an instructional strategy is widely recommended because it helps bridge the gap between students’ prior knowledge and new scientific concepts and supports the development of conceptual understanding in science learning (Orgill & Bodner, 2006;Harrison & Treagust, 2006). This approach aimed to link theoretical definitions with observable phenomena, helping students develop a deeper understanding of electric circuits.

Lesson two

The teacher began the lesson by presenting Table 3 (see Table 3 in section 4.2), which focused on key electrical concepts such as current, types of current, voltage, and resistance. The teacher first asked students, “What is electric current?” and encouraged them to share their ideas based on their prior knowledge and experiences. To guide their thinking, the teacher asked leading questions such as, “If electric charges are moving in a circuit, what does that movement represent?” and “Can you think of something in everyday life that moves in a similar way?” Students were guided to understand that electric current is the rate of flow of electric charges in a closed circuit. The teacher then introduced the water analogy, explaining that electric charges moving in a circuit are like water flowing through a pipe. The effectiveness of the water analogy in supporting students’ understanding of electric current and electric circuits has been reported in physics education research (Korganci et al., 2015; Harrison & Treagust, 2006; Harrison & Coll, 2007).

The teacher asked, “If water flows in a pipe, what does that tell you? And how would that relate to electric charges in a circuit?” The teacher used the water analogy to help students understand electric current. Students grasped that the flow of water represents the flow of electric charges, the pipe represents the wire that provides a path for the charges, and the pump represents the battery that drives the charges through the circuit. The opening and closing of the pump represent a switch that controls the flow. Finally, students understood that electric current is the rate of flow of electric charges in a circuit.

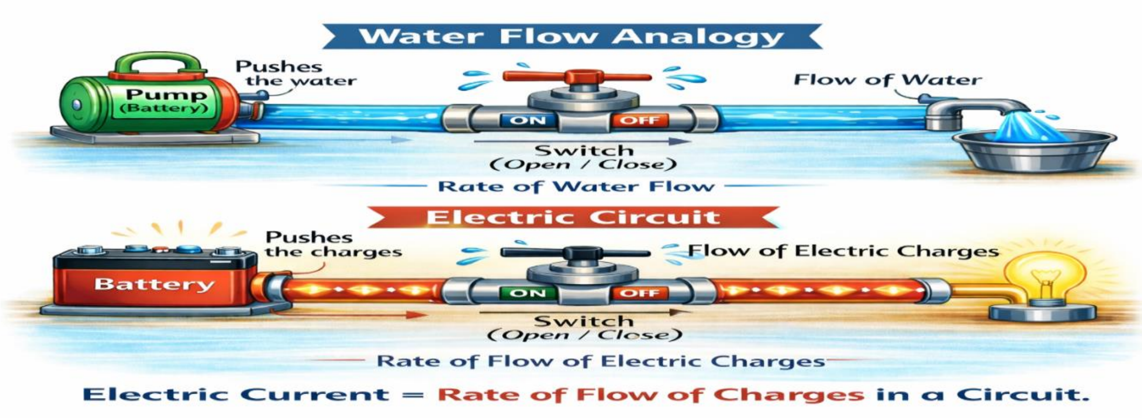
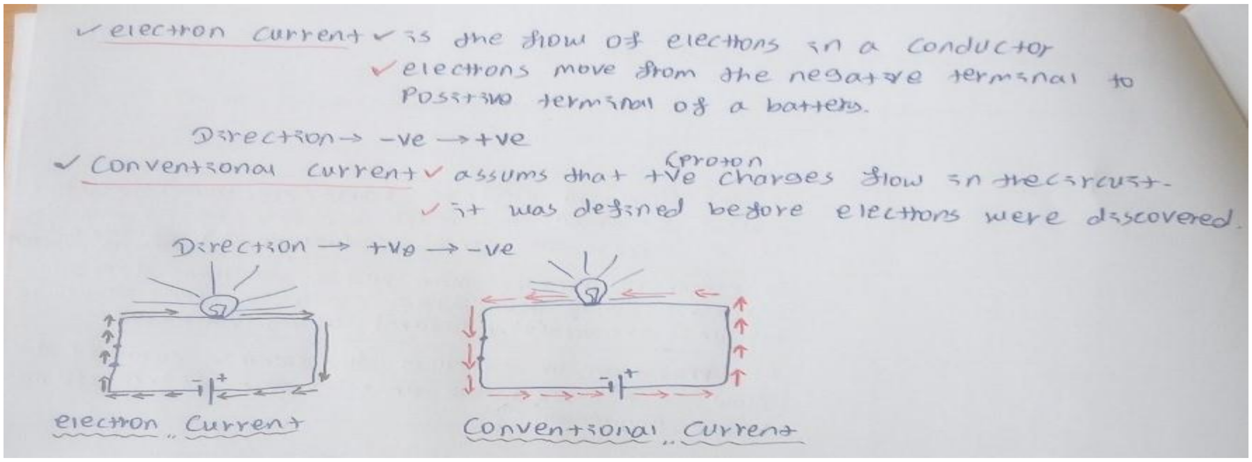


Fig 5: Water flow analogy

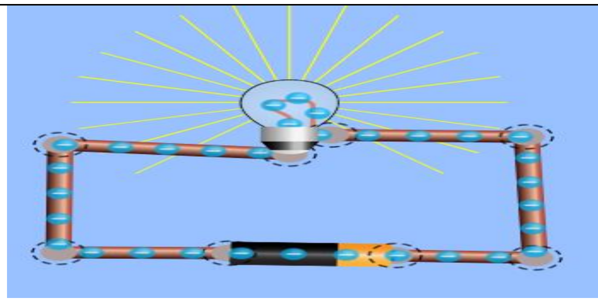
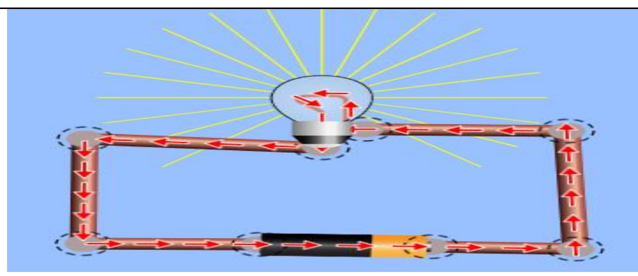
Then the teacher introduced two types of current by guiding students with questions such as: “What is electron current?”, “What is conventional current?”, “In which direction do electrons actually move?” Through discussions students learned that electron current is the actual flow of electrons from the negative terminal to the positive terminal, while conventional current is the assumed flow of positive charge from the positive to the negative terminal. Sample students’ response is attached below.



To deepen understanding, the teacher guided students to explore these concepts using the Circuit Construction Kit: DC. Students constructed a simple closed circuit with a battery, wires, and a bulb, and used the simulation to observe the movement of charges. By enabling the electron flow feature, students clearly observed that electrons move from the negative terminal to the positive terminal, helping them understand electron current.

The teacher then encouraged students to compare this observation with conventional current by asking guiding questions such as, “In which direction do we assume current flows in circuit diagrams?” Through observation and discussion, students recognized that conventional current flows from the positive terminal to the negative terminal, which is opposite to the actual movement of electrons. Students’ work describing electron current and conventional current using Circuit Construction Kit (DC) is shown below.

Table 3: Explanation of Types of Current using Circuit Construction Kit (DC)

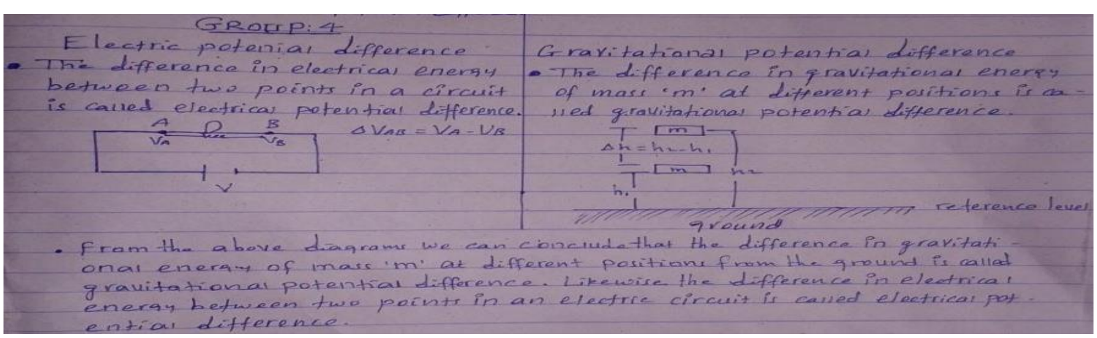
Terms	Explain Types of Current using Circuit Construction Kit (DC) Explanation:
Electron current	 The flow of electrons from negative terminal of the battery to the positive terminal of the battery. (-ve terminal to +ve terminal) is called electron Current. it is shown in the diagram below,
Conventional current	 The flow of protons from positive terminal of the battery to the negative terminal of the battery (+ve terminal to -veterminal) is called conventional current. It is shown in the diagram below.

After the students clearly understood current and the types of current, the researcher asked them to define voltage and resistance. To guide their thinking, the teacher asked simple and direct questions such as, “What is voltage?” and “What is resistance?” The researcher then guided students to define potential difference (voltage) by using an analogy of gravitational potential difference. The use of the gravitational potential difference analogy is effective in helping students develop a conceptual understanding of voltage and electric potential because it connects abstract electrical ideas with familiar experiences related to height, energy, and motion (D'Alessandris, 2020; Etkina et al., 2019; Knight, 2017).

Students were asked what happens when an object is lifted to a higher place, whether the object has more energy at a higher position or a lower position, what causes the object to move downward when released, and whether the object will move if there is no difference in height between two points. The teacher then related these ideas to electric circuits by asking what makes electric charges move in a circuit, leading students to conclude that voltage is the difference in electrical energy between two points that causes charges to flow.

To explain resistance, the teacher used the analogy of friction. Friction-based analogies are widely used in teaching electrical circuits because they help students understand resistance as opposition to flow of charges in a circuit (Mark david Walker; David Garlovsky, 2016). The teacher asked students to imagine pushing a box across a floor: the rougher the floor, the harder it is to move the box, just as higher resistance in a circuit makes it harder for electric charges to flow, while lower resistance allows them to move more freely.

Table 3: Explanation of Voltage and Resistance

<table>
<tr><td rowspan="2">Terms</td><td>Explain Voltage and Resistance</td></tr>
<tr><td>Definition:</td></tr>
<tr><td>Voltage</td><td>Electric potential difference (voltage) is the difference in electrical energy between two points in an electric circuit. In order to link the concept of electric potential difference to gravitational potential difference, students drew an electric circuit diagram and a gravitational potential energy diagram with the guidance of the teacher and described them as shown below.

</td></tr>
</table>

	After discussion, students concluded from the diagram that electric potential difference is the difference in electrical energy between two points in a circuit, represented as $V_A - V_B$. They also observed that gravitational potential difference refers to the difference in energy of a mass at different heights. From the picture, students identified a clear analogy between the two concepts, as both depend on differences between two positions. They agreed that both types of potential difference describe how energy varies within a system. Overall, the diagram helped students relate electrical and gravitational energy concepts visually.
Resistance	Resistance in an electric circuit is the opposition to the flow of electric charge, determining how easily charges can move through a component. A helpful analogy is friction: just as a rough floor resists the motion of a sliding box the rougher the floor, the harder it is to push the box likewise, resistance in a circuit opposes the movement of charges. A wire or component with high resistance makes it harder for charges to flow, while low resistance allows charges to move more freely. To help students understand the concept of resistance using the friction analogy, the teacher presented the diagram and guided students to compare the motion of an object moving across surfaces with different roughness to the flow of electric current in a circuit. The teacher asked direct questions such as: “What happens when an object moves on a rough surface compared to a smooth surface?”**,** “How does friction affect motion?”**,** and “In a circuit, what does resistance do to the flow of charge?” Through this brief discussion, students identified that increased friction makes motion more difficult, just as increased resistance reduces current. This approach helped students develop a clearer understanding of Electrical Resistance and its role in controlling current in a circuit as explained by Ohm's Law.

