University of Education,Winneba http://ir.uew.edu.gh

UNIVERSITY OF EDUCATION, WINNEBA

PhEt interactive simulations- A strategy for remedying students' misconceptions in some selected Mechanics Topics

MAXWELL OBENG

(8231610062)

A thesis in the Department of Science Education, Faculty of Science Education, submitted to the School of Graduate Studies in partial fulfilment of the requirements for the award of the degree of Master of Philosophy (Science Education) in the University of Education, Winneba

September, 2024

University of Education,Winneba http://ir.uew.edu.gh

DECLARATION

STUDENT'S DECLARATION

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

SIGNATURE: ……

DATE: ……

SUPERVISORS' DECLARATION

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

SUPERVISOR: DR. DESMOND APPIAH

SIGNATURE: …….

DATE: …….

University of Education,Winneba http://ir.uew.edu.gh

DEDICATION

This work is dedicated to my dear mother, Jane Aidoo, who has been encouraging me and extending her support and love when it was necessary and I have always looked upon her as my strength. I am thankful that her efforts and support have resulted in this success.

University of Education,Winneba http://ir.uew.edu.gh

ACKNOWLEDGEMENT

This work would not have been completed successfully without the contributions of many people. For this reason, heartfelt thanks to each of them. First and foremost, I would like to express my special thanks to my supervisor, Dr. Desmond Appiah, who guided the research and provided timely comments during different times. His motivation and professional help were valuable in the development of this research.

I am grateful to the administration, teachers, and students of Mankessim Senior High and Technical School who were involved in the research. I understand that a lot of time, effort, and resources were dedicated to such cooperation and openness, which enhanced the completion of this study.

I would like to express my warmest and deepest thanks to my family for their constant support and care in every aspect. Your belief and trust in me have always inspired me the most.

Finally, I want to express my gratitude to my friends and teammates who stood by me and supported me all through this journey and shared the same path with me. I appreciate your encouragement and your insights have also been invaluable.

University of Education,Winneba http://ir.uew.edu.gh

TABLE OF CONTENTS

Content	Page
DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENT	v
LIST OF TABLES	xi
ABBREVIATIONS	xii
ABSTRACT	xiii
CHAPTER ONE: INTRODUCTION	1
1.0 Overview	1
1.1 Background to the study	1
1.2 Statement of the Problem	2
1.3 Purpose of the Study	3
1.4 Research Objectives	3
1.5 Research Questions	4
1.6 Hypothesis	4
1.7 Limitations	4
1.8 Delimitation	7
1.9 Organisation of the Study	7
CHAPTER TWO: LITERATURE REVIEW	9
2.0 Introduction	9
2.1 Theoretical Review	11
2.1.1 The Nature of Students' Misconceptions in Mechanics	12
2.1.2 Conceptual Change and Learning in Physics	15
2.1.2.1 Dole and Sinatra's Cognitive Reconstruction of Knowledge Model (CRKM)	15

University of Education,Winneba http://ir.uew.edu.gh

2.1.2.2 Vosniadou's Framework Theory 17

2.2.3 Constructivist learning theories 19

2.1.3.1The Role of Technology in Physics Education 21

2.1.4 PhET Interactive Simulations in Science Education 25

2.1.5 Newton's Laws of Motion 29

2.1.6 Information Processing Theory 31

2.2 Theoretical Framework 32

2.2.1 Constructivist Learning Theory 32

2.2.2 Cognitive Load Theory 33

2.2.3 PhET Simulations and the Reduction of Cognitive Load 34

2.2.4 Inquiry-Based Learning Approach 35

2.3 Conceptual Review 37

2.3.1 Misconceptions in Physics 38

2.3.2 Conceptual Change 38

2.3.3 Interactive Simulations 39

2.3.4 Inquiry-Based Learning 40

2.4 Conceptual Framework 41

2.4.1 Input stage: Identification and Preparation 41

2.4.2 Processing Stage: Engagement and Conceptual Change 42

2.4.3 Output Stage: Evaluation and Learning Outcomes 43

2.5 Empirical Review 45

2.5.1 Use of PhET Simulations to Address Misconceptions in Mechanics 46

2.5.2 PhET and Cognitive Load Reduction 56

2.5.3 Inquiry-Based Learning and PhET Simulations 65

2.5.4 Blended Learning Models with PhET Simulations 80

2.5.5 Challenges in Implementing PhET Simulations 102

2.5.6 Using PhET Simulations in Improving Students Performance 123

University of Education,Winneba http://ir.uew.edu.gh

2.6 Summary 134

CHAPTER THREE: METHODOLOGY 136

3.0 Overview 136

3.1 Introduction 136

3.2 Research Design 137

3.3 Population of the study 139

3.4 Sample and sampling Technique 139

3.5 Data Collection Instruments 141

3.5.1 Interview 141

3.5.2 Pre-tests and Post-tests 141

3.5.3 Student questionnaire 142

3.6 Data Collection Procedures 143

3.6.1 Pre-intervention Phase 143

3.6.2 Intervention Phase (PhET Simulation Implementation) 143

3.6.2.1 Description of Lessons organised with PhET Simulations and How the Process Correct Misconceptions 144

3.6.3 Post-intervention Phase 147

3.7 Intervention (PhET Simulations) 148

3.7.1 Implementation Process 149

3.8 Data Analysis Processing 150

3.8.1 Quantitative Analysis 150

3.8.2 Qualitative Analysis 151

3.9 Validity and Reliability 152

3.9.1 Internal Validity 152

3.9.2 External Validity 153

3.9.3 Reliability 153

University of Education,Winneba http://ir.uew.edu.gh

3.10 Ethical Considerations 154

3.11 Summary 156

CHAPTER FOUR: RESULTS AND DISCUSSION 159

4.0 Overview 159

4.1 Demographic Characteristics of Participants 159

4.1.1 Implications of Demographic Data 161

4.2 Prevalent Misconceptions in Mechanics 161

4.2.1 Misconceptions Identified 162

4.2.2 Pre-Test Results 163

4.2.3 Pre-Test Questions and Statistical Data 164

4.4 Impact of PhET Simulations on Misconceptions and Performance 165

4.4.1 Pre-Test and Post-Test Analysis 165

4.4.2 Student Feedback on PhET Simulations 168

4.4.3 Engagement and Application of PhET Simulations 170

4.5 Analysis of Data from Questionnaires 171

4.6 Introduction of PhET simulations in remediating students' misconceptions 174

4.7 Discussion 175

4.7.1 Research Question one 176

4.7.1.1 Key findings 177

4.7.2 Research Question two 177

4.7.2.1 key findings 178

4.7.3 Research Question three 178

4.7.3.1 Key findings 179

4.7.4 Research Question four 180

4.7.4.1 Key findings 180

4.8 Hypothesis Testing 181

University of Education,Winneba http://ir.uew.edu.gh

4.8.1 Testing the Hypotheses 181

4.8.2 Implications for Teaching and Learning 182

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS 183

5.0 Introduction 183

5.1 Summary of Findings 183

5.2 Implications on Teaching and Learning 184

5.3 Recommendations 186

5.3.1 Recommendations for Teachers 187

5.3.2 Recommendations to Policymakers 188

5.3.3 Recommendations for Future Research 189

5.4 Overall Significance 189

5.5 Conclusions 191

REFERENCES 194

APPENDICES 203

APPENDIX A: TEST ITEM 203

APPENDIX B: QUESTIONNAIRE 207

APPENDIX C: DATA ANALYSIS 210

APENDIX D: INTERVIEW QUESTIONS 214

APENDIX E: WASSCE RESULTS ANALYSIS 215

APPENDIX F: LESSON PLAN FOR THE INTERVENTION 216

University of Education,Winneba http://ir.uew.edu.gh

LIST OF TABLES

Table	Page
1: Biodata of Participants	160
2: Pre-Test Results	163
3: Paired Sample Statistics (n=100)	166
4: Pre-Test and Post-Test Misconceptions Comparison	167
5: Pre-Intervention Confidence Levels	168
6: Post-Intervention Improvement	168
7: Effectiveness of PhET Simulations	169
8: General Performance in Physics	169
9: Students Engagement with PhET Simulations	170
10: Application to Real-World Situations	170
11: Comparison with Lecture Methods	171
12: Remediation of Misconceptions	171
13: Enhanced Understanding - Key Themes and Responses	172
14: Increased Engagement - Key Themes and Responses	173
15: Practical Application - Key Themes and Responses	174

University of Education,Winneba http://ir.uew.edu.gh

ABBREVIATIONS

SHS	Senior High School
PhET	Physics Education Technology
RPK	Required Prior Knowledge
SD	Standard Deviation
SPSS	Statistical Package for the Social Sciences
H0	Null Hypothesis
H1	Alternative Hypothesis
df	Degrees of Freedom
APA	American Psychological Association
ICT	Information and Communication Technology
P-value	Probability Value

University of Education,Winneba http://ir.uew.edu.gh

ABSTRACT

This study evaluates the efficacy of PhET simulations in correcting students' misconceptions in selected mechanics topics and enhancing performance at Mankessim Senior High and Technical School. The research sought to: identify misconceptions commonly held by learners use PhET simulations to address those misconceptions, and assess the impact of the intervention on student performance. The study adopted an action research design. Data collection involved pre-tests, post-tests, and student feedback surveys. One hundred (100) science students were purposively selected as the sample. Pre-test results revealed three common misconceptions: (1) misunderstanding the concept of inertia and its relationship to motion, (2) confusing Newton's First Law with Newton's Second Law of Motion, and (3) the belief that constant motion requires continuous application of force. To address these, a six-lesson instructional plan was designed and implemented using PhET interactive simulations. Each lessons were designed strictly on inquiry teaching strategies. Simulations allowed students to manipulate variables, observe what happens, and learn about guided inquiry with the goal of testing hypotheses and building meaning knowledge. The result was found to be much enhanced in terms of understanding and performance by the students. The mean score of 13.2 (SD = 2.5) during pre-test increased to 17.2 (SD = 1.8) during the post-test. A paired t-test statistic value of $t(99) = -21.0$, p-value = 0.002, indicates that the improvement observed is significant at the 0.05 level. This means that there is a 0.2% likelihood the difference in scores was due to chance and the intervention did have an impact on what students were being taught. Student feedback also validated quantitative findings: 94% reported they had more capacity to apply mechanics concepts in real life. Engagement-wise, 48% reported the simulations were very engaging and 26% reported they were extremely engaging. Qualitative feedback thematic analysis produced three emergent themes: increased conceptual understanding, increased interest and interaction, and increased capacity to transfer theory to practice. It concludes that PhET simulations are a successful pedagogical way of solving physics misconceptions and improving learning performance.

University of Education,Winneba http://ir.uew.edu.gh

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter introduces the background of the study. It focuses on the introductory components of a study which orderly incorporates the background to the study, statement of the problem, purpose of the study, research objectives, research questions, hypothesis, limitation, delimitation, and lastly the organization of the study.

1.1 Background to the study

Physics is a fundamental subject that explains natural phenomena, but students struggle with key concepts, particularly mechanics. Many students wrongly believe that there must be a force to sustain motion or that objects in motion have a tendency towards resting on their own without applying any external force (Cashata et al., 2022). These misconceptions are disruptive of more sophisticated understandings of physical concepts. Observations and interviews with students in Mankessim Senior High and Technical School pointed towards deep-rooted misconceptions in some physics mechanics topics. Students confusingly equated inertia with force, struggled with balancing and unbalanced forces, and were not readily able to translate theoretical notions to real life situations. These were also reflected in students' poor performance in physics, as evidenced by the consistent low WAEC scores (see Appendix E). The consistent application of lecturing techniques, which are directed towards memorization rather than comprehension of concepts, has contributed to these problems. In response to these misbeliefs, what is needed is a pedagogical approach that enhances conceptual understanding through interactive and engaging learning experiences. A possible solution is the use of PhET interactive simulations, which

University of Education,Winneba http://ir.uew.edu.gh

provide an interactive, dynamic, and experiential way of learning physics principles. Through the simulations, students are able to test and play with variables in a virtual environment, producing deepened understanding and eliminating misconceptions (Toma, 2023). This study was therefore prompted by the need to explore whether PhET interactive simulations can be used to remediate misconceptions among students regarding some mechanics topics and other selected mechanics concepts. By implementing technology in teaching physics, this study seeks to improve conceptual understanding as well as general student performance in mechanics.

1.2 Statement of the Problem

Despite all the pedagogical approaches to enhance physics teaching, Mankessim Secondary and Technical School students still do not comprehend some mechanics concepts. Over the years, new trends in science education-such as inquiry-based learning, problem-based learning, and technology-enhanced instruction-have been introduced, each with its theoretical advantages. However, the practical application of these approaches does not always yield the expected learning outcomes.

An initial interview with students at Mankessim Senior High and Technical School indicated that many students hold persistent misconceptions about motion and forces. For instance, some believe that inertia is a force, while others assume that an object in motion must always have a continuous force acting on it to maintain its movement. These misconceptions suggest a gap between theoretical pedagogical advancements and their effective implementation in the classroom.

Lecture-based methods, which are still commonly used by physics teachers, contribute to this issue. These methods rely heavily on passive learning, which often fails to engage students in the active construction of scientific concepts. Consequently, many

University of Education,Winneba http://ir.uew.edu.gh

students retain incorrect notions about mechanics, leading to poor performance in physics.

Given the ongoing shifts in physics education, there is a need to explore innovative, research-backed teaching strategies that can effectively address these misconceptions. One promising approach is the integration of PhET simulations into physics instruction. As highlighted by Perkins and Moore (2017), PhET simulations provide students with dynamic, interactive environments that allow them to test, visualize, and refine their understanding of scientific concepts. These virtual simulations bridge the gap between theoretical learning and practical application by fostering active participation, experimentation, and conceptual comprehension. Thus, investigating the effectiveness of PhET simulations in improving students' understanding of some mechanics concepts will provide valuable insights into the practical benefits of this emerging pedagogical trend.

1.3 Purpose of the Study

This thesis sought to identify and remediate some common misconceptions in mechanics topics for students in Mankessim Senior High and Technical School students by the use of PhET simulation.

1.4 Research Objectives

The objectives of this research are:

1. to identify common misconceptions in some selected mechanics topics among Mankessim Senior High and Technical School students.
2. to employ the use of PhET simulations to remediate the misconceptions.
3. to determine the effect of students' performance in some selected mechanics topics.

University of Education,Winneba http://ir.uew.edu.gh

4. to determine students' new conceptions through the use of PhET simulations.

1.6 Research Questions

1. What are the prevalent misconceptions in some selected mechanics topics among Mankessim Senior High and Technical School students?
2. Has the introduction of PhET simulations helped in remediating students' misconceptions in some selected mechanics topics?
3. What is the effect of the PhET simulations on students' performance in some selected mechanics topics?
4. What are the new conceptions through the use of PhET simulations as a tool for remedying misconceptions in physics education?

1.6 Hypothesis

The hypothesis is a testable case or expectation that focuses logical examination in the correct heading and structures the reason for exact review and trial and error. It helps analysts in methodically looking at peculiarities and adding to information inside their areas of specialization.

Null Hypothesis (H0): There are no discernible differences in the PhET simulations' remedial effectiveness on students' misconceptions about mechanics.

Alternative hypothesis (H1): There are discernible variations in the efficacy of PhET simulations as regards clearing up students' misconception about some selected mechanics topics.

1.7 Limitations

The participants' health status, mood and test anxiety may influence their responses to the data collecting instruments (questionnaires, interviews and test items).

University of Education,Winneba http://ir.uew.edu.gh

This research can be limited by time constraints, lack of funds or resources.

There will also be limitations of the sample size since only form two science students from this school will constitute it.

Furthermore, the study will also be limited to students who one way or the other reasons may absent themselves from school during the time of the research.

Every research has some limitations and challenges that can influence the results, as well as interpretations. Knowing and accepting these limitations not only enhances the credibility of the findings but also provides a basis for understanding what was really covered in the study.

There were several limitations and challenges in this study. The first and foremost limitation was that the study only had a few participants, since it was restricted to Mankessim Senior High and Technical School students, hence limiting the findings' scope. Because of the nature of the research being based on only one school, there are high chances that the findings will not be generalised due to variations of areas like teaching methodology, student population, and availability of materials and other resources. The intervention was also applied for only three weeks, duration too limited to explore thoroughly and evaluate if PhET simulations have any effects on the learners' understanding of some mechanics concepts. Differences among participants such as lack of internal motivation and engagement or level of prior knowledge have the potential to elicit different results, and though the researcher attempted to minimize those factors, fullness cannot be achieved in a real classroom situation. In addition, self-reporting questionnaires were used, and several bias sources associated with self-reports are possible when looking at the results.

University of Education,Winneba http://ir.uew.edu.gh

These limitations could impact the study's results in one way or the other. Since the study's findings are based on Mankessim Senior High and Technical School, the results may not hold for other schools. The limited number of participants in the study, which lacks diversity of participants, creates a lot of noise within the data to the point it is difficult to determine if any effects are statistically significant and the researchers' conclusions are valid. There was also the problem of self-reported data, where students were depended upon to give facts, sometimes the students were not straightforward, hence the results may not have been accurate comprehensively.

To resolve these shortcomings and increase the confidence of the findings, some mechanisms were put into practice. Triangulation was utilized by administering questionnaires, pre-tests and post-tests as methods of data collection whose results enhanced the verification of information. Detailed accounts of the research's vending technique, along with the processes of PhET simulations and the collection and analysis of data, were documented to allow for the possibility of the study being replicated and to explain the differences in the outcomes. The instruments and procedures were pilot tested to determine and correct any possible shortcomings early in the cause of the study hence improving the integrity of the data collection instruments. The research also gives a detailed description of the school's context, student population and other relevant factors that would be useful to interpreting the results. Finally, a research paradigm that utilized a combination of qualitative and quantitative approaches was employed to arrive at the conclusion of the study. Even though the qualitative data offered information on the students' experiences and emotions, the quantitative data acquired information concerning the cognitive change over the students.

University of Education,Winneba http://ir.uew.edu.gh

All research has limitations and acknowledging these limitations enhances the trustworthiness of findings (Creswell, 2021). By addressing these limitations through appropriate strategies, the study aims at providing useful insights on the effectiveness of PhET simulations in correcting students' misconceptions some selected mechanics topics.

1.9 Delimitation

This research will be conducted at Mankessim Senior High and Technical School in form two science classes. The study is therefore restricted to that particular group of students only.

The study will focus on only remediating students' misconceptions. The period for remediation will only be three weeks. Again, only one hundred (100) students were used for this study.

1.10 Organization of the Study

There are five chapters in this research project that are woven together.

Chapter one is the introduction of the research topic, explaining why it is important to conduct a study on the topic. It also has problem statement, objectives and research questions.

Chapter 2 gives an extensive discussion about literature review of mechanics concepts use of PhET simulations to address misconceptions, PhET and cognitive load reduction, inquiry-based learning and PhET simulation, blended learning methods with PhET simulation, challenges in implementing PhET simulations and using PhET simulations in improving students' performance and related theoretical frameworks.

University of Education,Winneba http://ir.uew.edu.gh

The third chapter therefore describes the method used like the research design, participants, and instruments procedures and data analysis.

Chapter four presents some findings of the study such as how much PhET simulations address students' misconceptions as well as providing results discussions.