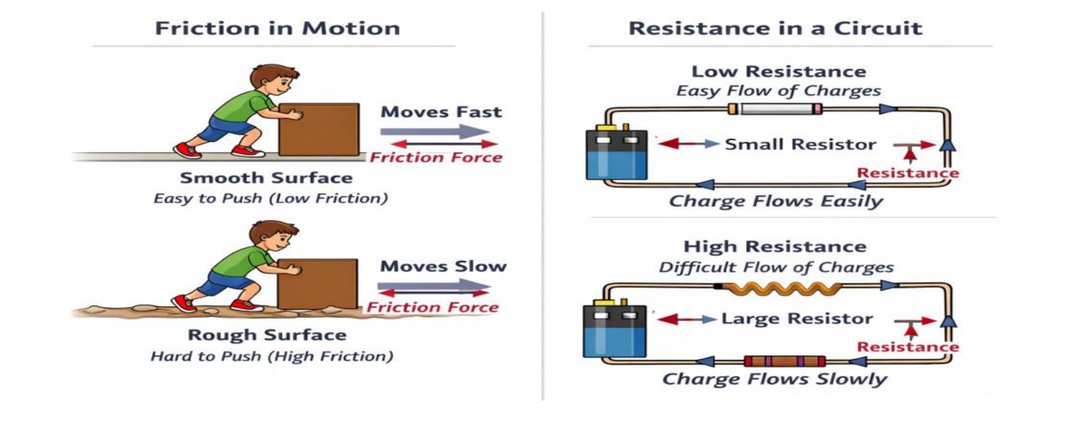
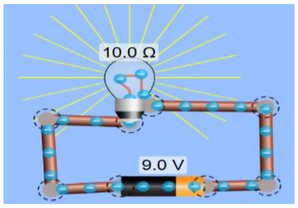
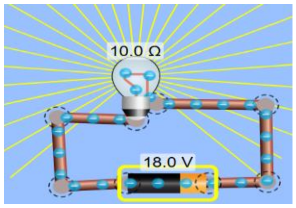
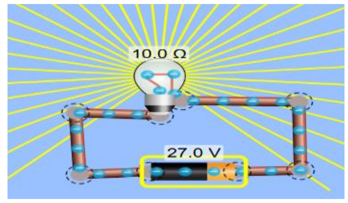
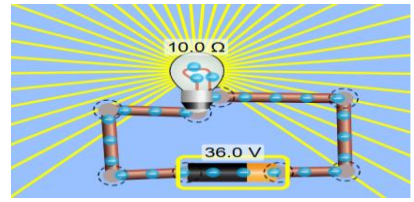


Fig 6: Friction analogy

From the diagram, the students have understood that when an object moves on a rough surface, it slows down more compared to a smooth surface because friction opposes its motion. This happens because a rough surface has more irregularities that increase contact between the surfaces, producing a greater frictional force that acts against the direction of motion and reduces the object's speed more quickly. The students related this idea to an electric circuit and understood that resistance plays a similar role by opposing the flow of electric charge. The students also understood that when friction increases, motion becomes more difficult, and in the same way, when resistance increases, the current in a circuit decreases.

At the final stage of Lesson Two, the researcher asked students to summarize the relationship between current and voltage as the number of batteries increased, as shown in Table 4 (see Table 4 in section 4.2). Students were first instructed to draw the circuit diagrams using the Circuit Construction Kit: DC (PhET) experiment, observe the changes in the brightness of the bulb, examine the relationship between voltage and current at constant resistance, derive the formula for Ohm's law, and then plot a voltage versus current graph from the given data to fully understand Ohm's law. Sample students' responses are attached below as follows:

Table 4: Relationship between current and voltage values as the number of batteries increase

Relationship between current and voltage values as the number of batteries increase			
I Circuit diagram	II Circuit diagram	III Circuit diagram	IV Circuit diagram
			
Voltage: 9.0 Volt Resistance: 10Ω bulb Current: Current: 0.90 A From Ohm's law $I = \frac{V}{R} = \frac{9V}{10\Omega} = 0.9A$	Voltage: 18.0 Volt Resistance: 10Ω bulb Current: Current: 1.80 A From Ohm's law $I = \frac{V}{R} = \frac{18V}{10\Omega} = 1.8A$	Voltage: 27.0 Volt Resistance: 10Ω bulb Current: Current: 2.70 A From Ohm's law $I = \frac{V}{R} = \frac{27V}{10\Omega} = 2.7A$	Voltage: 36.0 Volt Resistance:10Ω bulb Current: Current: 3.60 A From Ohm's law $I = \frac{V}{R} = \frac{36V}{10\Omega} = 3.6A$

The teacher asked what you understood from your observations. From their observations, students concluded that there is a direct relationship between current and voltage in an electric circuit. Their responses following group discussion are presented below.

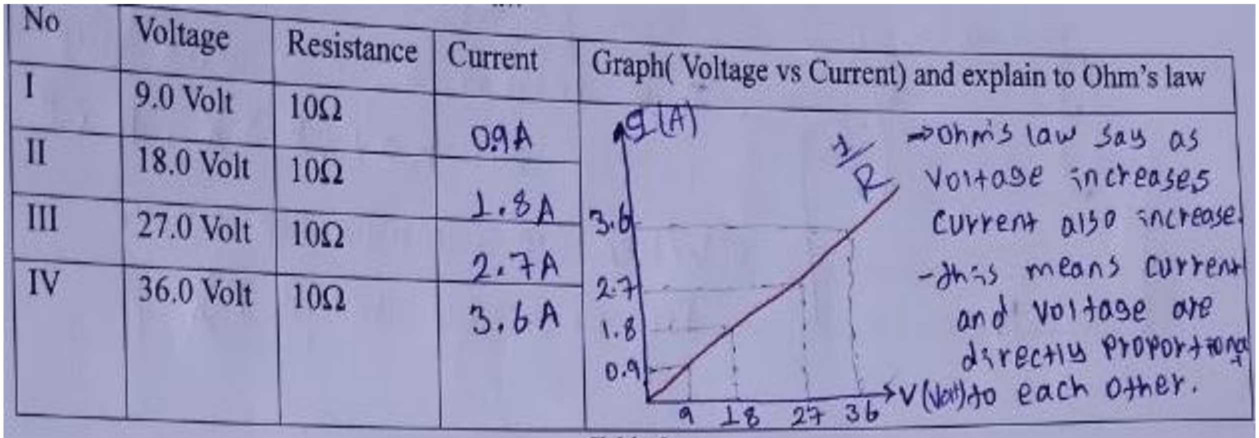
From the observations above, the brightness of the bulb increases as the voltage of the battery increases. From this we understand that the current in the circuit and the voltage across it are directly proportional when the resistance of the circuit is kept constant at a given temperature. Therefore voltage is directly proportional to the current when resistance is constant.
Mathematically this relationship is expressed as,
$V \propto I$, where R is constant at a given temperature. This relationship is called Ohm's law.
From Ohm's law the relationship between voltage, current and resistance can be expressed in three equivalent forms:

$$\boxed{V = IR, \quad I = V/R \quad \text{and} \quad R = V/I}$$

Where V is the voltage across the component, I is the current through it, and R is the resistance of the material.

Considering the change in voltage and current values in series circuits from the above table 4, draw voltage versus current graph and explain Ohm's law on the Table 5 (see Table 5 in section 4.2) below.

Table 5: Graphical representation for Ohm's Law



No	Voltage	Resistance	Current	Graph(Voltage vs Current) and explain to Ohm's law
I	9.0 Volt	10Ω	0.9A	→Ohm's law say as voltage increases current also increase. -This means current and voltage are directly proportional to each other.
II	18.0 Volt	10Ω	1.8A	
III	27.0 Volt	10Ω	2.7A	
IV	36.0 Volt	10Ω	3.6A	

Table 5

In this lesson, students developed a clear understanding of fundamental electrical concepts, including current, types of current, voltage, and resistance, through guided questioning, analogies, and PhET simulations. They distinguished between electron current and conventional current and related voltage and resistance to real-life situations. Through guided activities and PhET simulations, students explored electric circuits and observed how changes in voltage affect current. They developed a deeper understanding of electrical concepts by connecting theory with visual representations. These experiences helped them clearly recognize the direct relationship between voltage and current at constant resistance, leading to a meaningful understanding of Ohm's law.

Lesson three

The teacher started the lesson by presenting **Table 6** (see Table 6 in section 4.2), which listed the factors affecting the resistance of a given wire. The teacher then asked the students simple guiding questions such as, "What is resistance?" and "What factors do you think can change the resistance of a wire?" Students were encouraged to share their ideas based on their previous knowledge and earlier lessons on electric current and resistance. The students were expected to recall that resistance is the opposition to the flow of electric charge in a conductor.

After the initial discussion, the teacher introduced the computer simulation **PhET: Resistance in a Wire** and explained that it could be used to investigate how different physical factors affect the resistance of a wire. The teacher demonstrated how to adjust the variables in the simulation, including the length of the wire, the cross-sectional area (thickness) of the wire, and the resistivity of the material. The teacher showed students how to increase and decrease each factor using the control sliders and how to observe the corresponding change in resistance displayed in the simulation.

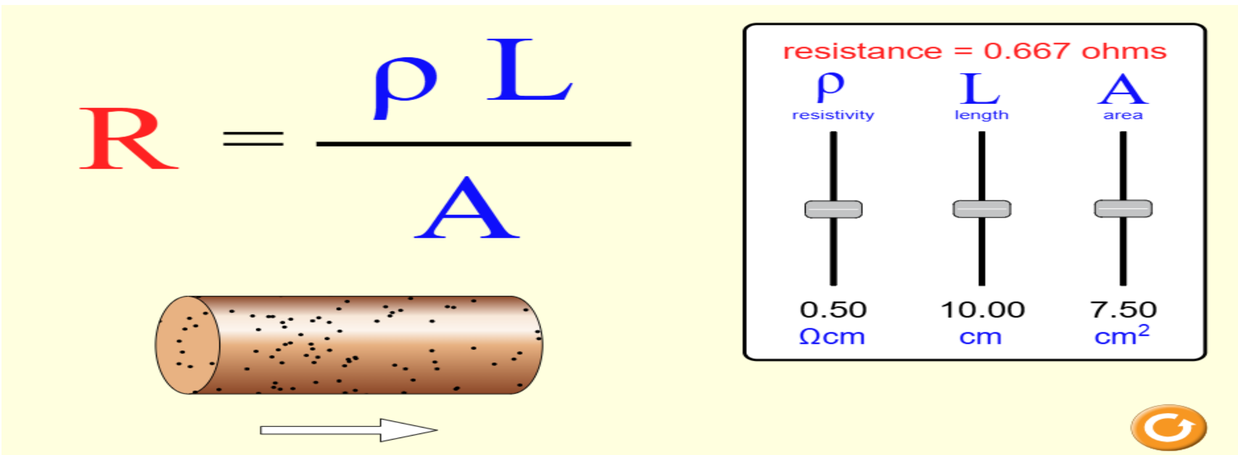


Fig 7: The resistance in a wire PhET experiment

Next, students were instructed to use the simulation to explore each factor one at a time and record their observations in **Table 6**. They were asked to increase and decrease the length of the wire and observe whether the resistance increased or decreased. Similarly, students adjusted the cross-sectional area of the wire and observed how making the wire thicker or thinner affected the resistance. Finally, they changed the resistivity of the material to see how different materials influence the resistance of the wire.