Chapter five consists of summary presenting main findings, conclusions, and recommendations plus suggestions for further studies in future.

University of Education,Winneba http://ir.uew.edu.gh

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

Physics learning plays a significant role in developing students' understanding of the physical world, problem-solving ability, and scientific investigation. As vital as it is, tremendous difficulties are faced by students in understanding simple mechanics concepts, leading to deep-seated misconceptions that impact their academic performance and use of physics concepts in practical scenarios (Banda & Nzabahimana, 2021; Chi, 2008). Mechanics, including Newton's laws of motion, forces, and energy conservation, is the most challenging since it is abstract and intuitive misconception from everyday life. Misconceptions that a constant force must be applied to remain moving or heavier objects fall faster than light ones have been widely documented (McDermott, 2001; Vosniadou, 2013). Unless they are solved, these different conceptions are sure to be deeply entrenched and stable, with negative effects on students' performance as well as restricting their use of scientific reasoning to answer questions (Redish, 2004; Wang & Yang, 2022). Such misconceptions may be addressed relying on a deep understanding of theoretical underpinnings of conceptual change in addition to instructional strategies that can lead to restructuring of knowledge. There are a number of theoretical frameworks, such as Dole and Sinatra's Cognitive Reconstruction of Knowledge Model (CRKM) and Vosniadou's Framework Theory, that note that conceptual change does not take place until the students have encountered cognitive conflict that compels them to revise their previous beliefs (Dole & Sinatra, 1998; Vosniadou, 2013). Research shows that passive learning methods such as listening to lectures and memorization are inefficient in creating conceptual change to a large degree as they do not require students to test or challenge what they have

University of Education,Winneba http://ir.uew.edu.gh

learned (Hake, 1998; Perkins et al., 2023). Instead, constructivist and inquiry-oriented pedagogies that allow active participation, experimentation, and self-construction have been found more successful in correcting misconceptions and facilitating deep learning (Chi, 2008; Lin, Chiu, & Wu, 2023).

Educational technology innovation in recent times has also introduced new ways of engaging learners to learn physics, with interactive simulations as a novel conceptual development tool. PhET Interactive Simulations, developed at the University of Colorado Boulder, offer an interactive, visual, and dynamic means through which students may learn physics principles by adjusting parameters, seeing the effects right away, and experimenting with hypotheses by trial and error in a controlled virtual environment (Adams, Paulson, & Wieman, 2008; Perkins et al., 2023). These simulations provide a forum where students can identify and alter their misconceptions through the observation in real-time of the implications of their thinking within a safe, supportive interactive environment (Wang & Yang, 2022). The effectiveness of PhET simulations has been well studied, and findings have shown that students learning through such interactive simulations gain more concepts than students instructed with traditional methods (Banda & Nzabahimana, 2021; Lin et al., 2023).

Besides, PhET simulations follow constructivist learning theory since they enable the students to build their own knowledge through active engagement and guided exploration as opposed to passive reception of information (Redish, 2004; Vosniadou, 2013). The simulations have proved effective in teaching students mechanics material such as Newton's laws, projectile motion, and conservation of energy. For example, software like "Forces and Motion: Basics" and "Energy Skate Park" enable students to visualize and make changes to the concepts of physics, thereby developing the idea

University of Education,Winneba http://ir.uew.edu.gh

inside them through the interactive process of learning (Perkins et al., 2023). Incorporating the instruments into teaching physics enables teachers to create more participatory and improved learning procedures, which help refine deeper understanding and improve students' performance in class.

This literature review addresses the sources and origins of students' misconceptions in mechanics, conceptual change models of descriptions, and the implementation of PhET simulations within physics education. By employing empirical data from educational psychology and physics education research, this literature review highlights the necessity of employing interactive technology to eliminate misconceptions, enable deep learning, and improve students' performance.

2.1 Theoretical Review

Understanding misconceptions in mechanics is a critical part of physics education research among students. Misconceptions are those alternative conceptions that do not match accepted scientific explanations and which are stable regardless of formal schooling (Banda & Nzabahimana, 2021). Misconceptions have been attributed to common experience, intuitive reasoning, meaning of words, and normal instruction that stresses more memorization than a solid conceptual grasp (Chi, 2008; Vosniadou, 2013). For example, students generally believe that a force must be applied constantly in order to maintain motion, which contradicts Newton's First Law of Motion (McDermott, 2001). Such misconceptions hinder students from applying physics concepts appropriately in problem-solving and real-life situations (Redish, 2004).

It is through teaching strategies based on cognitive and constructivist learning theories that such misconceptions are addressed. Conceptual change theories, such as the Cognitive Reconstruction of Knowledge Model (Dole & Sinatra, 1998) and

University of Education,Winneba http://ir.uew.edu.gh

Vosniadou's Framework Theory (2013), hypothesize that students must undergo cognitive conflict and be internally driven to swap out their earlier assumptions for scientifically accurate concepts. Active learning practices, such as inquiry-based instruction and interactive models, have been shown to be extremely effective at facilitating conceptual change (Hake, 1998; Lin et al., 2023).

One of the most promising approaches to physics education today is the employment of interactive simulations, such as those developed by the PhET Interactive Simulations project at the University of Colorado Boulder. The simulations provide interactive, visual, and dynamic experiences that allow students to explore and experiment with physics concepts in a virtual environment (Perkins et al., 2023). According to research, students using PhET simulations show significant improvement in conceptual understanding as they allow students to manipulate variables, test hypotheses, and get instantaneous feedback (Wang & Yang, 2022).

This is a theoretical review of the conceptual underpinnings of causes of students' misconceptions about mechanics, mechanisms of conceptual change, and what PhET simulations offer to help achieve scientific conceptualization. Building on the blending of concepts within educational psychology and physics education studies, this review is keen to promote student-oriented approaches to bypass misconceptions. The review stresses the importance of innovative teaching measures incorporating active learning engagement of learners and enhancing depth in understanding the concept of mechanics.

2.1.1 The Nature of Students' Misconceptions in Mechanics

Students learn misconceptions in mechanics due to previous experiences, intuitive reasoning, and partial or incorrect instruction. Misconceptions are firmly held beliefs

University of Education,Winneba http://ir.uew.edu.gh

that contradict scientifically acceptable principles, and learning physics thus becomes an issue. Research confirms that students consistently hold other concepts about Newton's law of motion, forces, and conservation of energy (Clement, 2020). Some of the most prevalent misconceptions include that motion requires a constant force and that heavier bodies accelerate faster than lighter bodies (Bao & Koenig, 2022). Misconceptions lead to problem-solving errors that are difficult to reverse and hinder deeper understanding of mechanics concepts (Duit & Treagust, 2021).

Recent studies have confirmed that such misconceptions remain common among students despite advances in teaching techniques. Banda and Nzabahimana (2021) undertook a literature review of 31 papers and found conceptual misunderstandings in physics to continue posing a big stumbling block for meaningful learning. Pranata (2024) also demonstrated how interactive study resources, such as game-based PhET simulations, successfully enhance learners' understanding of equilibrium systems by debunking unfounded preconceptions. Similarly, Lin et al. (2023) determined that students who underwent interactive simulations showed improved conceptual retention compared to peers taught with traditional teaching methods.

Research confirms that traditional learning strategies such as lecturing and memorization by rote are poor at managing misconceptions (Lindsey et al., 2022). Constructivist methods that facilitate active learning and thinking conceptually function better (Hewson & Hewson, 2023). PhET simulations have been perceived as a very effective means for conceptual change facilitation by providing interactive and graphical representation of abstractions (Perkins et al., 2023).

University of Education,Winneba http://ir.uew.edu.gh

Uwambajimana et al. (2023) found that the users of PhET simulations exhibited greater conceptual progression in electrostatics compared to their traditionally educated counterparts.

Misconceptions about mechanics can result from a multitude of sources such as:

Intuition and daily life: The students would approach physical phenomena and make sense of them based on prior everyday experience. For example, they could perceive that the existence of force is necessary in order to continue motion since in their everyday experiences' objects slow down due to friction (Bao & Koenig, 2022).

Language and terminological misconceptions: Scientific terms such as "force," "work," and "inertia" share everyday meanings that differ from their physics definitions, which is confusing (Brown & Clement, 2022).

Traditional teaching strategies: The majority of students master physics through rote learning and not conceptual knowledge, leading to surface learning rather than the rectification of deeply rooted misconceptions (Redish, 2023).

Cognitive constraints on abstract concept understanding: Some mechanics topics, for instance, Newton's Third Law or forces of non-contact, go against intuition and require abstract thought that cannot be acquired by students without guided exploration (Trowbridge & McDermott, 2021).

Ndihokubwayo, Uwamahoro, and Ndayambaje (2023) identify that interactive platforms such as PhET simulations fill such cognitive gaps with visual, interactive experiences that counter against incorrect ideas and promote appropriate conceptualization.

University of Education,Winneba http://ir.uew.edu.gh

2.1.2 Conceptual Change and Learning in Physics

To overcome misconceptions in physics, conceptual change is required, involving a process by which students drop their misinformed previous knowledge for scientifically accurate concepts. In contrast to rote learning, which typically results in surface understanding, conceptual change requires students to be actively engaged in reframing models of thinking. This is particularly challenging in physics because most misconceptions are deeply entrenched and reinforced through shared experiences (Lindsey, Heron, & Shaffer, 2022).

Conceptual change does not occur randomly; it requires intentional teaching approaches that make misconceptions explicit and permit cognitive restructuring. Conceptual change is best when students experience active, inquiry-based activities that cause them to challenge their preconceptions (Duit and Treagust, 2021). New research suggests that PhET interactive simulations are a powerful tool for inducing conceptual change in mechanics by creating cognitive conflict, visualization, and hands-on activity (Perkins et al., 2023).

Several theoretical frameworks exist to account for how learners reformulate their conceptualization, of which Dole and Sinatra's Cognitive Reconstruction of Knowledge Model (CRKM) and Vosniadou's Framework Theory are the most prominent.

2.1.2.1 Dole and Sinatra's Cognitive Reconstruction of Knowledge Model (CRKM)

Dole and Sinatra (1998) created the Cognitive Reconstruction of Knowledge Model (CRKM) to describe how students replace inaccurate knowledge with scientifically accurate concepts. The model describes three general conditions that must be met if conceptual change is to occur:

University of Education,Winneba http://ir.uew.edu.gh

Dissatisfaction with existing knowledge: Learners have to realize that their existing knowledge is inaccurate or incomplete.

Relevant interaction with novel information: Students needs to process novel ideas actively in a manner that overcomes their preconceptions.

Intelligibility, plausibility, and fruitfulness of novel concepts: The novel scientific explanation needs to be understandable, seem reasonable, and be beneficial in solving problems.

CRKM highlights the importance of cognitive engagement and motivation in concept change. Students will alter their preconceptions if they find the learning process interactive, stimulating, and congruent to their needs. This highlights the importance of active, inquiry-learning strategies such as PhET simulations, experiments, and solving problems in physics education (Banda & Nzabahimana, 2021).

Recent studies have confirmed the effectiveness of CRKM in guiding conceptual change. Lin, Chiu, and Wu (2023) indicated that students who underwent interactive simulation-based learning had higher conceptual change rates compared to those students who were educated via traditional lectures. Similarly, Redish (2023) argued that instruction informed by constructivist ideas significantly improves students' ability to detect and address their own misconceptions.

By applying CRKM to physics teaching, teachers are able to design instruction that:

- Involves students in cognitive conflict by presenting evidence against their misconceptions.
- Encourages active investigation with simulations, hands-on activities, and guided inquiry.

University of Education,Winneba http://ir.uew.edu.gh

- Promotes metacognition, with students being challenged to reflect on their thinking and alter their understanding accordingly.

PhET simulations are highly effective in this paradigm because they allow students to experiment, visualize, and receive immediate feedback, so they are more likely to see and remove their misconceptions (Uwambajimana et al., 2023).

2.1.2.2 Vosniadou's Framework Theory

Vosniadou (1994) proposed the Framework Theory, which views misconceptions as coherent, organized mental frameworks rather than disorganized errors. According to this theory, students construct their knowledge of physics on the basis of a synthesis of formal instruction and personal experiences. However, these frameworks have a tendency to encapsulate misconceptions that are hard to change because they seem logical based on everyday experiences.

For example, students may believe that a force is needed to keep an object moving because, in their everyday experience, objects slow down due to friction. This misconception is in line with their current mental framework but not with Newton's First Law (Bao & Koenig, 2022). It is not enough to merely give students the correct scientific explanation; they must reorganize their entire conceptual framework in order to fully grasp Newtonian mechanics.

Vosniadou's theory foresees that conceptual change is a process requiring much time and intensive cognitive engagement. Instructional strategies for promoting conceptual change need to:

- Activate students' prior knowledge and misconceptions through discussion or diagnostic assessment.

University of Education,Winneba http://ir.uew.edu.gh

- Introduce scientifically accurate concepts through visual, interactive media such as PhET simulations.
- Promote restructuring of knowledge by providing students with the opportunity to apply new concepts in diverse situations.

Research supports the merit of this practice. Perkins et al. (2023) found that students who used simulation-based learning activities demonstrated greater conceptual change than students who used textbook learning alone. The study highlighted that visual representations, interactive experimentation, and real-time feedback help students develop more accurate mental models.

Similarly, Ndihokubwayo, Uwamahoro, and Ndayambaje (2023) found PhET simulations to be particularly effective in allowing students to surmount forces and motion misconceptions as they manipulated variables directly and witnessed cause-and-effect relationships.

Both CRKM and Framework Theory provide strong theoretical support for using PhET interactive simulations to induce conceptual change in mechanics. The simulations promote:

Cognitive conflict, allowing students to become aware of inconsistencies in their understanding.

Active learning, wherein students can test hypotheses and receive direct feedback.

Scaffolded conceptual change, wherein the students are guided through the process of restructuring knowledge.

Research consistently shows that students who learn through simulation-based learning exhibit greater conceptual gains, enhanced understanding, and longer retention than students who receive conventional instruction alone (Lin et al., 2023). Through the

University of Education,Winneba http://ir.uew.edu.gh

integration of PhET simulations into the physics teaching, educators can create more efficient learning environments that address misconceptions and promote accurate conceptual understanding.

2.1.3 Constructivist learning theories

Constructivist learning theories emphasize the reality that prior knowledge is a determining factor in how students accept and interpret new knowledge. According to current studies on cognitive development and the Zone of Proximal Development (ZPD), students construct new knowledge based on their prior knowledge (Shabani, 2020; Lave & Wenger, 2019). However, when the previous knowledge of students is based on misconceptions, the erroneous conceptions have the potential to interfere with proper assimilation of scientific concepts and make conceptual change difficult (Duit & Treagust, 2021).

When physics is learned, students come to class with intuitive, experiential concepts about mechanics that are in conflict with formal scientific explanations. For example, most students believe that a force must be applied all the time to keep an object moving, a misconception that goes against Newton's First Law of Motion (Bao & Koenig, 2022). If these misconceptions are not confronted directly, students may not be able to fully absorb new information, leading to surface or fragmented understanding (Redish, 2023).

Effective physics teaching should take into account and address students' previous misconceptions rather than simply presenting accurate scientific concepts. It is suggested by research that if previous student knowledge is not taken into account, the students will:

University of Education,Winneba http://ir.uew.edu.gh

Memorize formulas and equations without understanding concepts, thus being unable to use concepts in novel situations (Lindsey, Heron, & Shaffer, 2022).

Construct incompatible mental models, where they recall scientific definitions but still use intuitive logic in solving problems (Vosniadou, 1994).

Support conceptual change, particularly if new information that challenges their well-developed beliefs is encountered (Dole & Sinatra, 1998).

Use PhET Simulations to Accommodate Current Knowledge

One of the most powerful tools for questioning and building students' prior knowledge is interactive and inquiry-based learning materials like PhET simulations. These computer simulations provide dynamic, graphical models of physics concepts, and allow students to test ideas in a safe, controlled, virtual setting. Rather than being lectured to about facts, students can adjust variables, observe cause-and-effect, and receive immediate feedback, which allows them to recognize contradictions in reasoning (Adams et al., 2008).

Research has demonstrated that PhET simulations are particularly effective for:

1. Eliciting and Challenging Misconceptions:

Through PhET simulations, students can experiment with preconceptions and instantly determine whether their assumptions are correct. For example, in a forces and motion simulation, students who believe motion requires constant force can experiment with applying forces on objects and observe how objects travel in frictionless environments (Perkins et al., 2023).

2. Facilitating Active Exploration and Inquiry:

University of Education,Winneba http://ir.uew.edu.gh

In contrast to the traditional lecture technique, by which physics concepts are usually presented as fixed facts, PhET simulations allow students to construct their own knowledge through anticipating, experimenting, and thinking. Research has confirmed that students who utilize interactive simulations attain significantly greater conceptual gains compared to students learning through direct instruction (Lin, Chiu, & Wu, 2023).

3. Providing Instant Feedback to Enable Learning:

In the majority of conventional problem-solving exercises, students do not receive feedback on their thinking until the time they complete an assignment or a test. However, with PhET simulations, students receive immediate feedback and can, therefore, correct their thinking immediately and build more scientifically sound mental models (Uwambajimana et al., 2023).

The majority of misconceptions in mechanics are due to experiences in everyday life, which seem to contradict official physics principles. PhET simulations aid the construction of a bridge from the intuitive conceptions of students to scientific conceptions by visual and experiential learning that allows them to grasp abstract phenomena (Duit & Treagust, 2021).

2.1.3.1The Role of Technology in Physics Education

The incorporation of technology in physics education has revolutionized the conventional method of teaching, making the learning process more interactive, engaging, and effective. Conventional practices such as reading textbooks and direct instruction cannot unlock the potential to engage students deeply and eliminate students' deeply held misconceptions regarding physics (Redish, 2023). Technology-enhanced learning (TEL), however, including simulation, virtual laboratory,

University of Education,Winneba http://ir.uew.edu.gh

augmented reality (AR), and artificial intelligence (AI)-driven tutoring systems, provides for active, interactive, and personalized learning experiences that enhance conceptual understanding and problem-solving (Lin, Chiu, & Wu, 2023).

Technology provides a number of advantages in learning physics, transforming the way students learn and interact with scientific ideas.

1. Enhancing Engagement and Motivation

Among the significant problems of physics education is student motivation due to the abstractness of the subject matter and the complexity of some of the concepts. Computer-based instructional technologies such as PhET simulations, virtual reality (VR), and game-like learning environments have been discovered to increase levels of student motivation and participation (Perkins et al., 2023).

For example, gamified simulations provide feedback and correct answers through rewards, providing feelings of achievement and interest (Pranata, 2024). Previous research has also demonstrated that the students using gamified physics applications have more persistence and spend longer working on physics problems than classroom students in standard classrooms (Uwambajimana et al., 2023).

2. Providing Real-Time Feedback and Interactive Learning Experiences

Traditional instruction does not give immediate feedback, and learners are not sure what they know about physics concepts until formal assessment. Technology-based online learning websites provide immediate feedback, and learners can rectify mistakes and know more immediately (Lin et al., 2023).

University of Education,Winneba http://ir.uew.edu.gh

PhET simulations allow learners to manipulate variables, observe outcomes, and receive immediate feedback on predictions and actions, and this leads to a clear idea of physics principles (Perkins et al., 2023).

Computer-assisted tutoring systems evaluate the responses of students and provide adaptive feedback and personalized instruction, enabling students to study at their own pace (Lindsey, Heron, & Shaffer, 2022).

3. Visualization of Abstract Concepts

Most of the concepts in physics, such as electromagnetic fields, quantum mechanics, and relativity, are difficult to visualize using static diagrams and equations. Technology-based visualizations and interactive models are used for this purpose.

Augmented reality (AR) and virtual reality (VR) enable experiential learning that helps students visualize gravitational fields, electromagnetic waves, and particle motion in 3D (Ndihokubwayo et al., 2023).

Simulation-based instruction has been particularly helpful in teaching wave interference, circuit behavior, and projectile motion by enabling students to manipulate parameters and observe outcomes in real time (Adams et al., 2008).

Research by Bao and Koenig (2022) found that students who used dynamic visualizations performed better than those who used static textbook diagrams only in concept tests.

4. Facilitating Inquiry-Based Learning Strategies

Inquiry-based learning (IBL) promotes active investigation and inquiry of scientific concepts through exploration by students, rather than passive reception of information.

University of Education,Winneba http://ir.uew.edu.gh

Technology facilitates IBL with interactive environments where students can conduct virtual experiments, test hypotheses, and analyze real-time data.

PhET simulations and virtual labs allow students to conduct experiments in a secure environment, fostering scientific thought and inquiry (Pranata, 2024).

Virtual labs and digital tools for data collection and analysis, including Tracker software and Logger Pro, allow students to snap motion, investigate forces, and read graphs, which reinforces the link of physics concepts to reality (Duit & Treagust, 2021). Research conducted by Lin, Chiu, and Wu (2023) found that students who were taught through inquiry-based instruction with technology performed higher on critical thinking and problem-solving abilities compared to students taught through traditional methods.

There are challenges, however, that teachers should consider:

1. Accessibility and Equity – Not all learners are equally accessible to digital hardware and high-speed internet, creating a digital divide in education (Hewson & Hewson, 2023).
2. Teacher Training and Support – Effective technology integration requires teacher training in digital pedagogies and technical support to fix problems (Redish, 2023).
3. Excessive Dependence on Technology – Technology facilitates learning but should enhance and not replace hands-on experiments and thinking activities (Lindsey et al., 2022).

The use of technology in physics education has transformed students' interactions with, visualization of, and understanding of abstract ideas. Technology, from interactive

University of Education,Winneba http://ir.uew.edu.gh

simulations to AI adaptive learning, has raised motivation, improved conceptual understanding, and encouraged inquiry-based learning. Its success, however, relies on equitable access, teacher preparedness, and seamless integration with traditional teaching methods. With continued technological advancement, its use in physics education will continue to expand, providing new opportunities to make learning more interactive, inclusive, and productive.

2.1.4 PhET Interactive Simulations in Science Education

PhET (Physics Education Technology) Interactive Simulations developed at the University of Colorado Boulder are a centerpiece in learning physics and science. Web-based simulations interactively involve students in very deep evidence-based learning exercises that allow students to experience intangible ideas of physics via virtual experimentation through doing (Perkins et al., 2023).

The power of PhET simulations lies in their interactive, game-like quality that engages students and makes it easier for them to learn concepts. PhET simulations have been found to offer better learning gains to students than students in classrooms where there are regular lectures (Lin, Chiu, & Wu, 2023).

PhET simulations possess several pedagogical benefits, particularly in physics, chemistry, biology, and mathematics. Their impact on conceptual change and problem-solving has been well-documented in educational research (Uwambajimana et al., 2023).

1. Enabling Students to Manipulate Variables and Observe Instantaneous Effects

One of the strongest aspects of PhET simulations is variable manipulation and observing instantaneous effects in an interactive environment.

University of Education,Winneba http://ir.uew.edu.gh

In the "Forces and Motion" simulation, students can vary parameters such as mass, force applied, and friction to observe their impact on acceleration and velocity, solidifying Newton's laws of motion (Perkins et al., 2023).

The "Circuit Construction Kit" allows students to build electric circuits, alter voltage and resistance, and observe directly changes in current, solidifying Ohm's Law and electricity principles (Lin et al., 2023).

By allowing students to control these variables, PhET simulations promote conceptual understanding and independent exploration.

2. Providing a Risk-Free Laboratory for Experimentation

The majority of physics experiments involve advanced equipment, safety hazards, or excessive expense. PhET simulations eliminate these constraints by offering a risk-free, low-cost alternative to traditional laboratory experiments (Bao & Koenig, 2022).

In the "Projectile Motion" simulation, launch angles, air resistance, and initial velocity are tweaked by the students in real-time without using laboratory equipment.

In the "Wave on a String" simulation, tension, amplitude, and frequency can be changed by students without waves-producing equipment (Ndihokubwayo et al., 2023).

Because PhET simulations are a safe environment, they encourage active learning and experimentation, making complex ideas more interactive and interesting.

3. Repeated Testing of Hypotheses and Inquiry-Based Learning

PhET simulations facilitate IBL in that they allow students to test and refine hypotheses through repeated experiments. It is a simulation of actual scientific research that strengthens the scientific method (Hewson & Hewson, 2023).

University of Education,Winneba http://ir.uew.edu.gh

In the simulation of "Energy Skate Park," students are able to explore the connection between kinetic and potential energy by adjusting track height and friction, which is conducive to the law of conservation of energy (Pranata, 2024).

The "Gravity and Orbits" simulation enables students to explore the motion of planets through changes in mass, velocity, and distance, leading to a better understanding of Newton's law of universal gravitation (Lin et al., 2023).

These simulations permit students to ask questions, manipulate parameters, and iterate to refine their understanding, a key aspect of inquiry-based science learning.

4. Closing the Gap Between Theoretical Principles and Everyday Applications

The majority of students struggle to connect abstract physical concepts with everyday applications.

PhET simulations bridge the gap and picture complicated ideas, revealing their real-world application.

The "States of Matter" simulation enables one to picture particle motion and phase change such that abstract thermodynamic concepts are brought into perspective (Duit & Treagust, 2021).

The "Molecular Shapes" simulation enables students to learn VSEPR theory and understand chemical bonding in three dimensions (Redish, 2023).

The "Radioactive Decay" simulation offers an interactive model of half-life and nuclear reactions, enabling students to learn about radioactivity and applications of radioactivity in medicine and energy (Lindsey et al., 2022).

PhET simulations enhance comprehension by relating theory to personal experience and make science more relevant and significant.

University of Education,Winneba http://ir.uew.edu.gh

Some studies have established that PhET simulations really make an impact on students' conceptual understanding and long-term retention of physics concepts:

Pranata (2024) found that the students learning with PhET simulations of Newtonian mechanics scored 23% higher on tests of conceptual understanding compared to students learning through traditional textbook-based instruction.

Uwambajimana et al. (2023) reported that students learning from PhET simulations of electrostatics retained information longer and developed fewer misconceptions than those in a conventional classroom.

Lin, Chiu, and Wu (2023) demonstrated students learning with interactive simulations performing better at problem-solving exercises and with a richer conceptual understanding of physics.

PhET simulations have numerous benefits, but challenges also go with their use:

Digital Accessibility – There are insufficient computers, tablets, or internet connectivity in some schools, restricting access to PhET simulations for students (Hewson & Hewson, 2023).

Teacher Training – Teachers require training in digital pedagogy and interactive teaching to utilize PhET simulations effectively (Redish, 2023).

Over-Reliance of Students on Simulations – While PhET simulations are helpful, they must be accompanied by laboratory experiments and theory problem-solving to provide a balanced learning experience (Duit & Treagust, 2021).

PhET simulations are a powerful pedagogical tool that enables concept understanding, interaction, and inquiry learning in teaching physics. Through the use of interactive experiments, real-time feedback, and concept visualization, the simulations bridge the gap between theory and practice. In spite of challenges, effective complementary use

University of Education,Winneba http://ir.uew.edu.gh

with traditional methods of instruction can result in optimal use, and they constitute a great tool in modern physics teaching.

PhET simulations have been utilized effectively on a broad array of mechanics subjects to enable students to visualize and engage usefully with underlying physics concepts. The simulations are interactive learning exercises that reinforce learning and eliminate misconceptions.

2.1.5 Newton's Laws of Motion

It takes mastery of Newton's laws to become an expert in mechanics, but it can be a problem for many students to handle with force, inertia, and acceleration. PhET simulations provide the interactive exploration of these topics:

"Forces and Motion: Basics" introduces the relationship among force, acceleration, and mass through pushing objects and observing what they do. Instant visual feedback by the simulation helps solidify Newton's Second Law.

"Laws of Motion" enables students to explore inertia and the impact of balanced and unbalanced forces on motion. Through hands-on experiments, students can observe Newton's First and Third Laws and eliminate some common misconceptions such as the necessity of a constant force to generate motion.

"Ramp: Forces and Motion" allows the students to experiment with friction force, normal force, and net force for an object sliding along a ramp to build their idea of force interaction in everyday experience.

It is difficult for students to conceive energy conservation and transformation. PhET simulations provide interactive simulations which introduce these hard ideas:

University of Education,Winneba http://ir.uew.edu.gh

"Energía Skate Park" allows students to investigate kinetic and potential energy transformations. Students are able to adjust variables like mass, initial velocity, and track shape to observe the conservation of energy and transformation of energy from one form to another, demonstrating the law of conservation of mechanical energy.

"Projectile Motion" introduces two-dimensional motion through the separation of vertical and horizontal components. By changing launch speed, angle, and gravity, students can develop an intuition about motion paths.

"Work and Energy" demonstrates how forces affect energy transfer so that students can connect force applications and kinetic and potential energy conversions.

PhET simulations have a number of benefits when teaching physics:

They enable students to test hypotheses and explore physics concepts without the constraints of a physical laboratory.

They enable inquiry-based learning since they cause students to adjust parameters and observe the outcome of their experiments.

They support multiple learning styles since they allow visual and kinesthetic learners to learn the content more effectively.

Experimentally, it has been shown that students learning through PhET simulations exhibit noticeable improvement in the comprehension of concepts over students taught with traditional teaching (Lin et al., 2023; Uwambajimana et al., 2023). With the use of such tools in teaching mechanics, teachers can facilitate students' engagement, conceptual understanding, and retention of physics concepts.

University of Education,Winneba http://ir.uew.edu.gh

2.1.6 Information Processing Theory

Information processing theory likens the human mind to a computer, stressing how information is taken in, worked on, put away, and remembered. It also stresses the importance of cognitive load and the limitations of working memory in learning complex concepts.

Sometimes, new concepts are a little too much for students when a lot of information is provided, and it results in information overload. So as to avoid this, teachers should know how to approach the problems and avoid cognitive overload by decomposing complicated concepts into simple ones. For instance, PhET simulations can serve as a tool for enhancing comprehension regarding concepts that might be difficult to grasp and are more abstract.

Using Schema Theory, a knowledge schema is defined as a framework that people use to underlie the establishment of concepts and the perception of objects. The misunderstandings usually arise as a result of wrong schemas; they have to be established correctly instead. This requires addressing conceptions through instructional strategies that help learners to build the right kinds of knowledge structures about the information.

An understanding of these cognitive theories provides significant insights into how students learn and how to deal with misconceptions. For instance, when teaching Newton's first law of motion, educators can: engage students' misinterpretations of inertia and motion through cognitive conflict make clear explanations that are comprehensible and credible, use PhET simulations as interactive tools to make abstract concepts more concrete and manageable, and also develop learning

University of Education,Winneba http://ir.uew.edu.gh

experiences that enable learners to test their understanding through experimentation and observation.

2.2 Theoretical Framework

Understanding how students construct scientific concepts and make sense of them lies at the center of constructing effective pedagogy. Misconceptions are prevalent hurdles to profound knowledge in studying physics, and as such theories of knowledge learning and conceptual change need to be explored. Constructivist theoretical models, theory of cognitive conflict, and technology-enhanced learning theories guide what influence existing student knowledge has on understanding physics concepts and how computer-based learning tools, such as PhET simulations, support conceptual change.

This theory review criticizes prominent education theories justifying the use of PhET simulations in physics instruction. It highlights the manner in which constructivist learning theories appreciate active construction of knowledge, cognitive conflict stimulates rich conceptual understanding, and technology-rich learning stimulates activity and inquiry-based investigation. Anchoring the research in these theory foundations, this review provides an overview of justifying the role that PhET simulations play in countering students' misconceptions and enhancing their learning experience.

2.2.1 Constructivist Learning Theory

Constructivist learning theory believes that students build new knowledge actively by connecting it to what they already know. Constructivist principles emphasize meaningful learning based on exploration, reflection, and social interaction (Shabani, 2020; Lave & Wenger, 2019). PhET simulations embody constructivist principles by

University of Education,Winneba http://ir.uew.edu.gh

providing interactive environments where students adjust variables, make forecasts, and receive immediate feedback, thereby building stronger conceptual understanding. Vygotsky's concept of the Zone of Proximal Development (ZPD) has since been built upon in more recent research to emphasize the way in which technologies, such as PhET simulations, function as scaffolding mechanisms to facilitate learners from where they are to greater conceptual achievement (Tomas et al., 2021). Additionally, studies bring to light that inquiry approaches-greater to constructivist learning-are greatly enriched by technology-based tools, as they motivate students to create hypotheses, test them out, and sharpen their knowledge based on immediate feedback (Zhao et al., 2022).

Additionally, the cognitive conflict theory, as being constructivist-oriented, suggests that students will be more likely to undergo conceptual change when they are confronted with discrepancies between what they observe and their prior conceptions (Duit & Treagust, 2021). The PhET simulations cause such cognitive conflicts in that they allow students to contrast their intuitive ideas with scientifically accurate models and therefore compel them to reshape their misconceptions into better approximations By integrating PhET simulations into the teaching of physics, educators can bridge the gap between scientific professional knowledge and everyday life, improving instruction to be more interactive, engaging, and effective (Lin, Chiu, & Wu, 2023).

2.2.2 Cognitive Load Theory

Cognitive Load Theory (CLT), as Sweller (1988) described it, proposes that learning effectiveness is based on the amount of mental effort used to make room for new knowledge. With the fact that working memory in human beings is finite (Miller,

University of Education,Winneba http://ir.uew.edu.gh

1956), cognitive overload will strangle students' capacity for comprehending abstractions. Sweller (2011) decomposes cognitive load into three types:

Intrinsic Load- The natural difficulty of material to be mastered. Newtonian mechanics, for example, comprises a number of connected principles, thus it is necessarily difficult.

Extraneous Load – The unnecessary mental effort caused by poor instructional design, such as confusing diagrams or excessive textual description (Chandler & Sweller, 1991).

Germane Load – Mental effort used to process, organize, and consolidate new information into long-term memory (Kirschner, Ayres, & Chandler, 2011).

PhET simulations optimize cognitive load by minimizing extraneous load while maximizing germane load. PhET simulations offer immediate feedback and dynamic visualizations, making abstract physics concepts more concrete and easier to understand (Perkins et al., 2023). In contrast to conventional problem-solving approaches, which tend to be based on heavy text and complicated equations, PhET simulations enable students to investigate concepts using interactive models, minimizing the cognitive burden of interpreting static representations (Lin, Chiu, & Wu, 2023).

2.2.3 PhET Simulations and the Reduction of Cognitive Load

The following processes underlie the efficacy of PhET simulations in the management of cognitive load:

Minimizing Split-Attention Effect – Traditional instructional materials tend to cause students to switch between two or more sources of information, such as diagrams, formulas, and written text, leading to cognitive overload (Mayer & Moreno, 2003). PhET simulations integrate these into a single interactive platform, where students can engage with concepts in an intuitive and streamlined manner (Adams et al., 2008).

University of Education,Winneba http://ir.uew.edu.gh

Reducing Redundant Information Processing – Research shows that when students are given redundant information (i.e., verbal descriptions that merely repeat text), cognitive load is increased (Sweller, van Merriënboer, & Paas, 2019). PhET simulations mitigate this by providing direct, visual, and interactive representations and reducing reliance on redundant instructional materials.

Supporting Active Participation and Scaffolding – Cognitive Load Theory emphasizes scaffolding as an aspect that makes the learning process less complicated (Kirschner, Sweller, & Clark, 2006). Scaffolding learning, PhET simulations support learning in the sense that they allow students to progress from simple interaction to advanced explorations, thereby gradually increasing germane cognitive load while lessening extraneous complexities (Wieman & Perkins, 2005).

Through being founded upon Cognitive Load Theory, PhET simulations make processing and remembering complex physics concepts by students possible. By incorporating immediate feedback, interactive visualisation, and reduced extraneous cognitive load, the instruments provide an efficient method of enhancing conceptual knowledge as well as problem-solving proficiency within physics learning. While challenges such as access to technology and teacher training continue (Hewson & Hewson, 2023), the potential of PhET simulations to maximize cognitive resources guarantees they are a worthwhile asset in today's science education.

2.2.4 Inquiry-Based Learning Approach

Inquiry-Based Learning (IBL) is a methodology of inquiry learning that facilitates active exploration and discovery, allowing learners to construct their own knowledge through experimentation, investigation, and questioning (Hmelo-Silver, Duncan, & Chinn, 2007). Unlike lecture instruction, in which passive reception of material occurs,

University of Education,Winneba http://ir.uew.edu.gh

IBL allows learners to engage actively with scientific principles, leading to more robust conceptual knowledge as well as critical reasoning (Llewellyn, 2013). PhET simulations are deeply aligned with the principles of IBL by providing learners with interactive, inquiry-learning environments in which to test hypotheses, manipulate variables, and see cause-and-effect in real-time (Adams et al., 2008). Through guided inquiry, students can:

Formulate and Test Hypotheses – By allowing students to predict and test in a virtual environment, PhET simulations promote scientific reasoning and hypothesis-driven learning (Wieman & Perkins, 2005).

Practice Experiential Learning – Kolb's Experiential Learning Theory (1984) states that learning occurs optimally through experience. PhET simulations provide an interactive platform where students can experience physics concepts, bridging the gap between conceptual knowledge and practical application (Lin, Chiu, & Wu, 2023).

Practice Problem-Solving Skills – Inquiry learning promotes higher-order thinking skills because students are forced to analyze results, see patterns, and draw conclusions on the basis of experimental data (Prince & Felder, 2006).

Theoretical models of misconceptions, conceptual change, technology integration, and constructivist learning provide a strong foundation for using PhET simulations in teaching physics. Constructivist learning theory, cognitive load theory, and research on inquiry-based learning underlie the understanding that interactive digital tools enhance the ability of students to comprehend abstract scientific principles, meet misconceptions, and develop problem-solving skills (Duit & Treagust, 2021; Sweller et al., 2019).

University of Education,Winneba http://ir.uew.edu.gh

Through an active engagement with students' misunderstandings, PhET simulations represent a highly effective way of enriching mechanics education. The capability to vary parameters, receive immediate feedback, and see abstract notions makes them superior to traditional forms of instruction via static diagrams and passive presentation (Lin et al., 2023).

Existing research validates their effectiveness in enriching conceptual understanding, improving motivation, and promoting inquiry learning (Finkelstein et al., 2005; Perkins et al., 2023). This evidence justifies incorporating PhET simulations into modern physics education. Execution, however, requires adequate teacher training, digital resource availability, and moderation between technology-aided and lab-based learning (Hewson & Hewson, 2023).