During the activity, the teacher asked guiding questions such as, "What happens to the resistance when the wire becomes longer?" "What do you observe when the wire becomes thicker?" and "How does changing the material affect the resistance?"

Students were asked to summarize the relationship between resistance and the three factors based on their observations and to write the mathematical formula used to calculate the resistance of a wire. The teacher facilitated a short discussion in which students shared their conclusions, leading them to understand that the resistance of a wire depends directly on its length and resistivity and inversely on its cross-sectional area.

Sample students' responses derived from their observations while using the PhET simulation, [Resistance in a Wire](), are attached below.

Students worked collaboratively in groups to discuss the changes observed in the simulation and then provided the following responses based on their observations.

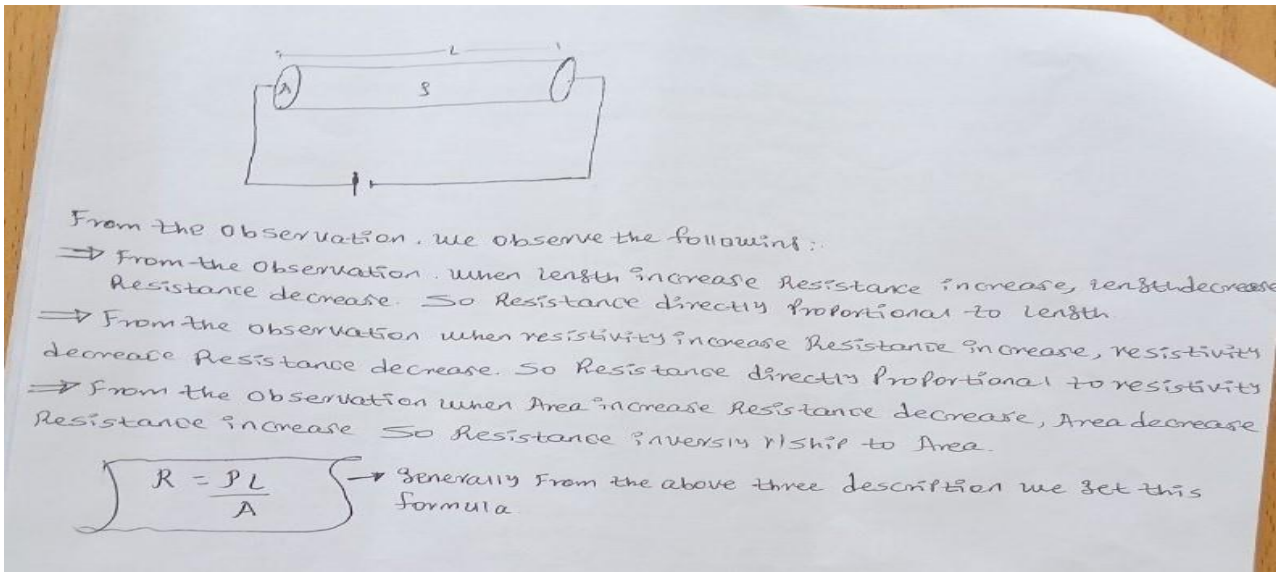
After conducting the resistance in a wire experiment, students carefully observed how different variables influence the resistance of a wire and recorded their findings in the provided worksheet. Working in groups, students manipulated the length of the wire, the cross-sectional area, and the resistivity of the material in the simulation and discussed the resulting changes in resistance. They then recorded their observations in the worksheet presented below.

5. In Table 6 below, the factors affecting the resistance of a given resistor (R) are listed. Using the "Resistance in a Wire" PhET simulation, determine whether the resistance of the wire increases or decreases when each factor is increased or decreased.

Factors affecting the resistance of a given wire		Resistance of the wire will be	From your observation write the formula to calculate resistance of a wire.
Length of the wire(L)	Length increased	increase	$R \propto L$, $R \propto \frac{1}{A}$, $R \propto \rho$ so from this we can say: $\boxed{R = \rho \frac{L}{A}}$
	Length decreased	decrease	
Cross sectional area of the wire(A)	Cross sectional area increased	decrease	
	Cross sectional area decreased	increase	
Resistivity of the material(ρ)	Resistivity of the material increased	increase	
	Resistivity of the material decreased	decrease	

Table 6

After completing the experiment and carefully recording their observations, students engaged in reflective discussions and analysis of the data they had collected. They compared how different variables such as the length of the wire, its cross-sectional area, and the material it was made from affected the resistance. By examining patterns in their results students were able to identify consistent trends and make connections between the experiment and the underlying principles of electricity. This process allowed them to move beyond simply noting measurements, encouraging them to think critically about cause-and-effect relationships, validate their observations through comparison, and develop a deeper understanding of how resistance behaves under varying conditions.


From the observation, we observe the following:

⇒ From the observation. when length increase Resistance increase, length decrease Resistance decrease. So Resistance directly proportional to length

⇒ From the observation when resistivity increase Resistance increase, resistivity decrease Resistance decrease. So Resistance directly proportional to resistivity

⇒ From the observation when Area increase Resistance decrease, Area decrease Resistance increase So Resistance inversly rlship to Area.

$$R = \frac{\rho L}{A}$$

→ generally From the above three description we get this formula

Students' responses indicate that they developed a sound understanding of the factors affecting the resistance of a wire through collaborative group discussion and observation of the simulation activities on resistance in a wire. The discussion enabled students to carefully examine how changes in length, cross-sectional area, and resistivity influence the resistance of a conductor.

Based on their observations, students correctly identified that when the length of the wire increases, the resistance increases, and when the length decreases, the resistance decreases. Similarly, students observed that increasing the cross-sectional area of the wire leads to a decrease in resistance, while decreasing the area results in an increase in resistance. In addition, students recognized that resistance increases when the resistivity of the material increases and decreases when the resistivity decreases.

Overall, the students were able to interpret the results of their observations, identify consistent relationships among variables, and generalize these relationships into a scientific formula describing resistance in a wire. The relationship they derived can be summarized as follows:

$$\boldsymbol{R = \rho \frac{L}{A}}$$

In this relationship, **R** represents the resistance of the conductor, **ρ (rho)** represents the resistivity of the material, **L** represents the length of the wire, and **A** represents the cross-sectional area of the wire.

This outcome indicates that students were able to move from observation to generalization, which reflects meaningful learning and conceptual development in the topic of electric resistance.

During the implementation of the first cycle, students actively participated in the PhET simulation activities and were able to observe changes in circuit behavior across the three lessons. However, their responses during class discussions and written tasks revealed noticeable gaps in their conceptual understanding. For example, when students were asked to explain the difference between an open circuit and a closed circuit, many correctly stated that a closed circuit allows charge to flow while an open circuit does not. However, when they were further asked why charge does not flow in an open circuit, students stated that "*current does not flow because the switch is off,*" but they did not explain the concept further; instead, they relied on their everyday experiences at home rather than describing the need for a continuous path for charge flow, and a few students were unable to provide any explanation. This finding is consistent with that students often rely on everyday reasoning rather than scientific concepts when explaining electric circuits (Li & Singh, 2016; Quezada-Espinoza et al., 2023).

Similarly, when students were asked to explain the concepts of current, voltage, and resistance, some responses reflected partial understanding. Some students described voltage as "*electricity in the wire*" or "*the power in the circuit*," while others stated that resistance "*uses up current*." Although these responses showed familiarity with the terms, they indicated confusion about their scientific meaning. This aligns with findings that students often struggle with fundamental electrical concepts and tend to develop alternative conceptions that differ from scientific explanations (Paula V. Engelhardt & Robert J. Beichner, 2004).

In addition, when students plotted voltage–current graph based on the data they obtained from the simulation, many were able to draw the graph correctly; however, they were unable to clearly describe the relationship between current and voltage represented in the graph. Most students simply plotted the points and connected them without explaining that the graph shows a direct relationship between voltage and current or that the slope of the graph represents resistance. Their responses indicated that they focused on drawing the graph from the data rather than interpreting its physical meaning. This supports research showing that students may demonstrate procedural skills without conceptual understanding, particularly when interpreting graphs in physics, even after instruction (Li & Singh, 2016)

In the third lesson, students used the “Resistance in a Wire” simulation to investigate the factors affecting resistance, such as the length and thickness of the wire. Most students correctly observed that increasing the length of the wire increases resistance and increasing the thickness decreases resistance. However, when asked to explain why these changes occur, some students responded that it is “*because the wire is long*” or “*because the simulation shows it*,” indicating that their understanding was based mainly on observation rather than scientific reasoning. This type of learning reflects surface-level engagement, which is less effective for developing deep conceptual understanding compared to active, interactive instructional approaches (Freeman et al., 2014; Prince, 2004). These responses demonstrated that although students were able to interact with the simulation and identify patterns, many of them had difficulty explaining the underlying physical principles, interpreting graphical relationships, and applying their knowledge to practical situations. These findings are supported by the literature, which indicate that although simulations enhance visualization, they do not automatically lead to deep conceptual understanding unless combined with active learning and reasoning processes (Zacharia & Constantinou, 2008).

Based on these findings which are supported by the literature, there is a clear need for more active, hands-on learning approaches. Project-based learning has been shown to promote deeper understanding by engaging students in meaningful tasks that require application, reasoning, and problem-solving (Thomas, 2000;Krajcik & Blumenfeld, 2005).

Therefore, to address the identified gaps in conceptual understanding, a hands-on project activity involving real circuit construction and measurement using ammeters and voltmeters was incorporated in the subsequent cycle.

Cycle two:

Lesson four

The teacher began the activity by presenting Table 7(see table 7 in section 4.2), which required students to draw both series and parallel circuits using the Circuit Construction DC simulation and to determine key electrical quantities, including equivalent resistance, current through each bulb, voltage drop across each bulb, and total current in each circuit arrangement. Before starting the calculations, the teacher guided students to recall fundamental concepts related to electric circuits by posing questions such as: “What is electric current?”, “What is voltage?”, “What is resistance?”, “State Ohm’s law,” and “How are current, voltage, and resistance related in an electric circuit?” Students recalled that electric current is the rate of flow of electric charge, voltage is the energy supplied to move charges through a circuit, resistance is the opposition to the flow of current, and Ohm’s law explains the relationship between voltage, current, and resistance.

Following this review, students worked collaboratively in groups to construct circuits consisting of two bulbs with resistances of 10 Ω and 20 Ω connected to a 60 V battery, first in series and then in parallel. They calculated the equivalent resistance for each configuration, determined the total current supplied by the battery, and computed the current through each bulb using appropriate formulas. In addition, students calculated the voltage drop across each bulb and recorded all results systematically in Table 7. They were further instructed to compare the total current with the current through each bulb and to examine the relationship between the total voltage and the voltage across individual components in both circuit types.

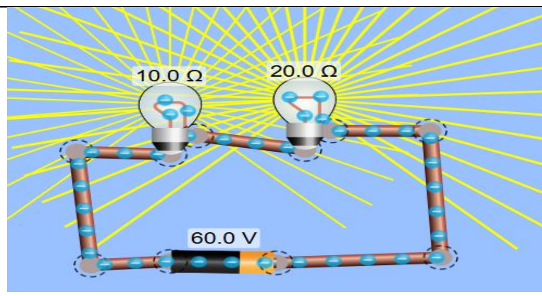
Throughout the activity, the teacher actively monitored students' progress, provided support where needed, and encouraged deeper thinking through guiding questions such as: "Is the current the same through each bulb in a series circuit?", "How does current behave in a parallel circuit?", and "What relationship exists between the total voltage and the voltages across each bulb in each circuit?" Students then summarized their findings, which helped them develop a clearer conceptual understanding of the relationships among resistance, current, and voltage in different circuit configurations.