By applying the power of technology and student-centered teaching methods, physics instructors can bridge the gap between intuitive misconceptions of physics students and formal scientific concept, ultimately improving learning in the teaching of mechanics.

2.3 Conceptual Review

Conceptual framework of this study is grounded on four interdependent pillars that are physics education misconceptions, conceptual change, interactive simulations, and inquiry-based learning. These are the concepts that introduce understanding and structure to grasp how PhET simulations operate as an instructional tool to allow students to understand physics, particularly where prior knowledge conflicts with scientific reality.

University of Education,Winneba http://ir.uew.edu.gh

2.3.1 Misconceptions in Physics

Misconceptions are deeply rooted, incorrect ideas which students carry with them to class and have normally acquired through general experience, street smarts, or intuitive reason. Misconceptions in physics education are most prevalent in the field of mechanics, where learners apply common sense about motion and force that go against established science principles (Duit & Treagust, 2021). For instance, there is the popular myth that it takes a continuous application of force to maintain an object in motion. This contradicts Newton's First Law, which states that an object will remain in its state of motion except if subjected to an external force.

These misconceptions are carried beyond formal education as they are ingrained in the cognitive structures of students. Misconceptions, as proposed by Chi (2008), are entrenched and recalcitrant, especially when new scientific solutions are presented without confronting such mistaken beliefs directly. Research has confirmed that unless students derive and reason extensively about their misconceptions, they will automatically resort to intuitive thinking in new problem situations (Redish, 2023; Vosniadou, 1994).

2.3.2 Conceptual Change

Conceptual change is the process whereby learners replace or significantly revise their misconceptions to construct more scientifically accurate conceptions. This process is central to science meaningful learning (Dole & Sinatra, 1998). Conceptual change theories emphasize the cognitive conflict — the moment when learners realize that their former conception is incompatible with observed evidence or scientific explanation.

For conceptual change to occur, students must sense a discrepancy between their current conception and a more accurate scientific representation. This is usually

University of Education,Winneba http://ir.uew.edu.gh

brought about by experiences that challenge their mental models, i.e., simulations, experiments, or real demonstrations (Chi, 2008; Posner et al., 1982). Most effective strategies in inducing conceptual change are analogical reasoning, guided inquiry, metacognitive reflection, and visual aids.

In this regard, PhET simulations play a significant role because they allow students to observe and alter physical parameters, examine outcomes, and reflect upon what they once thought. With the offering of a safe experimental context, simulations promote students to confront the limitations of their misconceptions and so build more realistic conceptual frameworks (Perkins et al., 2023; Wieman & Perkins, 2005).

2.3.3 Interactive Simulations'

Interactive simulations are software on computers that seek to visually and dynamically represent scientific phenomena. In physics education, simulations like those developed by PhET provide learners an opportunity to explore abstract concepts in a more visual and concrete manner (Adams et al., 2008). Simulations are different from static diagrams or figures in textbooks because they offer dynamic representations that respond to students' inputs such that there is real-time feedback and iterative exploration.

PhET simulations build on learning principles tested with research, promoting simplicity, interactivity, and accuracy. PhET simulations particularly lend themselves well to enabling students to test hypotheses, observe non-obvious forces (i.e., friction, gravity), and participate in active learning exercises (Wieman et al., 2010). An example includes a student who studies the relationship of force with motion and is able to experiment using a level of force of various amounts while viewing the accompanying acceleration without equipment present in laboratories.

University of Education,Winneba http://ir.uew.edu.gh

This interactive environment facilitates experimentation and inquiry, which are essential to addressing misconceptions. Furthermore, simulations reduce cognitive load by presenting information in a streamlined, interactive form, allowing students to focus on key variables without being overwhelmed by irrelevant information (Sweller, 2011).

2.3.4 Inquiry-Based Learning

Inquiry-based learning (IBL) is an inquiry-based teaching that encourages students to investigate, observe, and build their own information by questioning, testing, and thinking (Hmelo-Silver et al., 2007). IBL is a reversal of the more traditional approach to teaching where the teacher does the providing of information and the students only consume it. Instead, the students in an inquiry-based setting take an active role in learning, sometimes collaboratively and engaging in higher-order cognitive tasks.

PhET simulations are naturally CIB-friendly by giving students a space where they can vary variables, predict the outcomes, and analyze results. For instance, using a Newtonian mechanics simulation, students can verify the influence of mass, friction, or applied force on an object's motion. It is an imitation of the scientific process and builds important skills such as critical thinking, problem-solving, and data interpretation (Lin, Chiu, & Wu, 2023).

Additionally, IBL encourages students to put their thinking into words and deal with cognitive dissonance when their predictions don't match results seen - a key driver of conceptual change. The collaborative nature of some PhET-integrated lessons also allows for social learning, in alignment with Vygotsky's view of knowledge construction as a socially mediated activity (Vygotsky, 1978).

The concepts of misconceptions, conceptual change, interactive simulations, and inquiry-based learning are all interwoven in the context of modern physics education.

University of Education,Winneba http://ir.uew.edu.gh

Knowledge of these concepts provides a sound theoretical and practical basis for the integration of PhET simulations into the classroom. Through the resolution of students' misconceptions through interactive, visual, and inquiry-based learning, PhET simulations are an effective tool for enhancing conceptual understanding, especially in abstract topics like mechanics. Their alignment with contemporary learning theories renders them highly applicable to resolving current educational problems in science education.

2.4 Conceptual Framework

This conceptual framework anchors on a combination of four important theories in education: Constructivist Learning Theory, Cognitive Load Theory (CLT), Cognitive Conflict Theory, and the Inquiry-Based Learning Approach. Combined, the theories support the rationale for employing PhET simulations as an instructional method to address student misconceptions and enhance conceptual knowledge in mechanics, a subdiscipline of physics typically plagued with entrenched, experience-based misconceptions.

The framework was organized using the Input-Processing-Output (IPO) Model, which processively illustrates learning activity and result flow in implementing PhET simulations.

2.4.1 Input stage: Identification and Preparation

- Theory Foundation: Constructivist Learning Theory

  Supportive Scholars: Shabani (2020); Vygotsky (1978); Tomas et al. (2021)

  In this phase, the preparation needed in order to be able to cope with learners' misconceptions efficiently is highlighted.

University of Education,Winneba http://ir.uew.edu.gh

- Diagnosis of Misconceptions:

  Prior to instruction, diagnostic measures such as concept inventories, guided interviews, and pre-tests are administered in order to identify common misconceptions in mechanics (e.g., the belief that constant force must be applied to achieve perpetual motion, in contradiction to Newton's First Law). These tools take a baseline reading of learning deficits.

- Activation of Prior Knowledge:

  Instruction is aimed at engaging students' existing mental models. By constructivist tenets, students will learn optimally when they can connect new concepts to what they already know, even though it may be faulty. Recognition and development of these intuitive conceptions are vital in order to facilitate conceptual change.

- Selection of Targeted PhET Simulations

  Based on diagnostic results, instructors choose specific PhET simulations (e.g., "Forces and Motion: Basics") that best address identified misconceptions. They choose simulations not only based on content alignment but also due to their interactive and visual nature conducive to conceptual engagement.

2.4.2 Processing Stage: Engagement and Conceptual Change

- Theoretical foundation: Cognitive Conflict Theory (Duit & Treagust, 2021), Cognitive Load Theory (Sweller, 2011; Kirschner et al., 2011), Inquiry-Based Learning (Hmelo-Silver et al., 2007; Kolb, 1984).

  Here, learners work with PhET simulations using activities that challenge prior conceptions and solidify knowledge.

- Interactive Simulation-Based Learning:

  Variables are manipulated, virtual experiments are performed, and immediate feedback is given. Experiential learning and discovery through inquiry are

University of Education,Winneba http://ir.uew.edu.gh

supported by this interactivity. On Kolb's (1984) experiential learning cycle, concrete contact with subject matter results in reflection and restructuring of concepts.

- Cognitive Conflict and Conceptual Restructuring:

  PhET simulations are specifically designed to have inconsistencies between student predictions (based on their errors) and predicted outcomes shown within the simulation. This inconsistency will cause cognitive disequilibrium, a requirement for conceptual change (Duit & Treagust, 2021). Suppose a student would predict that a moving object would stop when the force is removed, but the simulation will illustrate continued motion within a friction-free environment.

- Optimizing Cognitive Load

  PhET simulations reduce external cognitive load by integrating visual, feedback, and interactivity into one setting (Mayer & Moreno, 2003). PhET simulations also improve germane cognitive load because they make learners think, assess, and absorb science concepts. Thus, students can focus mental ability on valuable learning instead of translating complex text or abstract graphs.

- Guided Inquiry and Collaboration

  Guided inquiry is supported by asking questions, encouraging predictions, and facilitating class discussions by teachers. Peer explanations and group work also support Vygotsky's (1978) view of learning as a socially mediated process.

2.4.3 Output Stage: Evaluation and Learning Outcomes

Theoretical Basis: All Theories Integrated

This stage assesses the impact of the PhET simulation intervention.

- Post-Assessment of Conceptual Change

University of Education,Winneba http://ir.uew.edu.gh

Post-tests, reflective journals, and performance tasks are used in order to evaluate changes in students' conceptual understanding. It focuses on identification of changes in patterns of reasoning and misconceptions replaced with scientifically accurate ideas.

- Improved Conceptual Understanding:

  The students should demonstrate a more rational and scientifically valid understanding of mechanics concepts such as inertia, force, and connections to motion.

- Reduction of Misconceptions:

  One of the most significant indicators of the success of the framework is the removal or minimization of misconceptions that the students had previously entertained, e.g., that heavier objects move faster than lighter ones, or that force is required to keep moving.

Enhanced Problem-Solving and Inquiry Skills:

By their active engagement, students develop the skill of forming hypotheses, analyzing patterns, and applying concepts to new situations—scientific thinking and inquiry-based learning traits (Prince & Felder, 2006).

This conceptual model outlines how blending constructivist learning, cognitive conflict, management of cognitive load, and inquiry-based practices with the help of PhET simulations has the potential to generate systematic revision of student misconceptions for repairing scientific knowledge. By identifying pre-conceived knowledge, engaging students in interactive and balanced cognitively aligned activities, and conceptual change assessment, the model presents a sound theory-informed model for enhancing teaching of physics.

University of Education,Winneba http://ir.uew.edu.gh

Below is the summarized conceptual framework that underpins the study which was developed by the researcher:

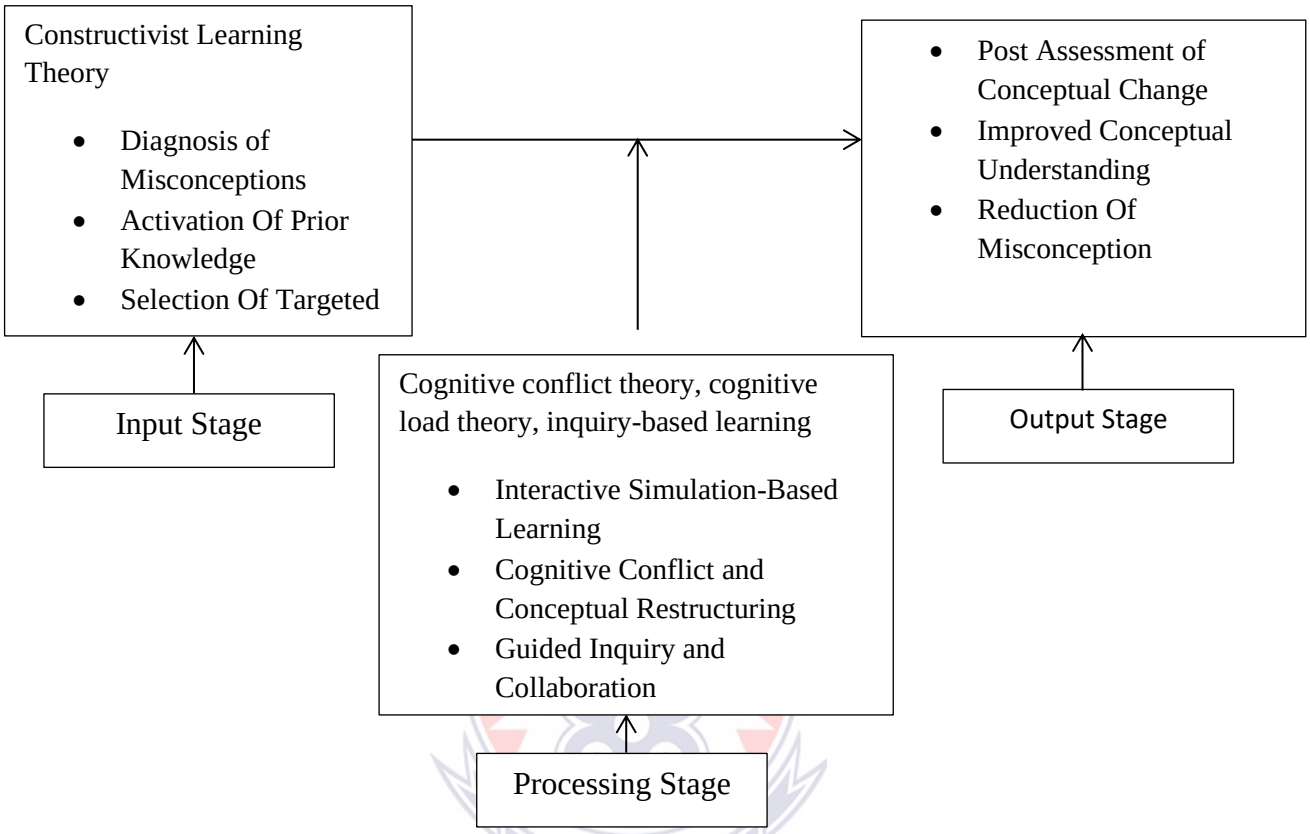


Figure: 1: Conceptual Framework

Source: field study (2024)

2.5 Empirical Review

PhET interactive simulations are globally recognized as new instruments for transforming abstract concepts in physics into active, visual, and interactive learning. To solve persistent misconceptions in mechanics, numerous research has explored utilizing PhET simulations to enhance students' conceptual understanding. This empirical synthesis consolidates recent studies from different educational settings to investigate how PhET simulations function as a remedial tool for misconceptions, particularly in Newtonian mechanics, motion, forces, energy, and related subtopics.

University of Education,Winneba http://ir.uew.edu.gh

This empirical synthesis is organized into five thematic areas. The first subsection (2.6.1) evaluates empirical evidence on the Use of PhET Simulations to Address Misconceptions in Mechanics. The second subsection (2.6.2) explains how PhET simulations decrease the cognitive load by offering simplified, interactive forms of complex physics phenomena. The third subsection (2.6.3) summarizes research investigating the synergy between PhET simulations and inquiry-based learning models in fostering conceptual change. The fourth subsection (2.6.4) is devoted to the integration of PhET into blended learning models, which improves the involvement and performance of students in face-to-face as well as virtual environments. Section (2.6.5) addresses the practical challenges faced by teachers and institutions in implementing PhET simulations in the classroom, including technological, pedagogical, and infrastructural limitations. Finally, section 2.6.6 highlights how PhET simulations contribute to improving students' overall performance in physics.

2.5.1 Use of PhET Simulations to Address Misconceptions in Mechanics

Systematic studies have proven the efficacy of PhET (Physics Education Technology) simulations in eliminating students' misconceptions in mechanics. The interactive software provides dynamic visualizations that oppose intuitive beliefs, resulting in a deeper understanding of underlying physics principles.

Finkelstein et al. (2005) conducted a landmark study at the University of Colorado that investigated the impact of PhET simulations on students' understanding of Newtonian mechanics, force, and motion. Researchers compared students instructed with traditional laboratory equipment to students who used PhET interactive simulations in guided inquiry settings. Results showed that PhET group students had better conceptual understanding, especially on diagnostic assessments such as the Force Concept

University of Education,Winneba http://ir.uew.edu.gh

Inventory (FCI). Surprisingly, these students demonstrated a better understanding of Newton's second and first laws, eliminating typical misconceptions such as the requirement for a force that is applied for a long duration to maintain motion. The interactive nature of the simulations made it possible for students to continually test and correct their preconceptions by observing instantaneous effects of force applications. Moreover, the research emphasized that simulations not only helped in cognitive development but also enhanced student interest and investment in learning, both in accordance with the requirements of constructivist learning as well as inquiry education.

Similarly, Müller et al. (2007) conducted a classroom intervention study in Germany that explored the effectiveness of using interactive simulations in correcting long-held student misconceptions regarding Newtonian mechanics. Their work was on upper secondary pupils who had shown intuitive but scientifically erroneous understandings of motion, primarily that force needs to be continuously applied in order to keep going. Through the introduction of PhET-type interactive simulations as part of standard instruction, students had the benefit of frictionless, idealized worlds in which they could test variables like mass, force, and velocity in real time. These manipulations provided students with instantaneous visual feedback as they could observe that a moving object continues moving with constant velocity if there is no net external force, according to Newton's first law.

This visual encounter with reality led to intellectual conflict, prompting students to think through and consolidate their previous knowledge. Müller et al. had mentioned that the students, post intervention, had very improved conceptual knowledge and were able to define why net force will result in acceleration and constant velocity in the

University of Education,Winneba http://ir.uew.edu.gh

absence of force. The study underscored the fact that the effectiveness of simulations depended not only on their interactivity, but also on the ability of simulations to model abstract physical phenomena in a fashion that is antagonistic to students' misconceptions-an instructional advantage frequently difficult to attain via isolated classroom demonstrations. The authors further determined that interactive simulations are a powerful tool for conceptual change if integrated with inquiry-based questions and teacher-led reflection.

Adams et al. (2008) conducted a large-scale survey in Canada that explored the effect of PhET simulations on students' conceptual understanding of kinematics and dynamics. Their study was on high school and introductory college students who previously demonstrated misconceptions in some of the key concepts of motion, such as velocity, acceleration, and force. The study aimed to test whether interactive simulations could rectify misconceptions and improve conceptual understanding in these areas.

Students using the PhET simulations performed markedly better with regard to ability in correct interpretation and application of principles of dynamics and kinematics. Compared with common educational traditions of either simply using theoretical exposition or employing use of static pictures, the PhET simulations had created dynamic environments with interactive room that allowed mass to be adjusted, initial velocity adjusted, as well as adjusting force and examining instant changes on movement of bodies. This interactive approach allowed students to explore a wide variety of physical circumstances and observe the immediate results of their actions, which assisted them in grasping abstract concepts more concretely.

University of Education,Winneba http://ir.uew.edu.gh

Among the primary advantages of PhET simulations, according to Adams et al. (2008), was the immediate feedback of the tool. When students were altering parameters during a simulation, the resulting alterations were instantly apparent, making students' understanding of relations among different physical quantities more solid. If, for example, they were studying projectile motion, the students would alter the launching angle or speed and see directly how the corresponding alterations affected the path of an object. This experiential learning was particularly helpful in creating true, lasting understanding, because students were able to try out their hypotheses, correct their mistakes, and evolve conclusions through trial and error.

Also, the researchers noted that the simulations fostered a more active learning style, in which students were not passive recipients of information but actively involved in solving problems and thinking critically. Through the provision of a safe and controlled environment within which students were able to make and test hypotheses, the simulations fostered inquiry-based learning and allowed students to gain a richer appreciation of kinematics and dynamics.

The study further clarified the role that PhET simulations played in creating collaborative learning. In a majority of the cases, the students worked together either in pairs or groups consisting of a small number of students, comparing findings, solving problems in unison, and comparing results. This mode of collaboration along with the simulation's interactivity resulted in better and better learning.

Generally, Adams et al. (2008) found that the employment of PhET simulations was of great benefit when it came to improving students' conceptual understanding of physics. By facilitating students to directly interact with and experiment with variables that govern physical systems, the simulations fostered a more experiential and intuitive

University of Education,Winneba http://ir.uew.edu.gh

learning process. The study highlighted the potential of PhET simulations to complement traditional teaching practices and enhance students' learning outcomes in kinematics and dynamics.

Several studies in the African context have highlighted PhET simulations as a tool for addressing misconceptions in mechanics, particularly in Ghana, where Banda et al. (2021) conducted an impressive study. In this research, the authors embedded PhET simulations in the curriculum of senior high school physics. The study specifically addressed projectile motion, which is reportedly a challenging concept for most students since it is abstract. Prior to the intervention, most students thought that horizontal and vertical motions were dependent upon each other, which typically made them confused while solving problems in projectile trajectory.

The PhET simulations provided an interactive and dynamic environment where students could visually adjust variables such as initial velocity, projection angle, and time. Students could clearly distinguish between the horizontal motion, which occurs at a constant speed, and the vertical motion, which is subject to gravity, by real-time observation of the motion of projectiles. This simulation experience allowed students direct observation of how the angle or initial velocity modification influences the projectile range and height without all real-physics laboratory complexities.

Use of PhET simulations reduced immensely misconceptions related to independence of horizontal and vertical motion components of projectile motion, Banda et al. (2021) mentioned. Students who used to struggle with these concepts could describe a clearer understanding, respecting the fact that the horizontal path of a projectile moves uniformly and the vertical one undergoes gravitational acceleration. The authors emphasized how the simulations not only helped the students to better understand this

University of Education,Winneba http://ir.uew.edu.gh

elementary concept but were also enhancing the overall problem-solving abilities of students in projectile motion. This was particularly evident in post-intervention testing, as students had a better ability to solve problems related to simultaneous motion of objects in flight.

Furthermore, the study highlighted the role of simulations in increasing the level of engagement of students. The interactive nature of the tool allowed learners to test different scenarios and solutions, resulting in a richer, more active learning experience. The authors also submitted that PhET simulations filled the gap between theoretical research and practical application, simplifying advanced concepts and rendering them less intimidating for students in poor learning conditions. The study then concluded that PhET simulations are an effective teaching method towards misconceptions resolution in mechanics with a high potential to enhance science education in Ghana and other such African contexts.

Adegoke (2012) carried out a study on PhET simulation application in Nigeria, which showed great improvement in students' knowledge with regard to Newtonian mechanics, particularly on the relationship between force, mass, and acceleration. Students had misconceptions based on their everyday sense prior to intervention, e.g., the idea that heavier objects require more force to push or the belief that one needs to increase the amount of force in order to increase speed. These were deep-seated misconceptions, and students found it hard to comprehend force in a scientific and systematic way. For example, most students did not value the fact that acceleration is independent of an object's mass given a constant applied force, or the fact that an object in motion need not have a constant force to continue moving with a constant speed.

University of Education,Winneba http://ir.uew.edu.gh

Adegoke (2012) utilized PhET simulations in dispelling such misconceptions by making students manipulate variables like force, mass, and acceleration in controlled, simulated environments. Through these simulations, students could see instantaneous results of the effects of changing a variable-like increasing the force applied to an object-on the acceleration with constant mass, or how increasing mass would affect the acceleration with constant force. The interactive nature of such simulations permitted instant feedback, and students could experience the abstract force and motion in ways that simply were not feasible with more traditional instruction. Through this, students were able to clarify their thinking on Newton's second law of motion (F = ma) and realize that force and mass do not necessarily interact in the intuitive manners in which they had initially presumed.

The study showed that the PhET simulations were not only helpful in correcting misconceptions but also in student engagement with the course material. Students who employed the simulations were more likely to participate actively in problem-solving and critical thinking since they could explore the effect of varying physical parameters and test their hypotheses. This process of experiential learning helped to reinforce the conceptual relationships between force, mass, and acceleration and led to more accurate and scientifically consistent internal models. Additionally, Adegoke's study highlighted that the simulations provided students with a visual understanding of these concepts and helped to make it easier for them to digest what they learned. It also helped them apply it to new situations.

In conclusion, Adegoke's (2012) research validated that PhET simulations are able to revolutionize physics education in Nigeria by helping students overcome misconceptions developed over years in mechanics. The ability to experiment and

University of Education,Winneba http://ir.uew.edu.gh

manipulate physical conditions in a simulated world facilitated students in learning complex concepts more effectively, leading to improved learning outcomes and deeper understanding of Newtonian mechanics.

Wambugu and Changeiywo's (2008) research in Kenya evaluated the effectiveness of PhET simulations in removing misconceptions of mechanics among high school students. Similar to earlier studies, theirs focused on the importance of interactive simulations in making abstract physics ideas concrete and comprehensible to students. One of the most fundamental misconceptions they aimed to change was that bodies in motion require a persistent force to maintain a state of movement, one of the most common student misconceptions at odds with Newton's first law of motion, that a subject in motion will remain in motion unless influenced by a force external to itself. Through the employment of PhET simulations in teaching, Wambugu and Changeiywo allowed students to visualize and work with various physical conditions, such as objects moving without forces exerted on them. The simulations provided an interactive and dynamic platform where students were able to witness firsthand that an object in motion continues to keep a constant speed unless a net external force acts on it. This instant visual experience proved to be a powerful means for challenging and confronting students' misconceptions. The ability of students to explore and tinker with these virtual circumstances allowed them to shift their understanding from intuitive, everyday experiences to a scientifically accurate grasp of the laws of motion.

The research also demonstrated the engagement benefits of simulation utilization. Students who used the PhET simulations not only were able to overcome their misconceptions, but they also became more invested in the learning process. The interactive nature of the simulations encouraged students to question, examine

University of Education,Winneba http://ir.uew.edu.gh

alternative scenarios, and test their hypotheses. This discovery approach, where students received instant feedback from what they were doing, encouraged a better understanding of the material. Wambugu and Changeiywo observed that this active learning environment really improved students' retention of their learning since they were more engaged and interested in learning. In interacting with the content in a hands-on way directly, students could develop more accurate mental models of Newton's first law and other fundamental mechanics concepts.

Lastly, Wambugu and Changeiywo concluded that PhET simulations were not only effective in addressing single misconceptions but also promoting overall student interest and learning gain. The ability to visualize and manipulate physical phenomena within a simulated world allowed students to form a more robust conceptual frame, which improved their comprehension and retention of significant physics concepts. The findings of this study underscore the need to utilize technology-enhanced learning tools, such as PhET simulations, to facilitate active learning and clear misconceptions in the study of mechanics.

Uwayezu and Yadav's (2023) study in Rwanda had compelling evidence of the effectiveness of PhET simulations in clearing misconceptions about projectile motion, a subject that proves tricky to students. Most schools, for instance in Rwanda, find it challenging to understand the graphical representation of motion, like the relationship between displacement, acceleration, and velocity. They interpret the variables to interact wrongly and assume that all objects in motion travel in the same direction, regardless of the influence of factors such as the angle of projection and initial velocity. In order to fight against such misconceptions, Uwayezu and Yadav employed PhET simulations in their physics classes, by which students were able to interact with and

University of Education,Winneba http://ir.uew.edu.gh

manipulate the key variables of projectile motion. By manipulating these simulations, students were able to change the projection angle, initial speed, and other parameters and observe the impact of such changes on the projectile path. The simulations provided feedback in real time, which allowed students to test hypotheses and understand how each variable impacted the trajectory of the projectile.

Perhaps one of the greatest strengths of the PhET simulations was the ability to view the interaction of variables in a dynamic, interactive form. Students could see directly the effect on the path of the projectile of changing the launch angle or speed, which was much more powerful than the static textbook diagrams or traditional demonstrations. In addition, through the interaction with the simulations, students were able to explore a range of alternative circumstances, which gave them more flexibility to test their understanding and rule out any lingering misconceptions.

The feedback provided by the simulations was central to helping develop conceptual understanding. Students were able to compare their forecasts with the true outcomes demonstrated by the simulation, which caused them to reflect on and enhance their mental models of projectile motion. This hands-on, visual approach not only helped students grasp the underlying physics principles more clearly but also enabled them to read projectile motion graphs more accurately. They were then capable of relating the velocity and acceleration changes to some aspects of the projectile path, which yielded a more comprehensive and accurate understanding of the concept.

The study by Uwayezu and Yadav identified the efficacy of PhET simulations as an instrument for instruction in advanced physics concepts, especially in contexts where access to standard laboratory facilities is limited. The interactive nature of the simulations provided students with an engaging and intuitive way of learning abstract

University of Education,Winneba http://ir.uew.edu.gh

concepts that might otherwise have been difficult for students to acquire. By allowing the students to experiment and physically manipulate physical variables themselves, PhET simulations helped bridge the theoretical-to-practical understanding gap. This approach not only clarified misperceptions but also enhanced students' interest and motivation and was hence a valuable aid to teaching contemporary physics.

2.5.2 PhET and Cognitive Load Reduction

This part explains some of the studies examining how PhET simulations can alleviate the cognitive load of learning and make physics concepts more accessible and easier to understand. Empirical evidence will show how PhET simulations facilitate schema construction, reduce extraneous cognitive load, and enhance students' learning experience as a whole by making physics concepts more tangible and less cognitively taxing. Studies on different continents provide empirical support for the effectiveness of PhET simulations in minimizing cognitive load in different learning environments. These findings highlight the potential of PhET simulations to maximize cognitive and emotional investment and make learning more effective and enjoyable.

Integrating PhET simulations in creative problem-solving frameworks has reported significant boosts in the cognitive learning outcomes of students as well as in their creative thinking abilities.

Yani and Widiyatmoko (2023) discussed the effectiveness of a PhET-supportive model of creative problem-solving in regards to the knowledge of students in vibration, wave, and sound. The study involved an experimental design with pretest and posttest data, indicating massive improvements in the creative thinking of students as well as in their cognitive learning outcomes while engaged in the PhET-supportive model.

University of Education,Winneba http://ir.uew.edu.gh

PhET simulations provided interactive and graphical models of complex physics phenomena, enabling schema development and reducing cognitive load. By providing the chance for students to manipulate variables and see effects instantly, these simulations facilitated better organization of information and hence reduced extraneous cognitive load and promoted deeper learning. The procedure aligns with cognitive load theory, whereby reducing unnecessary cognitive effort enhances learning efficiency.

Similarly, in a study done by Yani and Widiyatmoko (2023), they demonstrated how PhET simulation-supporting the model of creative problem-solving increased cognitive learning gains as well as students' creativity-thinking abilities significantly. Medium-size effects were presented within the research wherein N-gain results yielded the enhancement of students' creativity-thinking by 56.57% and their cognitive learning achievements by 57.08%. Findings attest that PhET simulation has immense ability to promote active learning along with conceptual understanding to reduce the feeling of cognitive overload.

These studies in aggregate highlight the efficacy of PhET simulations in reducing cognitive load by interactive and engaging learning experience. Through providing simplified complex information and instant feedback, PhET simulations enable learners to focus on key learning activities, which enhances understanding and memorization of scientific concepts.

Syifa et al. (2023) investigated a study exploring how PhET virtual simulations affected students' cognitive structures on diffraction and light interference concepts. The researchers found that the use of these interactive simulations had a profound impact on students' understanding of these abstract concepts. Visualization of wave phenomena and the ability to manipulate parameters such as wavelength and frequency

University of Education,Winneba http://ir.uew.edu.gh

allowed students to interactively explore the material, leading to a greater understanding of the underlying physics principles. By offering immediate feedback and a controlled environment in which students could try and correct variables, the PhET simulations minimized extraneous cognitive load and allowed students to focus on the conceptual nature of the material.

In this study, the researchers emphasized specifically the reduction of cognitive load, especially when contrasted with traditional learning methods, where students might struggle to visualize and comprehend the processes of diffraction and interference. The simulations provided a well-structured environment where students were able to explore the interdependencies between different variables in wave phenomena and thus make schema construction more efficient and reduce the mental effort needed to comprehend complex concepts.

This work draws on earlier work by presenting an example of the manner in which PhET simulations can promote greater, more natural understanding of complicated physical phenomena by breaking them into bite-sized pieces that are digestible by novices. With this method, not only does PhET simulation steer away from cognitive load, but learning also becomes more targeted and potent. During this time, while the students operated the simulations, they were also in a place where they were able to internalize the relationship between the parameters of the waves, and thereby, the action of light and diffraction patterns.

The findings of Syifa et al. (2023) are augmented by the general body of evidence regarding the utility of PhET simulations in countering cognitive load during physics learning. By demonstrating complex concepts in the form of interactive simulations, students can focus on meaningful conceptual learning without the added cognitive

University of Education,Winneba http://ir.uew.edu.gh

burden. This is particularly critical in areas such as diffraction and interference, where student comprehension often depends on their ability to think about abstract concepts. Thus, the study confirms the effectiveness of PhET simulations as a pedagogical tool for supporting both conceptual understanding and cognitive load management in learning physics.

Ng and Chua (2023) examined the effects of PhET simulations on the attitudes of Malaysian students towards learning physics in a fully virtual environment. The study focused on the engagement and cognitive load of students when engaging with virtual simulations, assessing their affective and cognitive responses to the learning process. The findings revealed that PhET simulations significantly improved students' attitudes towards physics by making abstract concepts more accessible and interesting.

The study demonstrated that PhET students were more engaged and interested in the topic since the simulations have the ability to reduce cognitive load. The interactive nature of the simulations allowed the students to visualize complex physics principles such as force, motion, and energy transfer, which helped them understand these principles better. In addition, the virtual learning environment facilitated self-paced learning, and students could experiment and see the effect of their actions immediately. This automatically relieved irrelevant cognitive load, enabling students to focus more on conceptualizing the underlying principles and not the technicalities of the learning process.

The study also highlighted that the students were able to organize information better using PhET simulations, leading to a more integrated understanding of physics principles. This aligns with cognitive load theory, which states that minimizing unnecessary cognitive work enhances learning efficiency as well as persistence.

University of Education,Winneba http://ir.uew.edu.gh

Generally, Ng and Chua's (2023) study endorse the notion that PhET simulations not only better students' conceptual understanding but also yield a more engaging and less cognitively demanding learning experience.

Wu et al. (2021) investigated the application of PhET simulations within a flipped classroom model to explore their impact on cognitive load as well as concept development. Their study aimed at chemistry majors, examining whether the incorporation of PhET simulations decreased cognitive load while simultaneously promoting deeper conceptual knowledge. By inverting the traditional classroom structure, the researchers were able to free students to study content outside of class through pre-lesson tasks, followed by in-class cooperative activities that employed PhET simulations to construct and reinforce basic ideas.

PhET simulations were found in the research to be particularly effective at keeping extraneous cognitive load low. Through the display of students as interactive, graphical depictions of complex chemical procedures, the simulations allowed learners to manipulate and experiment with variables simultaneously, receiving feedback instantly on hypotheses. This experiential, graphical approach put students to work on thinking critically about significant chemical concepts, but not being stuck in complex computation or technical details. The application of PhET simulations within the flipped classroom also encouraged active learning and peer discussion, further reducing cognitive overload through increased collaboration and group problem-solving.

Wu et al. (2021) noted that with decreased cognitive load in this manner, students were able to more readily enjoy more difficult, abstracted content without the weight of cognitively overloading. This approach attested to the efficacy of PhET simulations not only in enhancing conceptual understanding but also in creating a more effective and

University of Education,Winneba http://ir.uew.edu.gh

manageable learning environment. The study is in harmony with cognitive load theory by showing that PhET simulations can reduce unnecessary cognitive overload, thus maximizing learning efficiency and concept retention.

McKagan et al. (2009) investigated the ways in which PhET simulations can help learners manage cognitive load, with a view to reducing germane cognitive load. Germane cognitive load is the effort of mind applied to constructing and internalizing schemas, or the frameworks that allow individuals to better organize and understand new information. Their research showed how PhET simulations played a primary role in the construction of schemas by allowing students to construct dynamic, visual representations of complex physics concepts. Interactive learning mechanism simplified the process for students to link new information with existing knowledge and construct more productive learning and conceptual understanding.

The study highlighted that PhET simulations provided students with immediate feedback, which allowed them to experiment with various physical situations and observe the consequences of their manipulations. This direct contact with the material allowed students to build more robust mental models by reinforcing the relationships between the various variables and concepts. For example, students could manipulate variables such as velocity, force, and mass, observe how variations in these variables affected motion. By engaging in such hands-on exercises, students found it easier to internalize new knowledge, reducing the level of mental effort to understand abstract concepts.

Besides, McKagan et al. (2009) pointed out that the visual nature of the PhET simulations also helped play a significant role in reducing cognitive overload. By illustrating complex ideas with visualizations and interactive models, students were in

University of Education,Winneba http://ir.uew.edu.gh

a position to focus on the key aspects of physics without being distracted by unnecessary details or vague representations. This enabled the students to devote more cognitive efforts towards understanding the underlying concepts rather than struggling to process information.

Analysis by Anselmo et al. (2024), the authors conducted a systematic review that sought to find out the effectiveness of mobile learning tools, including PhET simulations, in enhancing physics education. The review aggregates evidence from various pieces of research conducted that have been focused on the application of mobile learning tools in the instruction of physical concepts.

The article also points out how mobile learning devices, including interactive simulations like PhET, enable students to break free from common misconceptions about physics through hands-on, visual, and interactive learning experiences. Anselmo et al. (2024) found that the devices contributed significantly to deepening conceptual understanding among students, particularly where learning traditionally proved to be difficult, like in mechanics, energy, and electricity. The graphical feedback provided by mobile instruments allows learners to experiment with hypotheses and observe the outcome of their actions, thus supporting active learning and deepening comprehension.

One of the key findings reported in the review was that mobile learning technologies, including simulations, decrease cognitive load for students. By breaking down complicated concepts into interactive elements, these technologies allow students to focus on understanding basic principles rather than memorizing facts. For example, students can observe the movement of objects, the relationship between variables, and

University of Education,Winneba http://ir.uew.edu.gh

experiment with different scenarios in real-time, all of which allow them to construct mental models and solidify their learning.

Moreover, the study revealed that mobile learning tools were particularly useful to enhance student motivation and participation. The availability and flexibility of mobile learning platforms make students self-directed in learning, with possibilities of self-learning and collaborative learning. Being able to access learning content beyond the classroom by means of mobile devices also enhances students' opportunities for practice and reinforcement, leading to higher retention and understanding of physics concepts.

The review also identified some limitations, i.e., the need for adequate teacher training and an adequate technological infrastructure, particularly in low-resource contexts. Despite such limitations, the general finding of the review is that the deployment of mobile learning tools, e.g., PhET simulations, can be a powerful strategy for improving the quality of physics education by reducing cognitive load, improving student motivation, and promoting more conceptual understanding.