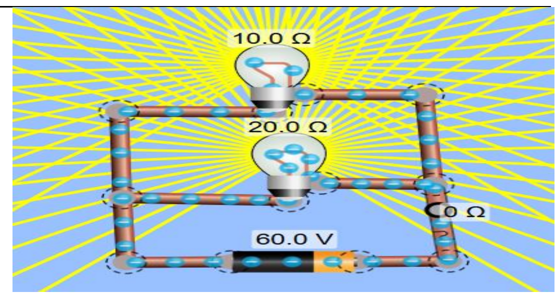
To further reinforce this conceptual understanding, the teacher extended the activity from a virtual environment to a practical, hands-on experience. After completing the simulation using the PhET tool, students engaged in constructing a real series lamp circuit using physical components. This hands-on project enabled students to apply their theoretical knowledge in a real-world context and to better understand the function of each component within an electric circuit. Sample students' responses are presented below.

Answer the following questions and record your answers in Table 7 below.

- Find the current value in total and over each bulb in each circuit?
- Find the voltage value over each bulb in each circuit?
- Find the equivalent resistance in each circuit?

Table 7: Questions to find the equivalent resistance the current through each bulb, the voltage drops across each bulb and the total current in each circuit.

<table>
<tr><td rowspan="2">Connection with</td><td colspan="2">Draw the circuits and find the equivalent resistance, the current through each bulb, the voltage drops across each bulb and the total current in each circuit.</td></tr>
<tr><td>Series Circuit</td><td>Parallel Circuit</td></tr>
<tr><td>2 bulbs with resistances 10Ω and 20Ω + 1 battery with 60V</td><td>

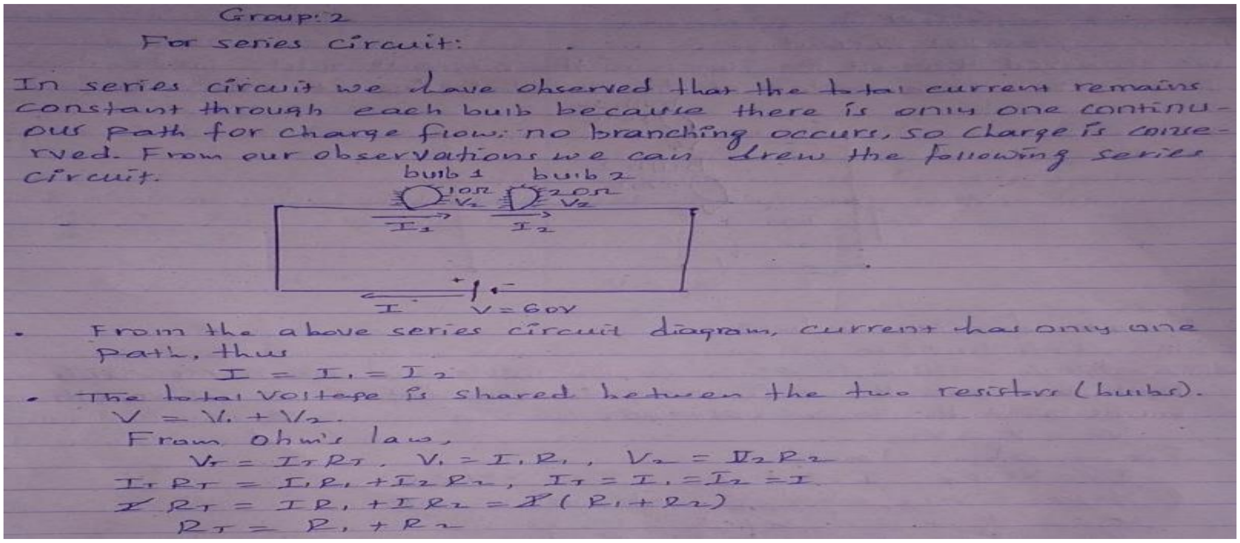
“Captured from the students’ computer screen.”</td><td>

“Captured from the students’ computer screen.”</td></tr>
</table>

After students drew the series and parallel circuits, the teacher asked them the following questions to guide their thinking and help them determine what happens in series and parallel circuits and how **Ohm's Law** can be applied to both types of circuits.

1. From your observation, what happens to the current as it passes through each bulb in a series circuit?
2. How is the total voltage shared among bulbs in a series circuit?
3. Using Ohm’s law, how do you find the total resistance of two resistors connected in series?
4. From your observation, how does the current behave when it reaches a junction in a parallel circuit?
5. What is the voltage across each branch in a parallel circuit?
6. Using Ohm’s law, how do you find the total resistance of two resistors connected in parallel?

Sample students' responses to the above six questions, after engaging in group discussion, are presented below. Sample students' responses to questions related to series circuit,



Group: 2

For series circuit:

In series circuit we have observed that the total current remains constant through each bulb because there is only one continuous path for charge flow: no branching occurs, so charge is conserved. From our observations we can drew the following series circuit.

bulb 1 bulb 2
10Ω V_1 20Ω V_2
I_1 I_2
I $V = 60V$

- From the above series circuit diagram, current has only one path, thus

$I = I_1 = I_2$

- The total voltage is shared between the two resistors (bulbs).

$V = V_1 + V_2$.

From Ohm's law,

$V_T = I_T R_T$, $V_1 = I_1 R_1$, $V_2 = I_2 R_2$

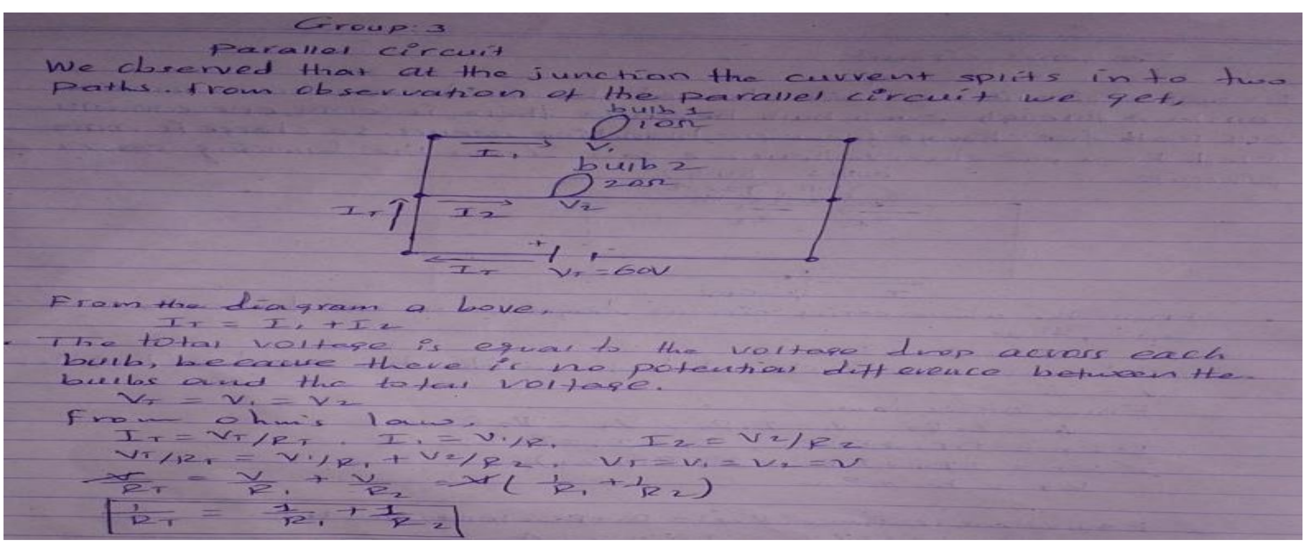
$I_T R_T = I_1 R_1 + I_2 R_2$, $I_T = I_1 = I_2 = I$

$\cancel{I} R_T = I R_1 + I R_2 = \cancel{I}(R_1 + R_2)$

$R_T = R_1 + R_2$

Students concluded that in a series circuit the current remains the same through each bulb because there is only one path for the flow of charge. They also observed that the total voltage from the battery is shared between the bulbs. In addition, students determined that the total resistance of the circuit is equal to the sum of the individual resistances of the bulbs.

Sample students' responses to questions related to parallel circuit,



Group: 3

Parallel circuit

We observed that at the junction the current splits into two paths. from observation of the parallel circuit we get,

bulb 1 10Ω
I_1 V_1
bulb 2 20Ω
I_T I_2 V_2
I_T $V_T = 60V$

From the diagram above,

$I_T = I_1 + I_2$

- The total voltage is equal to the voltage drop across each bulb, because there is no potential difference between the bulbs and the total voltage.

$V_T = V_1 = V_2$

From ohm's law,

$I_T = V_T/R_T$, $I_1 = V_1/R_1$, $I_2 = V_2/R_2$

$V_T/R_T = V_1/R_1 + V_2/R_2$, $V_T = V_1 = V_2 = V$

$\frac{\cancel{V}}{R_T} = \frac{V}{R_1} + \frac{V}{R_2} = \cancel{V}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$

$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}}$

Students concluded that in a parallel circuit the current splits into different paths at the junction. They also observed that the voltage across each bulb is the same as the voltage supplied by the battery. In addition, students determined that the total current is the sum of the currents in each branch, and the total resistance decreases when more branches are added.		
Equivalent resistance: Current (total): Current (each bulb): Voltage (each bulb):	Equivalent resistance (R_{eq}) $= R_1+R_2 = 10\Omega+20\Omega = 30\Omega$ $I_T = V_T/R_T = 60V/30\Omega = 2\,V/\Omega = 2A$ $I_T = I_1 = I_2 = 2A$, current is equal $I_1 = V_1/R_1$ $V_1 = I_1 \cdot R_1 = 2A \cdot 10\Omega = 20V$ $V_2 = I_2 \cdot R_2 = 2A \cdot 20\Omega = 40V$	Equivalent resistance $(\frac{1}{R_{eq}}) = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{10\Omega} + \frac{1}{20\Omega} = \frac{3}{20\Omega}$ $\frac{1}{R_{eq}} = \frac{3}{20\Omega}$ $\frac{3R_{eq}}{3} = \frac{20\Omega}{3}$ $\therefore R_{eq} = \frac{20}{3}\Omega$ $V_T = V_1 = V_2 = 60V$, no potential difference $I_T = \frac{V_T}{R_T} = \frac{60V}{\frac{20}{3}\Omega} = 9A$, $I_1 = \frac{V_1}{R_1} = \frac{60V}{10\Omega} = 6A$ $I_2 = I_T - I_1 = 3A$
Compare the total current with the currents through each bulb	From our observations and calculations results, we can conclude that in series circuit the current is the same at every point in the circuit beeause current has only one path in the circuit. But in parallel circuit the current has more than one path therefore the total current will be the sum of the currents through each resistor(bulb).	
Compare the total voltage with the voltages across each bulb	From the parallel circuit observation and calculation in series circuit the total Voltape is shared between the two bulbs based on their resistance values. But in parallel circuit the total voltage is the same as the voltage drop across each bulb beeause there is no potential difference.	

After discussion, observation of both series and parallel circuit diagrams, and performing the necessary calculations, students concluded that in a series circuit the current remains the same at every point and the voltage is shared among the components. They also determined that in a parallel circuit the voltage across each branch is the same, while the total current is the sum of the currents in each branch.

After completing the virtual experiments using the PhET simulation on both series and parallel circuits**,** the teacher provided students with hands-on projects to further strengthen their understanding through practical experience. In these activities, students constructed series and parallel lamp circuits using real equipment and materials.

The materials included a small head screwdriver, which was used to tighten and secure connections in the circuit components; wire cutters, which were used to cut wires to the required length; wire strippers, which were used to remove insulation from the ends of the wires to allow proper electrical contact; and a voltmeter which was used to measure voltage, an ammeter which was used to measure current in the circuit. Two AA batteries (1.5 V each) were used as the source of electrical energy. Switch was used to control current in the circuit. Two lamp holders were used to hold the bulbs in place and provide connection points, and two 3 V flashlight lamps were used as the load that produced light when current flowed through the circuit. Connecting wires were used to join all the components together.