Magkouta et al. (2024) examined the effect of teacher-led and student-led interactions with physics simulations on the learning process in their research paper delivered at the European Conference on Technology Enhanced Learning. The study took into account the effect that different modes of engagement with interactive physics simulations, such as those used in PhET, had on the learning outcomes and experience of students during class.

The study centered on two different methods: one where the teacher facilitated the students through the simulation, and another where students worked independently

University of Education,Winneba http://ir.uew.edu.gh

with their interactions with the simulation. The study identified that teacher-mediated interactions were most effective in creating structure and demystifying abstract concepts, especially for students who struggled with physics at first. It would be utilized for real-time feedback, guiding students step by step through the stages of simulation, and determining learners' focus on significant learning outcomes to reduce cognitive overload. It was particularly convenient in creating meaning of abstract aspects and avoiding ambiguity over the results of the simulations.

On the other hand, student-led interactions with the simulations allowed students to explore concepts on their own, which provided them with a feeling of ownership of learning. Students experienced more independent problem-solving and critical thinking, which contributed to the development of deeper conceptual understanding. The study found that this kind of learning enhanced students' problem-solving skills, promoted inquiry-based learning, and facilitated active engagement with the material. Magkouta et al. (2024) observed that the blend of teacher-supported and student-controlled interactions provided the best results. Teacher facilitation of the initial inquiry and provision of guiding support ensured that the students were not overwhelmed, but the student-controlled provision allowed greater involvement and agency. It provided the balance that allowed the students to construct cognitive schemas while minimizing cognitive load and maximizing conceptual knowledge.

The study concluded that combining both teacher-mediated and student-led approaches during the use of physics simulations can maximize the learning experience, where students both enjoy structured guides that they will gain from and are also motivated to engage and solve problems on their own.

University of Education,Winneba http://ir.uew.edu.gh

2.5.3 Inquiry-Based Learning and PhET Simulations

Yuliati, Riantoni, and Mufti (2018) conducted a study to identify the effectiveness of PhET simulations in enhancing problem-solving skills regarding direct current (DC) electricity concepts under inquiry-based learning. The study aimed to evaluate the effect of applying PhET simulations and inquiry-based learning approaches on the ability of learners to solve physics problems. The study was conducted among secondary school students, and electric circuit concepts, current, voltage, and resistance were the areas of interest for the study.

The outcome of this study showed that PhET simulations, when used in an inquiry-based learning setting, had a substantial impact on enhancing the problem-solving capacity of students studying DC electricity. One of the key findings was that students who used the PhET simulations were better able to explore electric circuits, test hypotheses, and examine the interactions between circuit elements. The interactive aspect of PhET simulations enabled the students to obtain immediate feedback so that they could attempt to modify their conception of ideas in the moment. While modifying variables such as resistance, voltage, and current, the students could observe the result of the modification and relate those findings with theoretical concepts in immediate time.

The study also underlined the role of inquiry learning in fostering problem-solving and critical thinking skills. Inquiry learning includes questioning, the development of experimental design, and the testing of outcomes independently, which corresponds with PhET simulations' discovery technique. The learners were more engaged and motivated if they were offered a chance to play around within other scenarios that are present within the simulations because they gained better insights into DC electricity.

University of Education,Winneba http://ir.uew.edu.gh

The process also enhanced their problem-solving skills for complex problems by actively engaging with the learning material and improving conceptual understanding. Moreover, Yuliati et al. (2018) emphasized the role of the inquiry-based learning technique in enabling learners to acquire higher-order thinking. Through the PhET simulations, not only did the students achieve conceptual understanding, but they also improved their problem-solving mechanism and analytical mind. Through this process, the students were encouraged to ask questions, test hypotheses, and think about the consequences, thereby justifying the acquisition of problem-solving abilities in the study of physics.

The study established that PhET simulations used in conjunction with inquiry-based learning can significantly aid students in problem-solving, particularly in subjects of problematic physics concepts like DC electricity. The interactive nature of the simulation allowed the students to see abstract concepts and thereby became better problem-solvers and learners. This research shows that PhET simulations have the potential to be an effective learning resource for physics, particularly with inquiry-based instructional approaches, as it allows for higher levels of engagement, critical thinking, and constructive problem-solving.

Agyei and Agyei (2021) further conducted research to determine the impact of PhET simulations in enhancing students' understanding of physics principles using an inquiry-based approach. The study, as determined by the European Journal of Interactive Multimedia and Education, set out how simulation can be used as a valuable pedagogical tool to guarantee active learning by students, critical thinking, and problem-solving skills—major components of an inquiry-based approach.

University of Education,Winneba http://ir.uew.edu.gh

In the study, the researchers integrated PhET simulations into physics education among a group of senior high school students in Ghana. Students were encouraged to utilize the simulations to explore fundamental physics phenomena such as force, motion, and conservation of energy. With simulation experience, students would be able to graphically vary parameters and immediately observe the effect of their variation in physical systems, which was central to the inquiry-based process. This direct, interactive method allowed students to develop a richer sense of concept and hypothesize and test their ideas against physical phenomena on a simulated space.

Agyei and Agyei (2021) confirmed that students using the PhET simulations demonstrated stronger conceptual understanding than students instructed via traditional methods. The researchers confirmed that the simulations allowed the students not only to grasp intricate physics concepts but also to enhance higher-order levels of interest and motivation towards learning science concepts. By providing an inquiry process, PhET simulations enabled students to question, hypothesize, virtual experiment, and analyze results—all of which are essential skills for scientific inquiry.

Besides, the research environment that PhET simulations provided immediate feedback, and this enabled the students to improve their understanding of concepts further as well as eliminate misconceptions. Interactive simulations promoted active learning as well as problem-solving in which the students developed a better understanding of the laws of physics. This is in line with the central pillar of inquiry-based learning where there is an emphasis on the importance of student-led exploration and critical thinking in learning.

Overall, Agyei and Agyei (2021)'s research exhibits the capability of PhET simulations to support inquiry-based learning within physics education. By the fact that students

University of Education,Winneba http://ir.uew.edu.gh

are able to interactively explore scientific concepts, experiment with hypotheses, and get instantaneous feedback, PhET simulations make it possible to have an interactive and learner-centered learning environment. The study finds that integrating simulation into the study of physics is not only able to enrich students' understanding of complex concepts but also assist in building beneficial inquiry skills essential for lifelong scientific learning.

Drastianti, Dewi, and Alighiri (2023) examined guided inquiry learning with supplementary PhET simulation for improving students' critical thinking skill and reaction rate concept. They researched, in this article in the International Journal of Pedagogy and Teacher Education, how through the combination of the inquiry method and interactive simulations chemistry concept knowledge, especially reaction rates, could be improved.

Researchers integrated PhET simulations as part of guided inquiry instruction in which students were invited to probe and test reaction rate simulations. Students were encouraged to question, develop hypotheses, experiment, and interpret results yet always employ the simulations to map the dynamicity of chemical reactions. Such design facilitated the use of inquiry technique by allowing learners to take control of learning by actively interacting, as opposed to passively learning information.

The study found that students who completed the inquiry-based learning process through PhET simulations demonstrated a dramatic improvement in critical thinking skills and enhanced understanding of reaction rates. The simulations enabled students to see the abstract chemical reaction concepts like concentration, temperature, and rate of reaction, which made them easier to comprehend the underlying concepts. In

University of Education,Winneba http://ir.uew.edu.gh

addition, the immediate feedback that was provided via the simulations allowed it to be easy for the students to identify patterns and test their conjectures in real time.

Drastisianti et al. (2023) concluded that the collaboration of guided inquiry learning and PhET simulations performed best insofar as promoting active engagement, critical thinking, and conceptual understanding. This was not only made possible for learners to test scientific principles in a tangible manner but also for them to learn problem-solving capabilities through the instigation of thinking analytically about the under-study principles. The study accentuates the ability of inquiry models of learning, particularly if supported by simulation, to increase understanding and build critical thinking capabilities in science education.

This study by Yulianti, Zhafirah, and Hidayat (2021) further investigated the effectiveness of guided inquiry learning and PhET simulations as a successful learning strategy to enhance junior high school students' critical thinking ability. The authors particularly investigated the process of how the students engaged with and learned from an inquiry-based learning with interactive simulations in physics education.

Guided inquiry learning is a pedagogy where students are provided with a systematic framework within which they can investigate scientific concepts by questioning, experimentation, and critical thinking. The approach emphasizes a great deal of active participation, where students do not just sit back and listen but are engaged in an investigative process and discovery. The incorporation of PhET simulations into this model enables students to play with physics concepts in an interactive virtual setting, where they have the ability to manipulate variables, test hypotheses, and see the results in real-time.

University of Education,Winneba http://ir.uew.edu.gh

The focus of the research was junior high school students, a very critical stage of their life as a learner, where fundamental scientific concepts in such courses as physics are taught. Use of PhET simulations in this study tried to bridge theoretical concepts with hands-on experience. For instance, students applied simulations in topics involving motion, energy conservation, and forces. Observing a depiction of such concepts in a visual representation, varying variables such as velocity, acceleration, and force, and observing the subsequent effect instantly captured related underlying physical concepts more effectively.

The guided inquiry part of the research involved scaffolding the students' experience by guiding them with questions, prompts, and discussions. Not only did this provide active problem-solving but also allowed for building critical thinking. The students were directed to hypothesize, predict, and justify observations, and this made the learning process more reflective and interactive. Through the simulations, students could attempt and improve their ideas, test situations, and understand how quantities of physical objects relate to each other. Through active learning, students were able to establish a more solid basis for physics concepts, as opposed to the conventional method of teaching, in which students are merely receivers of information.

Moreover, the real-time feedback provided by the PhET simulations was key to clearing misconceptions and solidifying conceptual understanding. By solving the simulations, students got immediate feedback about their actions, which allowed them to identify errors and enhance thinking processes. The trial-and-error process, together with teacher intervention, allowed students to rectify their misconceptions and internalize the correct principles of physics better.

University of Education,Winneba http://ir.uew.edu.gh

The result of Yulianti et al. (2021) study showed findings in that the inquiry-based learning approach with PhET simulation upgraded higher critical thinking ability. The increased problem-solving ability, enhanced analysis of physical phenomena, and increased ability to apply knowledge to cope with novel situations were said by the students. Further, the study concluded that by combining inquiry learning and simulations, the students were more interested in the topic of physics since it offered a chance for them to have a hands-on experience regarding their learning as opposed to being lectured about the topic in the classical sense.

Overall, this study attests to the effectiveness of employing inquiry-based teaching and PhET simulations in enabling improved understanding of physics concepts and enhanced critical thinking capabilities. It is a witness to the growing body of evidence that active learning strategies like guided inquiry, coupled with interactive simulations, can significantly improve students' learning in science education.

Fan (2015) conducted a study to determine if an inquiry-based learning (IBL) model with interactive simulations-PhET simulations, in this case-can be used to increase conceptual understanding among students in physics. The study consisted of 117 tenth-grade Chinese students from four classes at Beijing, China. Students were randomly assigned into two groups: an experimental group that learned from PhET simulations in addition to inquiry-based activities and a control group that was given conventional lecture-based instruction.

The IBL practice utilized in the research was founded on a 5E systematized process that encompassed engagement, exploration, explanation, elaboration, and evaluation (also synonymously called the 5E learning cycle). Experimental group learners throughout the classes were encouraged to create hypotheses, manipulate variables,

University of Education,Winneba http://ir.uew.edu.gh

note effects, and culminate with PhET simulations, particularly with topics such as force, motion, and energy conservation. These exercises supported active participation, careful investigation, and reflection, all of which are highly relevant to the goals of inquiry-based science education.

Pre-test and post-test results revealed that the experimental group scored significantly higher than the control group in conceptual understanding, acquisition of scientific inquiry skill, and confidence in learning. The most robust finding was the reduction of widespread misconceptions. For example, students initially believed that there will always be a force to maintain motion, but through being involved in several simulation-based inquiry activities, they better understood Newton's First Law of Motion.

Fan also pointed out that using simulations decreased abstract physics concepts' cognitive load through graphic, interactive, and prompt feedback allowing the students to bridge the gap between theoretical explanations and actual events. More importantly, the study failed to find any differences in learning outcomes at the statistical level depending on gender and achievement, meaning that inquiry-based simulation instruction was as effective with students of the same sex and of varying levels of achievement.

This study supports the argument of inquiry-based learning via PhET simulations as a successful pedagogy in fostering conceptual understanding and motivation. It supports the argument that if one gives students freedom to investigate, hypothesize, and test physics concepts in an interactive environment, not only do they get rid of misconceptions but also develop a more sustained and transferable understanding of scientific principles.

University of Education,Winneba http://ir.uew.edu.gh

Amri, Herayanti, and Gummah (2024) explored research that aimed to design and implement inquiry worksheets using PhET simulations as a tool to build students' mastery of physics concepts. The research was carried out in the setting of an Indonesian high school where researchers designed worksheets that incorporated the inquiry steps—problem identification, hypothesis formulation, experimentation using PhET, data interpretation, and conclusion—guided by the 5E learning model (Engage, Explore, Explain, Elaborate, Evaluate).

The study used quasi-experimental approach with two groups: an experiment group that used the inquiry-based PhET-enabled worksheets, and a control group that received the traditional instruction in the absence of the simulations. The overall aim was to determine the conceptual mastery improvement in regards to core concepts in physics such as energy conversion, Newtonian laws, and wave behavior.

Findings of the study were that students from the experimental group demonstrated significant increase in concept comprehension through pre- and post-testing. The integration of PhET simulations into inquiry-based worksheets provided a structured but flexible format wherein students could experiment and visualize ideas of concepts. Students were able to manipulate variables, see cause-and-effect, and reflective discussion was enabled through the worksheets. This combination of hands-on computational discovery and question scaffolding helped them to internalize advanced physics concepts better than the students in the control group.

Additionally, the researchers observed enhanced student motivation and engagement among the experimental group, which they explained by the interactive character of the simulations and the active learning environment evoked by the inquiry model. Teachers

University of Education,Winneba http://ir.uew.edu.gh

also experienced enhanced classroom discussion and greater depth of scientific questions being posed by students due to the worksheets.

Finally, the paper highlights that PhET simulations with guided inquiry worksheets are good learning materials that could be used to improve physics concept understanding. Authors are advocates for the broader application in secondary school settings, especially where physical lab facility is not readily accessible.

Pranata (2023) conducted an empirical classroom study that aimed to establish the impact of guided inquiry learning and PhET simulations on students' conceptual understanding of gravitational force. The study was prompted by the realization that students are likely to find abstract concepts in physics, especially phenomena of invisible forces such as gravity, difficult. Conventional pedagogy is not able to relate technical information with experiential knowledge, and this leads to long-term misconceptions, for example, that there is gravity only on Earth or that heavier bodies fall faster than lighter bodies when in a vacuum.

To address such problems, the study employed guided inquiry learning complemented with PhET's "Gravity Force Lab" simulation. The intervention was planned in the five steps of inquiry-based instruction: (1) Engagement, where the students were exposed to real-world problems with gravity; (2) Exploration, where the students used the PhET simulation to manipulate factors like mass and distance; (3) Explanation, where the students presented findings and used conceptual meanings to explain; (4) Elaboration, which challenged the students to use their learning in new contexts; and (5) Evaluation, which included formative and summative assessment.

University of Education,Winneba http://ir.uew.edu.gh

The quasi-experimental study utilized two groups: an experimental group that learned guided inquiry through PhET simulations, and a control group that was instructed with the traditional lecture-based approach. The population utilized was high school students enrolled in a physics course learning Newtonian mechanics.

Pre- and post-test findings showed a statistically significant gain in knowledge of gravitation interactions among the experimental group. Group members had a better ability to describe the inverse-square law of gravitation, forecast the consequences of gravitation in other planetary systems, and eliminate various misconceptions—such as the false belief that gravitational force is a function of object weight rather than mass. Moreover, PhET simulations use enabled interactive visualizations that reinforced the conceptual schemas of students. Students were able to visually perceive the consequences of modifying mass or distance on the gravitational force directly, and this made the physical principles more concrete and easier to remember. Guided inquiry also facilitated collaborative learning since the students collaborated to develop explanations, test hypotheses, and think aloud about their reasoning processes.

The study proved that PhET-supported inquiry learning significantly enhances students' conceptual understanding and permits correction of well-established misconceptions in physics. Pranata emphasized that fusion of inquiry pedagogy with interactive simulations creates an interactive learning environment in support of deep understanding, critical thinking, and long-term retention. It is especially useful in resource-constrained environments where physical lab experiments are not feasible.

Sitindaon, Bukit, and Turnip (2017) studied the effect of guided inquiry learning using PhET simulations on problem-solving ability and critical thinking capability of physics students. Sitindaon and team conducted the research in the setting of Indonesian senior

University of Education,Winneba http://ir.uew.edu.gh

high school, with electricity and magnetism as the learning topic, which is a subject frequently reported as conceptually challenging based on its abstract nature and unseen-ness in everyday life experiences.

The researchers employed quasi-experimental with two groups, an experimental group taught by guided inquiry model infused with PhET simulations, and a control group taught by normal expository instructions. The research population consisted of the students in Class XI of the science stream who were enrolled with cluster random sampling. The two groups received pre-tests and post-tests to assess changes in understanding concepts, critical thinking, and problem-solving abilities of students.

The guided inquiry process utilized by the experimental group was characterized by active student investigation of phenomena through PhET interactive simulations, more specifically those showing electric circuits, magnetic fields, and electric forces. Students were instructed to watch, hypothesize, test hypotheses by manipulating variables in the simulations, and have group discussions as a way to further their comprehension.

The findings showed that the experimental group students outperformed the control group significantly on the critical thinking and problem-solving tests. Simulations provided an interactive learning environment where students could visualize previously concealed phenomena such as the movement of electrons, the interaction of charges, and the effect of resistors in a circuit. Visualization reduced cognitive load and enhanced learners' capacity to make connections between practice and theory.

Furthermore, guided inquiry teaching promoted metacognitive reflection since students had to justify choice-making, debate simulation results, and adapt strategy based on

University of Education,Winneba http://ir.uew.edu.gh

that. Researchers stated that graphical interactivity and interactive engagement of PhET simulations played a special role in the education of abstract concepts in physics and the exercise of deductive reasoning when solving novel problems.

Sitindaon et al. found that the combination of guided inquiry pedagogy and PhET media not only strengthens conceptual knowledge but also strengthens higher-order thinking skills, critical to scientific success. The study verifies the broad thesis that active, student-centered learning models supported by technology such as PhET are more valuable than more conventional lecture-based models, especially in the sciences. Fitriani, Doyan, Taufik, and Wahyudi (2024) conducted research to identify the effect of guided inquiry learning assisted by PhET simulations on the critical thinking skills of students in physics. They were inspired by the growing need to enhance 21st-century skills—particularly critical thinking—of science instruction, in which conceptual concepts tend to be hard for learners to comprehend and engage with.

The study employed a quasi-experimental design of two groups, an experimental group gaining concepts of mechanics through guided inquiry aided by PhET media, and a control group learning based on traditional teaching approaches. The research entailed high school students attaining knowledge of mechanics concepts, Newton's laws of motion. Pre-testing and post-testing were employed as modes of collecting data to measure the attainment of learners' critical thinking skills.