Through these hands-on projects, students were able to apply their knowledge from the virtual simulations to real-life circuits, observe how components function together, and clearly understand the similarities and differences between series and parallel circuits.

Project 1: Building a Series Lamp Circuit

Objective: To construct a simple series circuit using two lamps and Two AA batteries (1.5 V each), and to measure the voltage across each lamp and across the entire circuit using voltmeter, as well as the total current and the current through each lamp in the circuit using an ammeter.

Equipment and Materials

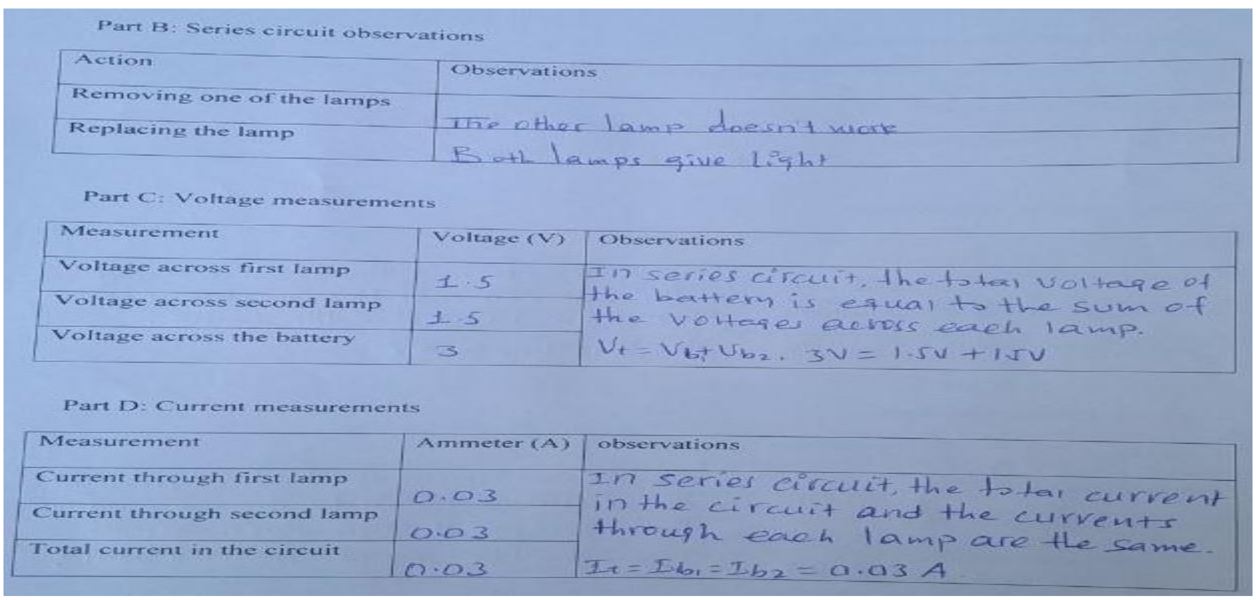
1. Small head screwdriver
2. Wire cutters
3. Wire strippers
4. Two 3 V flashlight lamps
5. Two AA batteries (1.5 V each)
6. Two lamp holders
7. One 6-inch (about 15 cm) piece of 22-gauge wire
8. Ammeter
9. Voltmeter
10. Switches

See the procedure students followed to construct series lamp circuit in appendix 2.

Results of Students' Observations in series circuit are presented below.

Students first constructed a series circuit using two bulbs (3V each) and two 1.5 V batteries connected in series as shown below. In the image below the switch is off.

The results of their project are summarized in the image below.



Part B: Series circuit observations

Action	Observations
Removing one of the lamps	The other lamp doesn't work
Replacing the lamp	Both lamps give light

Part C: Voltage measurements

Measurement	Voltage (V)	Observations
Voltage across first lamp	1.5	In series circuit, the total voltage of the battery is equal to the sum of the voltages across each lamp.
Voltage across second lamp	1.5	
Voltage across the battery	3	$V_t = V_{b1} + V_{b2}$. $3V = 1.5V + 1.5V$

Part D: Current measurements

Measurement	Ammeter (A)	observations
Current through first lamp	0.03	In series circuit, the total current in the circuit and the currents through each lamp are the same.
Current through second lamp	0.03	
Total current in the circuit	0.03	$I_t = I_{b1} = I_{b2} = 0.03\ A$

The students observed that when the series circuit was completed, both lamps lit but with reduced brightness because the total voltage from the batteries was shared between the two lamps. When one lamp was removed, the entire circuit stopped working and the other lamp also went off, showing that the circuit was broken. After reinserting the lamp, both lamps lit again. In voltage measurements, the students found that the total voltage was equal to the sum of the voltage drops across the two lamps, expressed as $V_{total} = V_1 + V_2, 1.5V + 1.5V = 3\ V$.

In current measurements, they observed that the current was the same at all points in the circuit, expressed as $I_{totla} = I_1 = I_{2,} = 0.03A$ confirming that current remains constant in a series circuit.

Project 1: Building a Parallel Lamp Circuit

Objective: To construct a simple parallel circuit using two lamps and Two AA batteries (1.5 V each), and to measure the voltage across each lamp and across the entire circuit using a voltmeter, as well as the total current and branch currents using an ammeter.

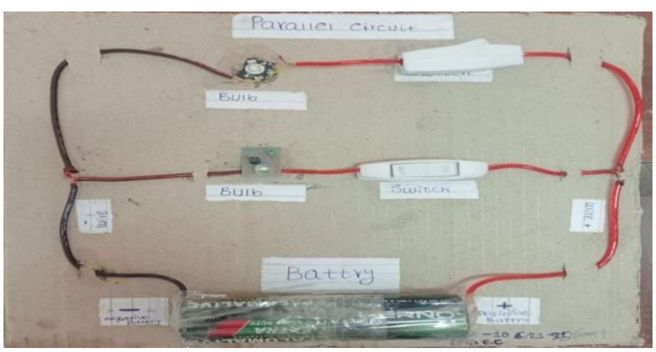
Equipment and Materials

1. Small head screwdriver
2. Wire cutters
3. Wire strippers
4. Two 3 V flashlight lamps
5. Two AA batteries (1.5 V each)
6. Two lamp holders
7. One 6-inch (about 15 cm) piece of 22-gauge wire
8. Ammeter
9. Voltmeter
10. Switches

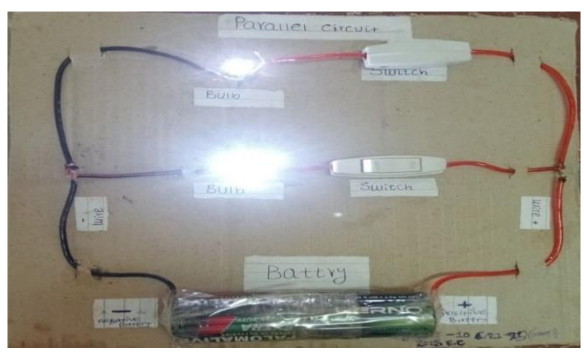
See the procedure students followed to construct series lamp circuit in appendix 2.

Results of Students' Observations in parallel circuit are presented below

Students first constructed a parallel circuit using two bulbs (3V each) and two 1.5 V batteries connected in parallel as shown below.

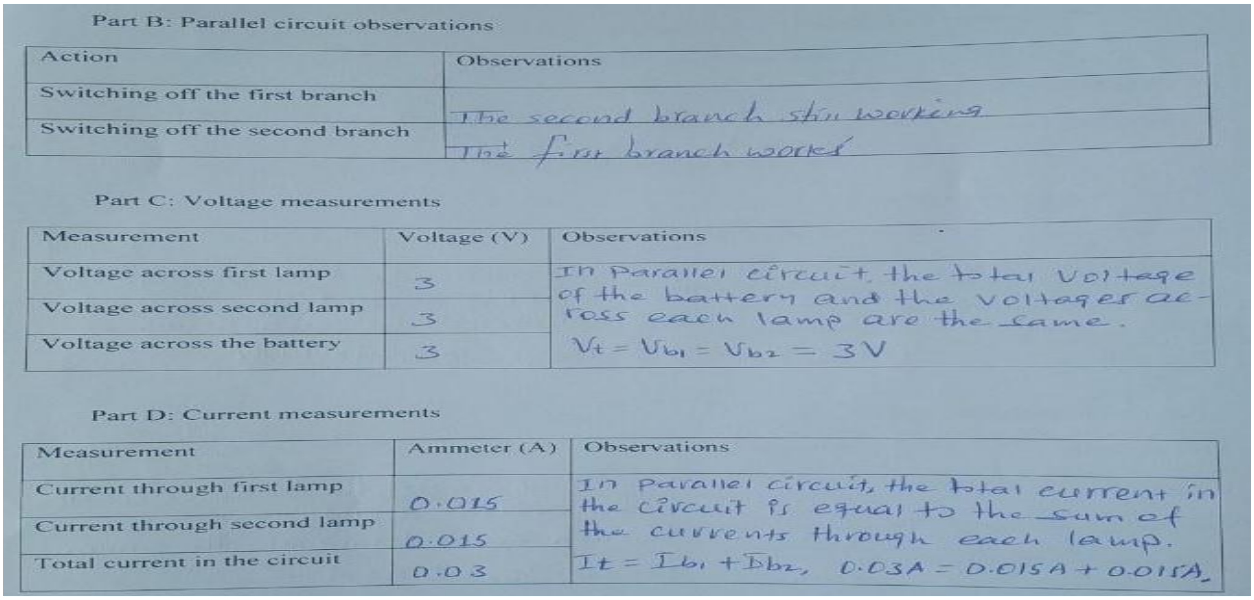


The switches are off



The switches are on

The results of their project are summarized in the image below.



Part B: Parallel circuit observations

Action	Observations
Switching off the first branch	The second branch stil working
Switching off the second branch	The first branch works

Part C: Voltage measurements

Measurement	Voltage (V)	Observations
Voltage across first lamp	3	In parallel circuit the total Voltage of the battery and the voltages across each lamp are the same.
Voltage across second lamp	3	
Voltage across the battery	3	$V_t = V_{b1} = V_{b2} = 3V$

Part D: Current measurements

Measurement	Ammeter (A)	Observations
Current through first lamp	0.015	In parallel circuit, the total current in the circuit is equal to the sum of the currents through each lamp.
Current through second lamp	0.015	
Total current in the circuit	0.03	$I_t = I_{b1} + I_{b2}$, $0.03A = 0.015A + 0.015A$,

The students observed that in the parallel circuit, both lamps lit with normal brightness when both switches were closed, showing that each branch received the full battery voltage. When Switch 1 was opened, Lamp 1 turned off while Lamp 2 continued to light normally, and when Switch 2 was opened, Lamp 2 turned off while Lamp 1 remained on. They also found that the voltage across each lamp was equal to the total battery voltage, expressed mathematically as $V_{total} = V_1 = V_2 = 3V$. In current measurements, the total current was equal to the sum of the branch currents, expressed as $I_{total} = I_1 + I_{2,}$ 0.015A+0.015A=0.03A, and each branch carried current independently depending on whether its switch was closed or open.

After completing the hands-on projects, students were able to clearly explain the distribution of current in series and parallel circuits, demonstrating a deeper understanding of how current behaves in different circuit arrangements. Similarly, they showed improved understanding of voltage distribution in series and parallel circuits, providing more accurate and scientifically sound explanations than they had before. These improvements suggest that direct manipulation of circuit components helped students confront and overcome common misconceptions related to electric circuits.

Although inquiry-based PhET simulations provided valuable visualizations and opportunities for exploration, the tangible experiences offered by hands-on projects appeared to have a greater impact on students' conceptual understanding and overall learning outcomes.