The PhET guided inquiry process used in this research involved systematic inquiry procedures: identification of the problem, generation of the hypothesis, experimentation using PhET simulations, analysis of data, conclusion drawing, and reflection. The interactive nature of the PhET simulations allowed students to

University of Education,Winneba http://ir.uew.edu.gh

experiment and visualize motion situations, forces, and object-object interactions in a virtual and manipulable environment.

The findings identified that the critical thinking capacity of students in the experiment group was statistically significantly greater than that of students in the control group. Students who experienced guided inquiry based on PhET performed better in all the major components of critical thinking, including interpretation, analysis, inference, evaluation, and self-regulation. All these initial gains in critical thinking traits were supplemented by the active involvement of the students in guided inquiry through the provision of instant visual feedback by the computer simulations.

The researchers established that the integration of PhET simulations into the guided inquiry model improved explanation depth of the students, facilitated hypothesis testing, and improved conceptual understanding. The interactive simulations enabled students to test and question their preconceptions and rectify their thought process through evidence-based argumentation. The inquiry model also improved a culture of learning where students became investigators rather than recipients of information.

This study documents the pedagogical value of combining directed inquiry with computer simulation in critical thinking development and contributes to the extensive literature supporting the potential of interactive, constructivist-driven materials such as PhET simulations to enhance student engagement, understanding, and higher-order thinking.

Gloria and Ramnarain (2021) conducted qualitative richness research into physical sciences teachers in South Africa making use of PhET interactive simulations in inquiry-based learning (IBL) settings. The research occurred against the backdrop of

University of Education,Winneba http://ir.uew.edu.gh

more comprehensive science education reform in South Africa demanding greater constructivist, student-centered instructional methods-most notably in schools with a lack or deficiency of traditional lab facilities.

Semi-structured interviews and observations of a purposive sample of physical science teachers from high schools in rural and urban provinces in South Africa were undertaken. The teachers had incorporated simulations to various levels and taught in rural and urban provinces. This assisted in collecting a wide variety of teacher experience and teaching strategies through the use of simulations, especially those created by the PhET project.

Teachers reported that PhET simulations were highly useful in augmenting the inquiry process. In particular, they allowed them to engage students in exploration and visualization of abstract physical concepts-e.g., electromagnetic fields, Newtonian mechanics, and wave interactions-that are often challenging for students to grasp based on textbook instruction alone. The interactive nature of simulations augmented students' inquiry by encouraging questions, hypothesis generation, and variable testing-key characteristics of guided and open inquiry.

One key observation was that students were more actively engaged in the process when working with simulations. Rather than receiving information in a passive way, students were engaged in prediction-testing cycles, adjusted parameters, and read results within an interactive process. For instance, students working on the "Forces and Motion" PhET simulation were able to adjust force and mass and observe direct manipulation of acceleration—so having the ability to learn Newton's Second Law in a highly hands-on way.

University of Education,Winneba http://ir.uew.edu.gh

The instructors noted that by using simulations, students were able to relate abstract physics to ordinary phenomena. The contextualization facilitated by this enabled conceptual change very effectively, particularly for students whose misconceptions had deep roots, i.e., heavier bodies always fall faster or motion always requires a sustaining force.

These didactic benefits in spite of it all, however, the work also cited a few practical demerits. The instructors also complained that the majority of the schools lacked the necessary ICT facilities, such as computers, projectors, or constant internet. Other instructors also complained that they were uncomfortable using simulations because they had not been adequately trained and developed professionally. In spite of all these challenges, however, the value of the simulations was not lost; rather, it emphasized the need for institutional support and capacity building to realize the full potential of such digital tools.

In general, Gloria and Ramnarain argued that PhET simulations are effective motivators for inquiry-based learning, particularly where there is no resource in the education system. They recommended that education policymakers support infrastructure and teacher training, and curriculum developers incorporate more explicitly simulations into national science education systems. The study makes a useful contribution to the now substantial literature on the effectiveness of virtual labs as a tool to enable inquiry, especially in situations where physical labs are not possible.

2.5.4 Blended Learning Models with PhET Simulations

Arifin, Razali, and Rahayu (2023) analyzed how the integration of PhET Interactive Simulations into a blended framework of instruction improved students' conceptual understanding and encouraged them to participate in learning activities in mixed

University of Education,Winneba http://ir.uew.edu.gh

fractions. Conducted in Indonesian primary schools, this study aimed to determine the means through which interlacing computer simulations with traditional face-to-face classroom teaching can enhance more meaningful understanding and participation among learners.

The study began by focusing on mixed fractions, a concept identified to be difficult for elementary school students long ago, typically leading to misconceptions and difficulties with applications in problem-solving. The PhET simulations used in this study allowed students to observe and work with the phenomenon of mixed fractions, changing values and experimenting with different situations in real-time. These simulations also provided immediate feedback, which enabled students to adjust their approach and correct mistakes in real time. The interactivity made the otherwise abstract concept of fractions more tangible and tangible, avoided mental overload, and facilitated an intuitive grasp of the subject matter.

The blended learning model involved both online learning through PhET simulations and instructor-guided conventional classroom teaching. This model allowed students to first learn the material independently through the interactive simulations and then attend in-person classes where they could solidify their knowledge through discussions, group work, and instructor feedback. This allowed students to learn at their own pace, rehearsing areas they struggled with, and also receive immediate feedback from their instructor to clarify questions and solidify their learning.

The results of the study confirmed that students who participated in this combined model of education gained substantially in both their maths attainment and aspiration for the subject. Post-testing results showed students who participated in PhET simulations in addition to conventional instruction scoring higher than those instructed

University of Education,Winneba http://ir.uew.edu.gh

exclusively with conventional methods. In particular, students showed increased skill in problem-solving with mixed fractions, particularly in activities where they had to manipulate and convert between improper fractions and mixed numbers.

The study also emphasized the importance of independent learning in fostering increased understanding. Since the students could use the PhET simulations at their own pace during non-class hours, they could practice and review challenging concepts on their own. This aspect of asynchronous learning benefited students who needed more time to reinforce their understanding, as well as students who wanted to challenge themselves with more complex problems. It allowed all students to learn the material in a way that was most appropriate to their needs and learning style.

Furthermore, the study determined the amplified student engagement which was facilitated through the incorporation of interactive technology and traditional teaching strategies. Students became more engaged and motivated to study mathematics, leading to enhanced classroom participation and retention of key concepts. The PhET simulations-induced active learning atmosphere encouraged students to pose questions, explore alternative solutions, and take responsibility for their learning process.

Overall, Arifin, Razali, and Rahayu's study reaffirmed the effectiveness of blended learning as a learning pedagogy for mastering compound math concepts like mixed fractions. Through blending PhET simulations with traditional teaching practice, the study demonstrated the ways in which technology can be used to support and enrich the learning experience, strengthening conceptual understanding and learner engagement. This process is a show of how blended learning models are capable of enhancing active learning and self-regulated learning, especially in courses that can benefit from interactive visual tools like PhET simulations.

University of Education,Winneba http://ir.uew.edu.gh

In Laurence C. Layson's study (2022), PhET Interactive Simulations was widely applied to online synchronous and asynchronous teaching of science in order to see the impact of the latter on learners' science process skills. The study was conducted with students of Grade 8 of Sto. Niño National High School, Philippines, where a two-group pre-test and post-test was used to evaluate the effectiveness of such simulations in enhancing varied science process skills such as observation, data collection, analysis, and testing hypotheses.

The research aimed to determine whether online learning based on PhET simulations significantly influenced students' inquiry-based learning and science process skills in comparison with face-to-face teaching. Synchronous courses, in which students and the teacher engage interactively at the same time, and asynchronous courses, in which students watch the content at their own pace, were both subjected to experimentation. The results of the study turned out to be a remarkable improvement in the students' ability to execute scientific procedures like the formulation of hypotheses, observation of physical phenomena, and derivation of conclusions from evidence. This was evident from the dramatic increase in their post-test scores compared to their pre-test scores.

Notably, the study proved that there was no statistical difference between the effectiveness of synchronous and asynchronous learning methods when employed together with PhET simulations, with a p-value of 0.057, proving that both instructional formats had similar outcomes in enhancing the science process skills of the students. This finding is particularly important as it establishes the flexibility of PhET simulations for various learning environments, thereby enabling instructors to choose between synchronous and asynchronous approaches based on their logistical needs or student preference.

University of Education,Winneba http://ir.uew.edu.gh

Additionally, the students were greatly satisfied with the simulations and informed that they loved the visual and interactive component of PhET tools as interesting and helpful to assist in achieving the comprehension of complex scientific topics. The students' ability to vary variables, observe changes immediately, and make tests allowed them to experience more of an interactive learning environment that is important to develop critical thinking and problem-solving skills.

Layson's study is among the growing evidence for the integration of PhET simulations into modern education systems, especially in the case of online and distance learning. The study suggests that PhET simulations can be a useful tool in the facilitation of student engagement, conceptual understanding, and scientific inquiry in modes of delivery. The study emphasizes how technology and interactive tools need to be incorporated into learning to enhance outcomes, particularly in an age where online and hybrid models of learning are picking up steam.

Layson determined that PhET simulations need to be incorporated into science education curricula, proposing their application not only in online learning platforms but also in traditional classroom settings. This research shows that educators can utilize these simulations to create a more vibrant, interactive, and efficient learning environment, allowing students to gain the skills needed to excel in science and allied sciences.

Nisa et al. (2021) assessed the impacts of a blended learning model where PhET simulations were used as part of it on the achievement of elementary school students, the example being for a Grade VI science class. The study was conducted in Indonesia and involved combining both online and offline learning approaches, with PhET simulations as one of the main tools for the blended learning approach. This was aimed

University of Education,Winneba http://ir.uew.edu.gh

at satisfying diverse learning requirements of students in a way that allowed them to experience interactive, computer-driven simulations within a flexible, student-led environment while continuing to enjoy old-style face-to-face instruction.

The primary objective of the study was to determine whether applying PhET simulations alongside the conventional teaching methods would assist in enhancing students' understanding of complex scientific principles. The researchers compared two groups: one that was presented with the blended system and PhET simulations and another that was presented with the conventional classroom instruction. Pre- and post-intervention tests were used in measuring students' learning.

The study results showed an impressive performance improvement among students participating in the blended learning program with PhET simulations. The students showed better understanding of the scientific concepts learned through the curriculum, particularly in historically difficult-to-grasp subject matter such as energy transfer, forces, and motion. The simulations provided a dynamic platform for students to experiment and play with variables in real-time, allowing for a visual and experiential learning that fixed intangible concepts.

One of the most significant findings of the study was that the blended learning approach incorporating PhET simulations facilitated active learning. With the simulations, the students were able to experiment with hypotheses, observe consequences, and explore scientific concepts in a way that was more efficient and engaging than in the classroom lectures by themselves. Active involvement with the simulations produced not only better conceptual understanding, but also problem-solving ability and critical thinking on the part of the students. In addition, the blended learning approach allowed students

University of Education,Winneba http://ir.uew.edu.gh

to learn on their own at their own rates, and this brought individualized learning and enhanced overall student motivation.

The study also demonstrated the advantage of blended learning towards improving the interest and participation of students. The interactive simulation nature of the PhET simulations encouraged the students to become more engaged in the process of learning, which created an improved interest in science. Increased engagement resulted in an improved positive attitude towards learning, leading to the overall success of the use of blended learning.

Nisa et al. (2021) concluded that applying PhET simulations within a blended learning environment has the potential to enhance students' learning outcomes to a great degree. The study confirmed that this technique not only improves students' performance academically but also involves active, student-centered learning, which is essential in building problem-solving and critical thinking skills. Through the integration of both digital simulations and traditional classroom instruction, teachers can create a more engaging and effective learning experience for students, particularly in the realm of complicated subjects such as science.

Kurniadi, Handayanto, and Sutopo (2023) highlighted the efficacy of a virtual blended learning model with the use of PhET simulations to foster students' comprehension of complex fluid mechanics concepts. The research was conducted in Indonesia and targeted secondary school students who were struggling to comprehend the complex ideas of fluid dynamics, a subject that is always tricky in a face-to-face classroom environment. The research aimed to determine how the combination of face-to-face instruction with virtual learning through interactive simulations could reinforce a more

University of Education,Winneba http://ir.uew.edu.gh

in-depth conceptual comprehension of fluid-related phenomena and thus the general comprehension of physics by the students.

The blended learning model employed in this study had both online and offline elements. The students received normal classroom lectures, which were supplemented by online learning modules where they used PhET simulations. These simulations provided dynamic visual representations of fluid concepts like fluid flow, pressure, buoyancy, and volume-pressure relation, which made abstract theories more concrete. The virtual environment allowed for the manipulation of several variables, e.g., fluid pressure or velocity, and observation of the impact of such manipulations in real time. This hands-on experience with the virtual models helped students gain a more intuitive understanding of how fluid dynamics work in various conditions.

The study put respondents into two groups: the experimental group, where they were instructed using the virtual blended learning model with PhET simulations, and the control group, where a more conventional instruction-only approach was used. Both groups were administered pre- and post-tests to identify their conceptual knowledge of the fluid mechanics concepts. The pre-test served to provide baseline knowledge among students, while the post-test served to ascertain conceptual mastery after intervention.

The research results indicated that the group that had been exposed to PhET simulations as part of their blended learning experience had significantly better conceptual understanding of fluid dynamics compared to the control group. More specifically, students in the experimental group had a much better grasp of key principles such as Archimedes' principle, fluid pressure, and Bernoulli's principle after exposure to the simulations. The ability to test and visualize how a change in a single parameter-a fluid

University of Education,Winneba http://ir.uew.edu.gh

pressure or velocity, for instance—would change the behavior of the system was found to be highly effective at solidifying students' understanding of these abstract concepts. Further, the study indicated that PhET simulations served to reduce cognitive overload. Fluid mechanics is a subject that involves students grappling with abstract concepts that aren't easily discernible in everyday life. However, the dynamics and interactivity of the PhET simulations helped students absorb these abstract notions in small chunks. As they could see how different variables impacted fluid behavior, students were able to focus more on conceptual understanding of the topic at hand without the distraction of unnecessary information. This reduction in cognitive load allowed a more focused and meaningful learning experience.

Furthermore, the study revealed the impact of the virtual blended learning model on motivation and engagement of students. The interactive nature of the simulations provided students with the opportunity to try out physics concepts in an interactive and self-paced manner, and this encouraged further inquiry and independent learning. The ability to manipulate variables and receive immediate feedback not only enhanced learning fun but also cultivated essential thinking and problem-solving skills. These elements of fun and control are imperative in enhancing the long-term retention of material among students.

The authors concluded that the use of PhET simulations within a virtual blended learning model significantly enhanced the comprehension of fluid mechanics concepts among students. By combining interactive simulations with traditional face-to-face instruction, the approach allowed students to visualize and engage with physics in a way that traditional methods could not. The study emphasized that the virtual blended learning model is particularly valuable for learning complex and abstract concepts, like

University of Education,Winneba http://ir.uew.edu.gh

fluid mechanics, where visualization of phenomena is central to understanding. This approach, the authors sustained, can be applied to other areas of physics education, rendering learning more enjoyable and effective for students in other subjects.

Lastly, Kurniadi et al.'s (2023) research provides us with a helpful insight into how PhET simulations can be utilized to enhance the learning and teaching of physics concepts, particularly in a blended learning environment. The study shows that by integrating technology into instruction, particularly in subjects that require conceptual visualization, educators can make the learning process interactive, enjoyable, and effective that not only improves the understanding of the topic by the students but also enhances skills such as problem-solving and critical thinking. The success of this virtual blended model of learning in this study can possibly provide a blueprint for the future practice in other areas of science education where similarly abstract and difficult concepts are to be learned.

Wieman, Adams, and Perkins (2008) present a landmark and revolutionary paper highlighting the tremendous potential of Physics Education Technology (PhET) simulations in revolutionizing science education, particularly in teaching and learning physics. The authors, who are pioneers in physics education research, developed PhET with the dream of making the invisible visible and making abstract scientific concepts more intuitive and accessible to students at all levels of education.

The article, published in Science, explores both the theoretical underpinnings and practical applications of PhET simulations. The authors argue that traditional teaching methods often fail to make students understand deeply ingrained concepts in physics due to the intangibility of the subject matter, lack of interactivity, and linear

University of Education,Winneba http://ir.uew.edu.gh

presentation of knowledge. PhET simulations were created to fight against such limitations by making learning interactive, dynamic, and rich in visuals.

One of the fundamental aspects of PhET simulations is that they are founded on research-based design. Wieman et al. describe how the simulations are grounded in learning theories, primarily constructivism, which argues that learners actively construct knowledge through experience and interaction. The simulations promote active learning because they allow students to manipulate variables, test hypotheses, and observe outcomes in real time. For example, in an energy conservation simulation, students can change the mass or height of an object and immediately observe the impact on kinetic and potential energy, promoting intuitive learning and meaningful connections.

One of the strong points of this study is that it highlights the minimization of cognitive load, a basic principle in educational psychology. As authors explain, PhET simulations are designed with the goal to eliminate extraneous cognitive load-by removing irrelevant information and distracting elements-and focus on the core ideas that learners are supposed to learn. In addition, simulations also support germane cognitive load by helping students develop schema through visual cues, feedback, and exploration. This approach enables students to move from surface to deeper conceptual understanding.

PhET simulation efficacy was validated by rigorous empirical research. The authors reported large student gains in conceptual understanding in a number of studies and institutions. For instance, when comparison studies were done with one group of students learning through PhET simulations and the other through conventional teaching, the simulation group consistently scored higher on concept tests such as the Force Concept Inventory (FCI). The gains were attributed to the fact that the

University of Education,Winneba http://ir.uew.edu.gh

simulations bridged the gap between theoretical comprehension and real-world phenomena, especially in abstract topics such as electric fields, quantum mechanics, and energy systems.

Moreover, the simulations were found to enhance student motivation and engagement. Students described the simulations as enjoyable, user-friendly, and helpful in visualizing difficult concepts. Teachers also noted that class participation and the quality of student inquiry were enhanced when simulations were included in lessons. The simulations allowed for a low-risk environment where students could try things out without fear of failure—a key element in encouraging exploration and fostering scientific thinking.

Wieman et al. (2008) also highlighted the accessibility and scalability of PhET simulations. Because they are free online, these tools are especially valuable in under-resourced schools or countries where laboratory equipment may be limited or nonexistent. This reduces the barrier to high-quality science education and allows teachers worldwide to provide high-quality, interactive instruction at minimal cost.

In summary, Wieman, Adams, and Perkins (2008) is seminal evidence that PhET simulations are more than just visual aids but are dense pedagogical tools that support learning through interaction, visualization, and inquiry. By grounding the simulations in educational research and iteratively refining them based on feedback and research, the authors have developed a resource that has impacted physics education globally. Their work continues to influence curriculum development, teacher training, and student learning in diverse educational contexts.

University of Education,Winneba http://ir.uew.edu.gh

Putranta and Kuswanto (2018) conducted a significant study for the development of critical thinking skills of senior high school students through a hybrid learning model based on Problem-Based Learning (PBL) and PhET interactive simulations. The research was implemented in Indonesia and followed a quasi-experimental approach with a comparison of an experimental group learning through PBL with PhET simulations and a control group learning through conventional lecture-based instruction.