4.5 Level of Students' Misconceptions about Electricity after Implementation

Table 4: Frequency Distribution of Students' Post-test Total Misconceptions

Post-test total misconceptions					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	9	25.7	25.7	25.7
	1	10	28.6	28.6	54.3
	2	8	22.9	22.9	77.1
	3	7	20.0	20.0	97.1
	5	1	2.9	2.9	100.0
	Total	35	100.0	100.0	
	Total	35	100.0	100.0	

The result in Table 4 above shows that student's post-test misconceptions after the intervention. The majority of students scored 1 misconception (28.6%), followed by students with no misconception (25.7%). Additionally, 22.9% and 20.0% of the students scored 2 and 3 misconceptions respectively, while only 2.9% scored 5 misconceptions. The finding indicates that guided inquiry-based learning integrated with PhET simulation helped reduce students' misconceptions.

Table 5: Paired Sample t-test Result of Students' Misconceptions.

Paired Sample Statistics								
Variable	Mean	Paired Differences		95% CI of the difference				
		Std.Dev	SE. D	Lower	Upper	t	df	sig.
Pre-Post TMC	2.25	1.84	.31	1.63	2.89	7.27	34	.000

The result analysis of the paired sample t-test in Table 5 above revealed that there was a statistically significant mean score difference in students' misconceptions before and after the intervention ($t = 7.27$, $df = 34$, $p < .05$). The mean difference score was 2.26, indicating that student's misconceptions was substantially reduced after the implementation of guided inquiry-based learning integrated with PhET simulation. The 95% confidence interval of the difference ranged from 1.63 to 2.89, which further confirms the significance of the improvement.

The finding suggests that guided inquiry-based learning integrated with PhET simulation helped students overcome misconceptions. Therefore, the intervention was effective in minimizing students' misconceptions and promoting meaningful physics learning in the secondary school classroom context.

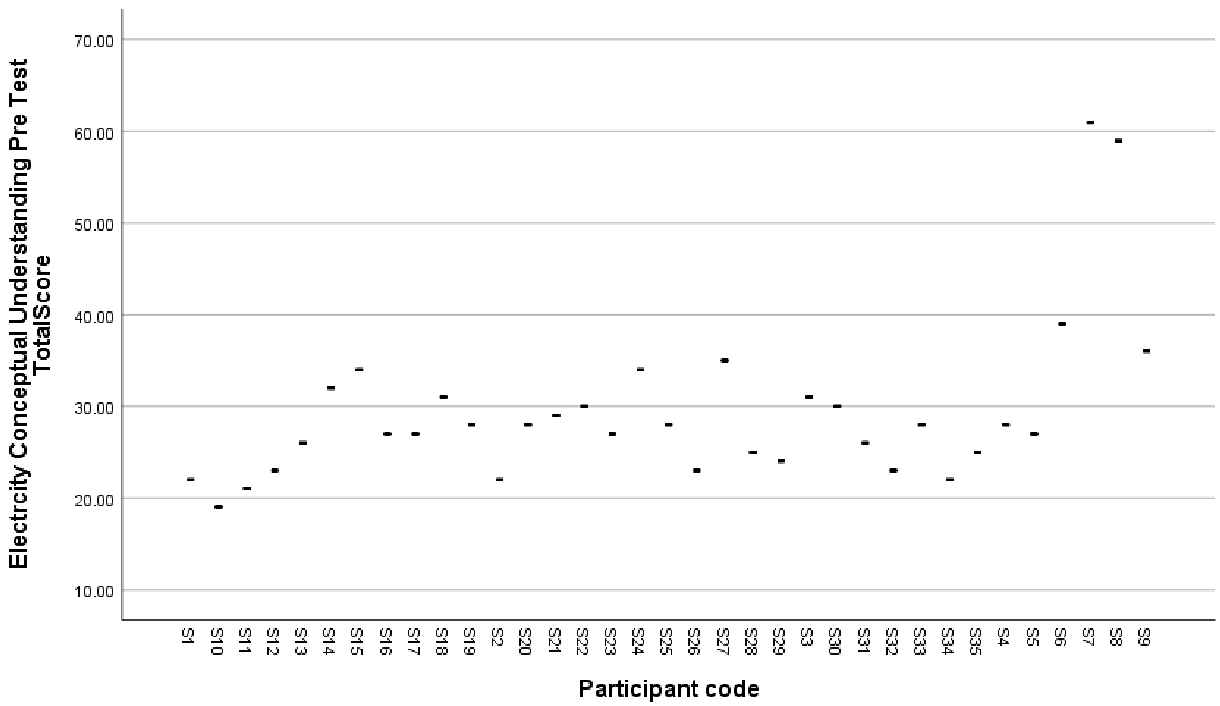
4.6 Effects of Guided Inquiry Based Learning Integrated with PhET Simulation on Students Conceptual Understanding in learning Electricity Concepts

The result analysis in table 1 (see table 1 in section 4.1) above, there was a mean score difference between students' pre-ECUT and Post-ECUT within the group. To check whether this means score difference statistically significant or not, the assumptions of normality and homogeneity of variance were evaluated.

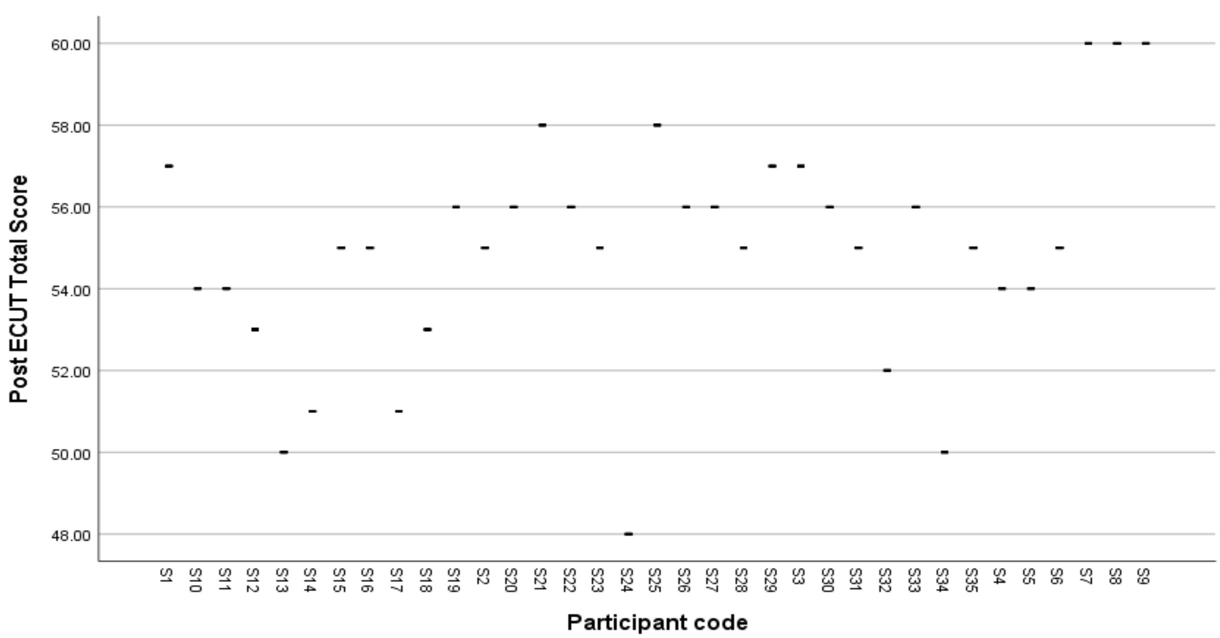
The paired sample t-test assumes that the dependent variable is continuous and that the observations are independent of one another. The independent variable should approximately distribute normally, and there should be no outliers present in the data.

The first assumption was related to the nature of data obtained to analyze the dependent variable (Conceptual understanding). Thus, the data is continuous and the observations are independent to one another. That is the score of an individual participant did not affect the score of the other. The skewness and kurtosis value of the test scores were lying between -2 and +2 as shown in table 1(see table 1 in section 4.1) above which confirms the data was approximately normally distributed. In addition, from the visual inspection of the box-plot, no outlier is observed from both pre and post ECUT score.

Distribution of students Pre ECUT Total Score



Distribution of students Post ECUT Total Score



Therefore, paired sample t-test was employed to evaluate the mean score difference on students' conceptual understanding before and after the intervention within the group.

Table 6: Paired Sample t-test Result of Students' ECUT.

Paired Sample Statistics								
Variable	Mean	Paired Difference		95% CI Difference				
		Std.Dev	SE. D	Lower	Upper	t	df	Sig.
Post-Pre ECUT	25.51	8.03	1.36	28.27	22.76	18.8	34	.00

The result analysis of the paired sample t-test above revealed that there was a statistically significant mean score difference on students' electricity conceptual understanding test scores before and after guided inquiry-based learning integrated with PhET simulation (t=18.8, df=34, p<.05). The result analysis showed that students were better understood the concepts of electricity found in different topics after GIBL integrated with PhET simulation. The finding showed that GIBL integrated with PhET simulation is a better teaching and learning classroom instruction that helps to have meaningful physics learning at this secondary school context.

4.7 Limitations of the study

The study had some limitations that should be considered when interpreting the findings. First, the study was conducted in only one selected school, which may limit the generalizability of the results to other schools or educational contexts. Second, the study did not examine whether the observed improvement in students' conceptual understanding was partly influenced by repeated exposure to the topic during the intervention cycles. Finally, although different instructional methodologies were implemented across the two cycles, the study focused on the overall improvement in students' learning outcomes and did not specifically compare the effectiveness of the additional methodology introduced in Cycle 2 with the methodology used in Cycle 1.

CHAPTER 5: DISCUSSIONS, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion of the Findings

The primary purpose of this study was to investigate the effectiveness of Guided Inquiry (GI) integrated with PhET simulations in improving Grade 10 students' conceptual understanding of electricity and reducing misconceptions in a secondary school in Bahir Dar City, Ethiopia. The findings revealed that students initially possessed low conceptual understanding and widespread misconceptions regarding electric circuits, current, voltage, resistance, and the behavior of series and parallel circuits. Following the implementation of the Guided Inquiry–PhET intervention, substantial improvements were observed in students' conceptual understanding, accompanied by a significant reduction in misconceptions.

The pre-intervention assessment demonstrated that many students held alternative conceptions about fundamental electricity concepts. Students commonly believed that electric current is consumed by bulbs, voltage behaves similarly to current, and current decreases as it passes through circuit components. These misconceptions are consistent with findings reported in physics education research, which has repeatedly shown that students often develop intuitive but scientifically inaccurate explanations of electrical phenomena (Engelhardt & Beichner, 2004; Achor et al., 2022). Similar findings have also been reported in Ethiopia, where students frequently experience difficulties understanding electricity concepts due to teacher-centered instructional approaches and limited laboratory experiences (Dega et al., 2013). The persistence of these misconceptions before the intervention indicates that traditional classroom instruction alone was insufficient to support meaningful conceptual change.

The quantitative findings showed a statistically significant improvement in students' conceptual understanding after the implementation of Guided Inquiry integrated with PhET simulations. The paired-sample t-test revealed a significant difference between pre-test and post-test conceptual understanding scores ($t = 18.80$, $df = 34$, $p < .05$), indicating that the intervention had a substantial positive effect on students' learning. This finding is consistent with constructivist learning theory, which argues that learners actively construct knowledge through exploration, experimentation, reflection, and interaction with their environment (Ainsworth et al., 2011;

Antypas et al., 2025). During the intervention, students engaged in questioning, prediction, virtual experimentation, observation, data analysis, explanation, and collaborative discussion. These activities enabled students to challenge their prior conceptions and reconstruct scientifically acceptable understandings of electricity concepts.

The observed improvement is consistent with previous studies that have demonstrated the effectiveness of inquiry-based learning in enhancing conceptual understanding. Guided inquiry encourages students to formulate explanations, test hypotheses, interpret evidence, and justify conclusions, thereby promoting deeper learning rather than rote memorization. Similar results have been reported by Hmelo-Silver et al. (2007), Meltzer & Thornton (2012), and Sari et al. (2024), who found that inquiry-oriented instruction significantly improves students' conceptual understanding and scientific reasoning skills. The present study extends these findings to the Ethiopian secondary school context and provides evidence that guided inquiry can effectively support students' learning of abstract electricity concepts.

The findings also highlight the important role of PhET simulations in supporting conceptual learning. Electricity concepts are often difficult for students because many electrical processes are invisible and abstract. Through PhET simulations, students were able to visualize electric current flow, voltage distribution, circuit behavior, and resistance effects in ways that are difficult to observe in conventional classroom settings. The simulations provided immediate feedback and allowed students to manipulate variables, test predictions, and observe outcomes in real time. This interactive environment helped students connect theoretical concepts with observable representations, thereby reducing the abstract nature of electricity.

The positive contribution of PhET simulations observed in this study agrees with previous research. Interactive simulations have been shown to enhance conceptual understanding by making scientific phenomena visible, interactive, and experimentally accessible (Anisa & Astriani, 2022; Banda & Nzabahimana, 2022; Fan et al., 2018; Finkelstein et al., 2006). The present study further demonstrates that the effectiveness of simulations is maximized when they are integrated within a guided inquiry framework. Students did not merely observe the simulations; rather, they used them as tools for investigation, prediction, experimentation, and explanation. This integration of guided inquiry and simulation appears to have played a critical role in promoting conceptual development.

These findings are also consistent with Zacharia & Constantinou (2008), who argued that simulations become most effective when combined with active inquiry processes and meaningful instructional guidance.

Another important finding of the study was the significant reduction in students' misconceptions after the intervention. The paired-sample t-test results indicated a statistically significant decrease in misconception scores, suggesting that the Guided Inquiry–PhET approach was effective in facilitating conceptual change. Students developed more scientifically accurate understandings of current behavior in series circuits, voltage distribution across components, and current division in parallel circuits. The opportunity to test their ideas against observable evidence allowed students to recognize inconsistencies in their prior beliefs and gradually replace them with scientifically acceptable explanations.

Despite these positive outcomes, some misconceptions remained after the intervention. A number of students continued to confuse current and voltage relationships or relied on local reasoning when explaining circuit behavior. Some students were able to provide correct answers but struggled to offer scientifically sound explanations. These findings suggest that conceptual change is a gradual process and that deeply rooted misconceptions cannot always be eliminated through short-term interventions. This observation aligns with conceptual change theory, which argues that students' prior conceptions are often resistant to change and require sustained instructional support, repeated exposure to contradictory evidence, and opportunities for reflection (Duit & Treagust, 2003).

The persistence of certain misconceptions also indicates that technology alone is insufficient for promoting deep conceptual understanding. Although simulations provide powerful visualizations and opportunities for exploration, students still require teacher guidance, collaborative discussion, questioning, and reflective reasoning to connect observations with underlying scientific principles. Therefore, the success of the intervention can be attributed not only to the use of PhET simulations but also to the guided inquiry processes that structured students' learning experiences. This finding supports previous studies emphasizing that simulations are most effective when embedded within sound pedagogical frameworks (Banda & Nzabahimana, 2022; Fan, Geelan, Gillies, et al., 2018).

An important contribution of this study lies in its relevance to the Ethiopian educational context. Many Ethiopian secondary schools face challenges such as limited laboratory resources, inadequate instructional materials, and a predominance of teacher-centered pedagogical practices (Dega et al., 2013; Worku & Alemu, 2021). Under such conditions, PhET simulations provide a practical and cost-effective alternative for supporting laboratory-based learning experiences. The findings suggest that Guided Inquiry integrated with PhET simulations can serve as an effective instructional approach for improving conceptual understanding even in resource-constrained educational settings. However, the findings also indicate that simulation-based learning should complement rather than replace hands-on practical activities whenever laboratory facilities are available. This conclusion agrees with Tenzin et al. 2024), who found that combining simulations with hands-on activities produces stronger conceptual learning outcomes than either approach alone.

Furthermore, the Design-Based Research (DBR) approach employed in this study contributed significantly to the success of the intervention. Through iterative cycles of implementation, reflection, evaluation, and redesign, the instructional activities were continuously refined to address students' learning difficulties. For example, additional scaffolding and hands-on circuit construction activities were incorporated when students continued to experience conceptual challenges. This iterative process improved the quality of instruction and demonstrated the value of DBR as a framework for developing effective classroom interventions.

Overall, the findings of this study demonstrate that Guided Inquiry integrated with PhET simulations is an effective instructional strategy for improving students' conceptual understanding of electricity and reducing misconceptions. The approach promotes active learning, scientific inquiry, conceptual reasoning, collaboration, and visualization of abstract concepts. The study contributes to the growing body of physics education research and provides empirical evidence supporting the integration of inquiry-based learning and interactive simulations in Ethiopian secondary school physics education.

5.2 Conclusions

This study investigated the effectiveness of Guided Inquiry (GI) integrated with PhET simulations in enhancing Grade 10 students' conceptual understanding of electricity and reducing misconceptions in a secondary school in Bahir Dar City, Ethiopia. The findings revealed that students initially demonstrated low levels of conceptual understanding and held numerous misconceptions related to electric circuits, current, voltage, resistance, and the behavior of series and parallel circuits.

The implementation of the Guided Inquiry–PhET intervention resulted in significant improvements in students' conceptual understanding of electricity concepts. The statistical analysis showed a significant difference between pre-test and post-test conceptual understanding scores, indicating that the intervention positively influenced students' learning outcomes. Through guided inquiry activities, students actively engaged in questioning, prediction, experimentation, observation, discussion, and explanation, enabling them to construct scientifically accurate understandings of electricity concepts.

The study also found that the integration of PhET simulations provided valuable opportunities for students to visualize abstract electrical phenomena that are difficult to observe in traditional classroom settings. The interactive nature of the simulations enabled students to explore relationships among electrical variables, test their predictions, and receive immediate feedback, thereby supporting meaningful learning and conceptual development.

Furthermore, the intervention significantly reduced students' misconceptions about electricity. Many students replaced their alternative conceptions with scientifically acceptable explanations after engaging in guided inquiry activities supported by PhET simulations. However, some misconceptions persisted, indicating that conceptual change is a gradual process that requires continuous instructional support and repeated opportunities for reflection and evidence-based reasoning (Duit & Treagust, 2003).

The findings demonstrate that the combination of Guided Inquiry and PhET simulations is an effective approache for promoting conceptual understanding and addressing misconceptions in electricity. The study also highlights the potential of simulation-supported inquiry learning as a practical instructional strategy for schools with limited laboratory resources. In the Ethiopian context, where many schools face challenges related to inadequate laboratory facilities and instructional materials, Guided Inquiry integrated with PhET simulations offers a feasible and effective alternative for improving electricity teaching and learning.

In conclusion, Guided Inquiry integrated with PhET simulations is an effective pedagogical approach for enhancing students' conceptual understanding of electricity and reducing misconceptions. The study contributes to physics education research by providing empirical evidence that inquiry-based learning supported by PhET simulations can promote meaningful conceptual learning and improve the quality of physics education in Ethiopian secondary schools.

5.3 Recommendations

Based on the findings and conclusions of the study, the following recommendations are forwarded.

5.3.1 Recommendations for Physics Teachers

1. Physics teachers should integrate inquiry-based instructional strategies into electricity lessons to promote active student participation, conceptual reasoning, and scientific discussion.
2. Teachers should use PhET simulations and other interactive technologies regularly to help students visualize abstract electricity concepts such as electric current, voltage, resistance, and circuit behavior.
3. Teachers should focus more on conceptual understanding and reasoning rather than emphasizing memorization of formulas and routine problem-solving alone.
4. Physics teachers should continuously identify and address students' misconceptions through questioning, classroom discussion, conceptual tasks, and formative assessment activities.
5. Teachers should combine simulation-based activities with hands-on practical experiments to strengthen students' understanding of electric circuits and measurement skills.
6. Collaborative learning activities should be encouraged during physics instruction so that students can discuss ideas, compare explanations, and construct scientific understanding together.

5.3.2 Recommendations for Schools and Educational Stakeholders

1. Schools should improve access to digital resources such as computers, projectors, and internet connectivity to support technology-assisted physics instruction.
2. Educational authorities and school administrators should provide continuous professional development training for physics teachers on inquiry-based learning and simulation-supported teaching strategies.
3. Curriculum developers should integrate inquiry-oriented simulation activities into physics textbooks, laboratory manuals, and instructional materials.
4. Schools should encourage student-centered teaching approaches that support experimentation, exploration, discussion, and problem-solving in physics classrooms.
5. The Ministry of Education and other educational stakeholders should support the implementation of low-cost digital learning technologies such as PhET simulations, particularly in schools with limited laboratory facilities.

5.3.3 Recommendations for Future Research

1. Future researchers should conduct similar studies with larger sample sizes and in different schools to improve the generalizability of the findings.
2. Further studies should investigate the long-term effects of inquiry-based learning integrated with PhET simulations on students' retention of electricity concepts.
3. Future research should examine the impact of simulation-supported inquiry instruction on students' attitudes, motivation, and interest toward learning physics.
4. Similar studies should be conducted in other physics topics such as mechanics, magnetism, waves, optics, and modern physics to examine the broader effectiveness of inquiry-based simulation instruction.
5. Researchers should further investigate how students' misconceptions change during inquiry-based interventions and how different instructional scaffolds can support conceptual change more effectively.

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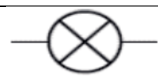
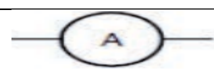
Appendixes

Appendix 1: Diagnostic Test of Students' Conceptions in Static and Current Electricity

<u>Conceptual Understanding Test on Secondary School Students' conceptions about Static and Current Electricity</u>

I. <u>Chose the correct answer from the given alternatives and support your answer by reasons.</u>

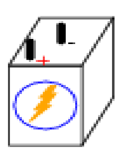
1. Which one of the following is correctly matches the name, symbol and usage of a component of an electric circuit?

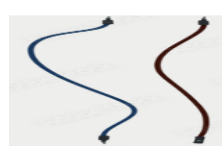
	Name	Symbol	Usage
A.	Bulb or lump		bulb glows when charge moves through it
B.	Resistor		provides energy for charge to move
C.	Voltmeter		measures current in a circuit
D.	Ammeter		measures potential difference

Your explanation……………………………………………………………………………………

2. What is required for a bulb to light in a simple battery-bulb circuit?

Bulb Battery Wires

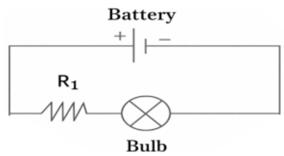




A. Connect one wire from the battery to one side of the bulb
B. Connect wires from both terminals of the battery to the two metal contacts on the bulb holder
C. Just place the bulb near the battery
D. Connect the bulb directly across only the positive terminal

Your explanation…………………………………………………………………………………

3. This question is about changes made in a sample electric circuit. For each situation, mark an **X** in the box next to the correct response and explain why you chose it.



a) If R_1 decreased, brightness of the bulb;

❑ Increases ☐ Decreases ☐ Stays the same

Your explanation.……………………………………………………………………………………

b) If R_1 increased, brightness of the bulb;

❑ Increases ☐ Decreases ☐Stays the same

Your explanation.……………………………………………………………………………………

c) If the magnitude of the battery increased, brightness of bulb;

❑ Increases ☐ Decreases ☐ Stays the same

Your explanation.…………………………………………………………………………………

d) If the magnitude of the battery decreased, brightness of bulb;

❑ Increases ☐ Decreases ☐ Stays the same

Your explanation.……………………………………………………………………………………

Use the statement and fig 2 below for questions 4 and 5

In the circuit fig 2 below, the resistance of bulb 1 is greater than the resistance of bulb 2.

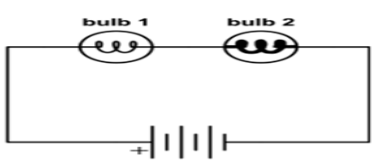


Fig 2

4. Question 6 (Fig. 2): Compare the current through the bulbs

A. The current through bulb 1 is greater than the current through bulb 2.

B. The current through bulb 1 is less than the current through bulb 2.

C. The current through bulb 1 is the same as the current through bulb 2.

D. It is not possible to compare the current through the bulbs.

Because………

5. Question 7 (Fig. 2): Compare the potential difference across the bulbs.

A. The potential difference across bulb 1 is greater than the potential difference across bulb

B. The potential difference across bulb 1 is less than the potential difference across bulb 2.

C. The potential difference across bulb 1 is the same as the potential difference across bulb 2.

D. It is not possible to compare the potential difference across the bulbs.

Because………

Use the statement and fig 3 below for questions 6 and 7.

In the circuit fig 3 below, the resistance of bulb 1 is greater than the resistance of bulb 2.

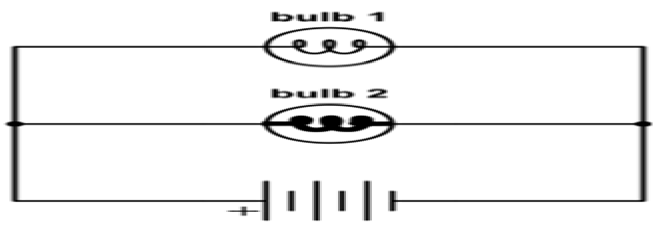


FIG 3

6. Question 8 (Fig. 3): Compare the current through the bulbs.

A. The current through bulb 1 is greater than the current through bulb 2.

B. The current through bulb 1 is less than the current through bulb 2.

C. The current through bulb 1 is the same as the current through bulb 2.

D. It is not possible to compare the current through the bulbs.

Because………

7. Question 9 (Fig. 3): Compare the potential difference across the bulbs.

A. The potential difference across bulb 1 is greater than the potential difference across bulb 2.

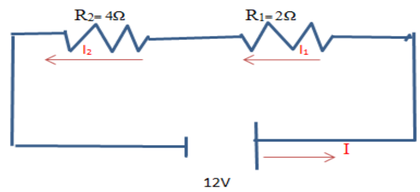
B. The potential difference across bulb 1 is less than the potential difference across bulb 2.

C. The potential difference across bulb 1 is the same as the potential difference across bulb 2.

D. It is not possible to compare the potential difference across the bulbs.

Because………

8. In the figure below two resistors 2Ω and 4Ω are connected in series with 12V battery.



a) What are the total current and the currents across 2Ω and 4Ω resistors, respectively?

A. I= 2A, I_1= 1A, I_2= 1A **C.** I= 2A, I_1= 2A, I_2= 2A

B. I= 2A, I_1= 1.5A, I_2= 0.5A **D.** I= 2A, I_1= 0.5A, I_2= 1.5A

b) What are the voltages across 2Ω and 4Ω resistors, respectively?

A. V_1= 6V, V_2= 6V **C.** V_1= 8V, V_2= 4V

B. V_1= 4V, V_2= 8V **D.** V_1= 2V, V_2= 10V

c) What is the total resistance of the circuit?

A. R_{eq}= 18Ω **B.** R_{eq}= 10Ω C. R_{eq}= 1.33Ω **D.** R_{eq}= 6Ω

From question number 14 a), b) and c) what did you say about series circuit?

....

9. In an electric circuit, an ammeter is always connected:

A. In series to measure electric current C. In series to measure voltage

B. In parallel to measure electric current D. In parallel to measure voltage

Your explanation……………………………………………………………………………………

10. In an electric circuit, a voltmeter is always connected:

A. In series to measure electric current C. In series to measure voltage

B. In parallel to measure electric current D. In parallel to measure voltage

Your explanation……………………………………………………………………………………

Appendix 2: Procedures of Student's Circuit Construction Projects

Project 1: Building a Series Lamp Circuit

Procedure Students Followed

Part A: Constructing the Series Circuit

Step 1: Preparing the connecting wire

Students cut a 6-inch length of wire and used the wire stripper to remove insulation from both ends.

Step 2: Connecting the first lamp holder

Students attached the red wire from the positive terminal of the battery to one terminal of the first lamp holder and tightened the screw using the screwdriver.

Step 3: Connecting the second lamp holder

Students connected the black wire from the negative terminal of the battery holder to one terminal of a switch and then connected the other terminal of the switch to one terminal of the second lamp holder.

Step 4: Completing the series connection

Students used the prepared 6-inch wire to connect: The unused terminal of the first lamp holder to the unused terminal of the second lamp holder. This connected the lamps **end to end**, forming a series circuit.

Step 5: Inserting the lamps and batteries

Students placed one 3 V lamp into each lamp holder and put the two AA batteries into their place.

Part B: Testing the Series Circuit

Step 6: Removing one lamp
Step 7: Replacing the removed lamp

Part C: Measuring Voltage with a voltmeter

Step 8: Measuring voltage across the first lamp and the second lamp

Students touched: The red probe to one terminal of the first lamp and the black probe to the other terminal. They then recorded the reading and students touched the probes to the terminals of the second lamp. They then recorded the readings.

Step 9: Measuring total voltage across the battery

Students touched: The red probe to the terminal connected to the red battery wire and the black probe to the terminal connected to the black battery wire. They then recorded the reading.

Part D: Measuring Current in the Series Circuit using ammeter

Step 10: Measuring the total current in the circuit

Students disconnected one wire between the battery and the first lamp holder. Then they connected the ammeter in series: The red probe was connected to the wire from the battery and the black probe was connected to the terminal of the first lamp holder. They then recorded the reading.

Step 11: Measuring current through the first lamp and the second lamp

Students opened the circuit just after the first lamp and inserted the ammeter in series at that point. They then recorded the reading and students opened the circuit after the second lamp and inserted the ammeter in series at that point. They then recorded the readings.

Project 2: Building a Parallel Lamp Circuit

Procedure Students Followed

Part A: Constructing the Parallel Circuit

Step 1: Preparing the connecting wire

Students cut a 6-inch length of wire and stripped insulation from both ends using a wire stripper.

Step 2: Connecting the power source

Students connected the red wire from the positive terminal of the battery to the positive side of the circuit to supply current to both branches.

Step 3: Building the first branch (Lamp 1 with switch 1)

Students connected one terminal of the first lamp holder to Switch 1, and then connected Switch 1 back to the main circuit line, forming the first independent branch.

Step 4: Building the second branch (Lamp 2 with switch 2)

Students connected the second lamp holder in a separate branch, attaching one terminal of the lamp to Switch 2**,** and then connecting Switch 2 back to the main circuit line.

Step 5: Completing the parallel connection

Both lamp branches were connected across the same battery terminals, ensuring each lamp had its own independent path in parallel.

Step 6: Inserting lamps and batteries

Students placed one 3 V lamp into each lamp holder and put the two AA batteries into their place.

Part B: Testing the Parallel Circuit

Step 7: Switching off one branch students turned off Switch 1.

Step 8: Switching off the second branch students turned off Switch 2.

Part C: Measuring Voltage with a Voltmeter

Step 9: Voltage across Lamp 1 and Lamp 2

Students connected the voltmeter across the terminals of Lamp 1 and recorded the reading and students connected the voltmeter across the terminals of Lamp 2 and recorded the reading.

Step 10: Total voltage across the circuit

Students measured across the battery terminals and recorded the total voltage.

Part D: Measuring Current with an Ammeter

Step 11: Total current measurement

Students inserted the ammeter into the main circuit line before the branches and recorded the total current.

Step 12: Current in branch 1 and current in branch 2

Students placed the ammeter in series with Lamp 1 (before Switch 1) and recorded the current. And Students placed the ammeter in series with Lamp 2 (before Switch 2) and recorded the current.

Appendix 3: Sample lesson plan

Daily Lesson Plan

School Name: - **Time**:-45'
Teacher Name: Lingerew. Dessalegn **Period** (1)
Grad: - 10 Section: --- **Pre-requisite Knowledge & Skill**: - knowledge of simple circuits from grade 8 GS subject on page 212
Subject: - Physics **Rational of the Topic**: - Helps to develop students' conceptual understanding of current, voltage, and resistance while enabling them to make sense of the electrical devices they use in everyday life and prepare for further study in physics and technology.
Topic: - Unit 4 Static and Current Electricity
Lesson 1:- 4.8 Current, Voltage, and Ohm's Law
Specific Objectives: - by the end of this lesson students will be able to

- define current, voltage, and resistance;
- state Ohm's Law;

Date	Activities	Time	Teaching Methodology: Teacher activities	Teaching Methodology: Student activities	Teaching aid	Assessment
----------	Introduction	7'	➢ Ask students about an open and a closed circuit. 1. describe the differences between an open and a closed circuits and list the components used to sketch your circuits and their usage in the circuit ➢ Ask students to recall 1. The definitions of current, voltage, and resistance	➢ Describe the differences between an open and a closed circuits. ➢ List the main components used to sketch a simple circuit and explain the role of each component in the circuit. ➢ Recall the definitions of current, voltage, and resistance from the Grade 8 General Science. ➢ Recall the relationships between current, voltage, and resistance in a simple circuit from the Grade 8 General Science.	Computers and https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_all.html	➢ Describe the differences between an open and a closed circuits. ➢ List the main components used to sketch a simple circuit and explain the role of each component in the circuit. ➢ Define current, voltage, and resistance; ➢ Describe the relationships between current, voltage, and resistance in a simple circuit

			from the Grade 8 General Science. 2. The relationships between current, voltage, and resistance in a simple circuit from the Grade 8 General Science.			
	Main activities	30'	➢ Arrange students in groups of five students and facilitates students to define current, voltage, and resistance and state Ohm's Law;	➢ In a group students ✓ Define current, voltage, and resistance and state Ohm's Law using three virtual laboratory PhET experiments such as circuit construction Kit: DC PhET Experiment Ohm's Law PhET Experiment and resistance in a Wire PhET Experiment.	Computers, https://phet.colorado.edu/sims/html/ohms-law/latest/ohms-law_all.html, https://phet.colorado.edu/sims/html/resistance-in-a-wire/latest/resistance-in-a-wire_en.html and https://phet.colorado.edu/sims/html/circuit-construction-kit-dc/latest/circuit-construction-kit-dc_all.html	➢ Define current, voltage, and resistance? ➢ State Ohm's Law both qualitatively and mathematically?
	Summary	8'	➢ Observe and appreciate each group ➢ Give a correction if there is any a conceptual difficulty or misconceptions observed during group discussions	➢ Each group will present their final points about the definitions of current, voltage, and resistance and the relationships between current, voltage, and resistance in a simple circuit based on the results obtained from the two virtual lab PhET experiments.	Computers, https://phet.colorado.edu/sims/html/ohms-law/latest/ohms-law_all.html and https://phet.colorado.edu/sims/html/resistance-in-a-wire/latest/resistance-in-a-wire_en.html	➢ From your results obtained from the two virtual lab PhET experiments define current, voltage, and resistance and describe the relationships between current, voltage, and resistance in a simple

			and presentations about the definitions of current, voltage, and resistance and the relationships between current, voltage, and resistance in a simple circuit			circuit(ohm’s law)

Learner Support: - ------------

Teacher Name: Lingerew. D

Sign:

Date:-……………

Advisor Name: Dr. Aysheshim Mengistu

Sign: - _____________

Date:-…………….

School Director: Name: …….

Sign: - ______________

Date: - ------ /-------/----