The research revealed that the experimental group students showed outstanding development in critical thinking, particularly in problem formulation, argument assessment, and coming to logical conclusions. The development was measured through pre-test and post-test, which revealed that the use of PhET simulations with the PBL model surpassed the traditional teaching approach in promoting higher cognitive thinking to a larger extent.

The study emphasized that the blended learning environment, which combined both online and face-to-face elements, offered a flexible and interactive learning process. In this environment, students used PhET simulations not only in class but also independently at home, with the ability to review physics concepts several times at their own pace. This independent learning aspect of blended learning assisted in maintaining ongoing engagement and knowledge retention.

PhET simulations offered visual and interactive illustrations of intangible physics notions like Newton's laws, motion, energy, and electricity. This enabled students to try out hypotheses, view results, and make inferences in a way that resembles experimentation in the real world. The simulations also lessened the cognitive load

University of Education,Winneba http://ir.uew.edu.gh

through the simplification of complicated processes into intuitive animations, which helped students create mental representations of scientific phenomena.

Moreover, the PBL component forced students to resolve real-world physics issues by working together, thereby fostering communication, collaboration, and critical argument—essential competencies in scientific research. The incorporation of simulations in this setting supported students' abilities to connect theoretical concepts to real-world applications, leading to improved concept mastery and problem-solving. Putranta and Kuswanto concluded that blended learning with the use of PhET simulations is an effective instructional approach, especially for developing higher-order thinking and inquiry-based understanding. The study supports the more specific assertion that technology-supported pedagogies, if carefully blended with constructivist models of instruction, can enhance traditional physics teaching to be more active, efficient, and student-centered.

Assawaphum, Premthaisong, and Chaipidech (2023) conducted an interesting study on the analysis of the utilization of blended learning models integrated with PhET simulations in teaching and learning mathematics, particularly the topic of fractions. The research was carried out at the International Conference on Computers in Education and aimed to determine whether the application of interactive simulations within a blended approach had the potential to raise the interest, understanding, and performance of learners in math concepts that are normally abstract and difficult to understand for primary school and lower secondary school level students.

The study adopted a quasi-experimental approach, in which two batches of students learned the same topics of fractions-i.e., equivalent fractions, addition and subtraction of fractions, and comparing fraction values. The experimental group was exposed to a

University of Education,Winneba http://ir.uew.edu.gh

model of blended learning by combining face-to-face learning with digital resources, namely the PhET Interactive Simulations, while the control group received traditional classroom learning without using any digital tool. The PhET simulations used in the study offered dynamic, interactive representations of fractions that allowed students to see how fractions are constructed, decomposed, and compared through colorful and interactive interfaces.

Pre-test and post-test assessments were used for assessing conceptual understanding, problem-solving correctness on fractions, and application of knowledge to novel situations. The findings revealed that the experimental group of students had a significant improvement in their cognitive capacity, as evidenced by the experimental group's higher post-test scores when compared with the control group. Further, the study revealed that students using PhET simulations were more motivated and interested in the subject. The visual and interactive nature of the simulations reduced the cognitive load that is typically associated with learning fractions, especially for students who struggle with abstract mathematical symbols and processes.

Further, the study was also aimed at understanding how blended learning facilitated student-centered and personalized learning. The use of PhET simulations allowed students to learn at their own pace according to individual needs, revisit simulations as and when needed, and experiment with different scenarios to reinforce learning. Instructors also benefited from the model, with the simulations being excellent instructional support that were able to plug holes in pre-knowledge and allow for formative assessment by observing student interaction with the simulations in real time. The researchers concluded that the use of PhET simulations within a blended learning environment is highly effective at facilitating meaningful conceptual learning. The

University of Education,Winneba http://ir.uew.edu.gh

approach encourages active learning, improves conceptual retention, and builds essential 21st-century skills such as problem-solving, critical thinking, and independent learning. The findings suggest that blended learning with PhET simulations is an effective and innovative approach to not just science but also mathematics and other disciplines where visualization and conceptual manipulation are significant.

Benta and Wiyanto (2024) study sought to analyze the effectiveness of a blended learning model incorporating PhET simulations and physical props in enhancing the conceptual understanding of physics concepts, specifically the topic of Work and Energy, among students. The study was conducted among secondary school students in Indonesia and attempted to determine how the integration of digital tools and physical learning materials could boost both the engagement and conceptual understanding of students.

In the study, the researchers divided the students into two groups: a control group and an experiment group. The experiment group was subjected to the blended learning model, which involved the use of PhET simulations and the use of physical objects such as springs, pulleys, and weights to model the concepts of force, work, energy, and motion. These props were created to help students visualize abstract concepts by means of concrete, hands-on activities. The control group, however, received traditional instruction without the use of these learning tools, with textbook descriptions and lectures alone.

PhET simulations were at the center of the intervention because they introduced students to interactive, visual representations of physical phenomena in which they could experiment and manipulate variables such as force and energy in virtual laboratories. The simulations enabled students to test these variables, observe the

University of Education,Winneba http://ir.uew.edu.gh

changes that took place, and immediately see how an alteration in one part affected the entire system. This instant feedback was priceless in helping students understand the basic concepts of energy conservation and transfer.

In conjunction with the computer simulations, the physical props in the experimental group allowed the students to have an additional level of learning by grounding the virtual world with tangible, real-world experiences. For instance, students used springs to represent energy storage, and pulleys to model the mechanical advantage of a system. By using these props, students could relate the theoretical knowledge from the simulations to the physical world surrounding them.

Its effectiveness was gauged through pre- and post-tests that assessed the students' conceptual understanding of Work and Energy. The results indicated that the experimental group learned significantly better than the control group in understanding and application of physics concepts. Not only did the experimental group enhance their explanations of concepts such as the conservation of energy, but they also demonstrated a better ability for the application of the concepts to problem-solving contexts, showing that the blended learning approach facilitated a more meaningful grasp of the content.

This study highlights the potential of a blended learning model in bridging the gap between virtual simulations and hands-on activities in bringing students a combined and engaging learning experience. The combination of PhET simulations and physical props enables students to interact with abstract representations and tangible models, thereby enriching their understanding and retention of complex scientific phenomena.

Moreover, the research contends that the approach can be particularly valuable in physics education, where it is difficult to visualize and handle abstract concepts like energy transfer and force. Blending virtual simulations with real experiments allows

University of Education,Winneba http://ir.uew.edu.gh

students to bridge theory and experiment, reinforcing their understanding of basic concepts. The findings of this study contribute to the overall body of research on blended learning and assist in the growing trend of more interactive and engaging learning environments in science classrooms.

In conclusion, the paper by Benta and Wiyanto presents a sound case for the use of blended learning models that mix PhET simulation use with the use of physical props. It contends that this can significantly enhance students' conceptual understanding, engagement, and problem-solving ability in physics, which can eventually result in a more effective and enjoyable learning experience.

Radulović et al. (2023) investigated the impact of a blended learning approach (BLA) incorporating the utilization of PhET simulations on students' motivation in learning physics. The study, conducted with 128 high school students in Novi Sad, Serbia, aimed to find out how a combination of interactive simulations and traditional teaching may influence student motivation and engagement in direct current learning.

The study divided the students into two groups: an experimental group, to which the blended learning model was applied, and a control group, to which traditional teaching methods were applied without the use of simulations. The experimental group was exposed to instruction in which PhET simulations were integrated into the learning experience to allow the students to visualize and interact with abstract concepts in physics, like circuit behavior and current flow, in a more intuitive and dynamic way. The control group, meanwhile, underwent the conventional method of learning through textbook, lecture, and problem-solving drills.

University of Education,Winneba http://ir.uew.edu.gh

The findings indicated that the experimental group manifested a notable enhancement in their motivation to learn physics, particularly in the components of self-efficacy—students' perception that they can succeed in physics tasks—and the perceived value of studying the subject. These students were more secure in their knowledge of physics principles and enjoyed the class more. The interactive PhET simulations provided instant feedback, allowing students to experiment with different variables and see real-time effects, building a greater sense of engagement with the content.

Specifically, the study identified that students who were female and students who had less prior academic achievement showed the most improvement in motivation. Such students struggled more with physics and were more likely to be frustrated with traditional methods. However, the use of PhET simulations appeared to bridge the gap through the provision of an interactive way of accessing abstract concepts and building confidence. This suggests that blended learning, in this case through simulations, can be an effective way of addressing gender disparities and helping students who are in danger of disengaging with the subject.

In addition to that, the study showed the experimental group also had a higher sense of ownership of their own learning. The interactive nature of the simulations, whereby students were able to manipulate variables and observe the results, facilitated active learning and independent learning. This aspect of blended learning allowed students to learn problem-solving and conceptual understanding of physics at a deeper level since they were able to test different situations and try out hypotheses.

The authors concluded that blended learning, especially if augmented with interactive simulations like PhET, is an efficient method for enhancing student motivation and engagement in learning physics. The article advocated the integration of such

University of Education,Winneba http://ir.uew.edu.gh

technology-based approaches into mainstream instruction, especially for topics that students have historically found difficult, like electricity and circuits. By providing students with an active learning experience that intermingles theory and interactive practice, teachers can help develop a more engaging and accessible learning process.

Furthermore, Radulović et al. (2023) recommended that educators and instructors endeavor to incorporate PhET simulations in online and traditional classrooms since the flexibility of blended learning models facilitates a more individualized mode of instruction. Using simulations, students receive immediate feedback and can learn at their own pace, and thus, better retention of concepts and long-term conceptual mastery are promoted.

In conclusion, this study contributes to the cumulative body of evidence of the effectiveness of blended learning with PhET simulations in enhancing learning outcomes and student motivation in physics. The fact that it has a positive impact on the engagement of students, especially students who would otherwise struggle with the subject, points to the potential of these types of educational tools in making learning more accessible and inclusive.

Najib, Yaacob, and Md-Ali (2022) investigated the effectiveness of incorporating PhET interactive simulations into a blended learning model of secondary school physics education. The research was conducted with the objective of overcoming chronic challenges faced by students in acquiring challenging concepts of physics, as well as fostering greater student motivation and engagement.

The background to the research was secondary school students who often struggle with abstract physics principles such as force, energy, and motion. The traditional methods of instruction, which involve lectures and textbooks, were not considered sufficient to render such principles relevant and understandable. The researchers were of the opinion

University of Education,Winneba http://ir.uew.edu.gh

that the use of PhET simulations in a blended learning environment could account for this discrepancy by providing a more active and stimulating way of learning.

Blended learning, as envisioned in this study, is a combination of normal face-to-face learning with online activities. The hybrid model offers greater flexibility and personalized learning, and the PhET simulations offer a visual and interactive supplement to normal lessons. PhET simulations, offering dynamic visualizations of physics phenomena, allow students to alter variables and observe the implications in real-time, making abstract concepts more tangible.

There was a pre-test and post-test design in the research to identify how effective the blended learning approach was on the academic performance of the students. The students in the experimental group were exposed to a series of physics lessons using the PhET simulations as part of their regular classroom instruction, while the control group underwent conventional teaching without the utilization of simulations.

Results revealed that students in the experimental group showed significant improvement in their conceptual grasp of the big physics ideas. Their scores in the post-test were considerably higher than in the pre-test, revealing that the PhET simulations were effective in enhancing their conceptual understanding. The interactive nature of the simulations allowed the students to engage actively with the content, experiment with different variables, and see the effects in real time. This practical method assisted students in going beyond mere memorization and developed a more meaningful understanding of physics concepts.

In addition to the improvement in academic performance, student motivation and engagement were also examined in the research. Students reported more interest and enthusiasm when learning physics through the PhET simulations. They enjoyed the interactive and visual simulations, which made learning physics more enjoyable and

University of Education,Winneba http://ir.uew.edu.gh

less intimidating. The majority of students also reported that they felt more confident that they could learn and use physics concepts after using the simulations.

The study also highlighted the advantages of the blended learning model itself. The students liked the flexibility of it, as it allowed them to learn at their own pace and review difficult concepts through the use of the online simulations. The model took the best of both worlds—providing the structure and support of face-to-face learning and allowing students to explore and learn about the material independently through the online component.

Furthermore, the study pointed out how blended learning using PhET simulations had the potential to promote a learner-centered approach to learning. The interactive simulations promoted active learning, where the students were the explorers who experimented with hypotheses and observed outcomes, leading to better retention of the material and greater comprehension of the physics underlying it. The approach also facilitated collaborative learning because the students could learn in groups while they worked on problems and exchanged the findings of their simulations.

Based on these findings, Najib, Yaacob, and Md-Ali concluded that the use of PhET simulations in blended learning environments could enhance the understanding of physics concepts and the desire to learn among students. They recommended that educators incorporate such interactive simulations into teaching to render learning more effective and interesting. More studies on the long-term impact of blended learning with PhET simulations were also called for by the paper, and it put forward the idea that such models could be extended to other subjects and levels of education. By embracing technology-based learning approaches, teachers could more effectively

University of Education,Winneba http://ir.uew.edu.gh

serve students' varying needs and ready them for achievement in a world led by technology.

2.5.5 Challenges in Implementing PhET Simulations

Laurence (2022), in a Philippines context, investigated integration of PhET simulations into synchronous and asynchronous science learning online on students' science process skills. While the study confirmed the benefits of simulations in science instruction of inquiry, visualization, and enthusiasm, it also unveiled severe challenges in effective integration.

Among the most prevalent challenges that were witnessed included a lack of technological infrastructure, especially for rural or under-resourced public schools. Students did not use computers or laptops but mobile phones, which were not completely capable of interacting with feature-rich PhET simulations. This device limitation made students unable to fully be able to manipulate variables, visualize intricate models, and interact with the simulations to their full, especially in asynchronous sessions where teacher support could not be offered in real time.

In addition, connectivity problems were the biggest hurdle. Success with online PhET-based lessons-particularly during the COVID-19 pandemic when online learning became the new norm-hinged on speedy and consistent internet connectivity. Students with slow or interrupted connections would likely face frequent interruptions in loading simulations, thereby leading to frustration and disconnection. Asynchronous learners particularly were left to self-calculate and review simulations within a timely manner without the immediate feedback of the instructor.

University of Education,Winneba http://ir.uew.edu.gh

Teacher problems were also discovered by the research, namely lack of confidence and competence in using PhET tools effectively. Most teachers, while wanting to innovate, lacked proper training in the use of simulations as part of inquiry-based pedagogies. Some could not relate simulations to specific curriculum outcomes or design complementary learning activities that would promote deeper learning. Lacking proper professional development, the simulations were, at times, applied in too simplistic a fashion, with their pedagogical potential untapped.

Furthermore, student activity and responsibility became top priorities with asynchronous modes. Although PhET simulations are meant to be student-led and self-paced, Laurence determined that when they were not accompanied by structured direction-via inquiry sheets or video lectures-students simply clicked passively through simulations. This open-ended participation squandered opportunities for reinforcement of ideas and intellectual analysis.

Finally, simplicity of instructions and language were also mentioned as minor but significant problems. Certain PhET simulations' English-only interface was difficult for some students to handle, particularly in environments where English was not the primary language of instruction. This sometimes-caused confusion or misinterpretation of simulation components, diminishing learning effectiveness.

Laurence (2022) concluded that schools must address infrastructural requirements, engage in certain teacher training, and devise support materials leading the student exploration to enable successful integration of PhET simulations, especially in online or blended learning environments. This action would narrow the gap between simulations' potential and classroom use.

University of Education,Winneba http://ir.uew.edu.gh

Salame and Samson (2019) examined the application of PhET simulations in United States general chemistry lab courses, presenting an overview of pedagogical benefits as well as challenges to students and instructors in applying computer simulations in regular science classes. The researchers engaged undergraduate students enrolled in a general chemistry course where PhET simulations were used as an adjunct to lab instruction and conceptual understanding.

Although the researchers noticed that simulation promoted students' engagement and helped them visualize abstract concepts of chemicals such as molecular interaction and energy transfer, they also noted some problems during the process of implementation. On one of the major concerns listed, student resistance to alternative learning technology, students first were skeptical regarding the instructional value of simulations and had a preference instead for hands-on laboratory experiments which they perceived as more "real" or more scientifically challenging. Resistance was partly due to unfamiliarity with computer-based learning environments and belief that simulations could not provide the haptic presence of physical laboratories.

The study also identified that instructor preparation and preparedness were a primary issue. Some instructors lacked the technical proficiency or confidence to effectively integrate the simulations into the curriculum. This created inconsistent usage patterns and superficial adoption of the simulations at times, diluting their intended benefits of inquiry-based learning.

Furthermore, time constraints within lab schedules limited the extent to which students were able to experiment with the simulations. In a very structured lab period, students did not have sufficient time to test several variables in the simulations or consider

University of Education,Winneba http://ir.uew.edu.gh

conceptual importance of visualizations. Thus, some potential cognitive benefits from the use of PhET were not achieved.

The second issue that the authors recognized was that there was a need for guided guidance. While PhET simulations were designed to be employed in an exploratory, student-directed style, the researchers found that unless activity worksheets containing step-by-step guidance or instructor facilitation were provided, students utilized the simulations either passively or without conceptual relevance to the underlying chemistry principles. This highlighted a need for scaffolding guidance to organize students' investigations.

Salame and Samson (2019) emphasized that, although PhET simulations have the potential to extend laboratory learning by interactive, graphical representations of dynamic and microscopic events, their teaching effectiveness requires pedagogical planning, student readiness, and integration into the curriculum. They encouraged the use of simulations to augment, rather than supplant, conventional laboratories and proposed professional development workshops to initiate instructors into using these tools.

Salame and Makki (2021) oriented their study towards the implementation of PhET simulations within a general chemistry course with an attempt to assess the influence of the simulations on the students' attitude toward learning as well as on their grades. The authors observed that chemistry as one of the countless abstract topics proves to be often challenging for the students to learn. In particular, abstract concepts such as atomic theory, molecular structure, and chemical reaction are difficult to visualize and understand through traditional, lecture-based teaching. PhET simulations, however,

University of Education,Winneba http://ir.uew.edu.gh

came up with an effective solution by enabling interactive and graphical models of such abstract concepts to be made available.

The study proved that students who were using PhET simulations had much higher conceptual knowledge of significant chemistry concepts than those who were undergoing traditional instruction. The interactive aspect of the simulations allowed students to change variables like temperature, concentration, or pressure in chemical reactions and view the effect in real-time. This hands-on ability allowed the students to comprehend the chemical process involved in a more holistic, intuitive way, which is generally hard to achieve from simple textbook reading.

Besides, the researchers found that the use of PhET simulations had a positive effect on students' attitude towards studying chemistry. Students reported enhanced motivation and interest since they were more involved in their studies. The majority of the participants reported that the simulations made abstract concepts tangible and learning fun. By visualizing phenomena previously difficult to visualize, students developed a greater appreciation of the subject, intrinsic as well as extrinsic motivation. Moreover, the study revealed that PhET simulations not only improved students' knowledge but also positively affected students' belief in themselves as capable of doing chemistry. This effect was considerable in the sense that the simulations allowed students to learn concepts at their own pace, reinforcing their learning and providing them with instant feedback, which is crucial for mastery development.

In learning outcomes, the research confirmed that students who employed PhET simulations performed better on retention of chemistry concepts. The interactive simulation provided a more stimulating environment for students to relearn concepts with enhanced long-term retention as well as students' capacity to make better

University of Education,Winneba http://ir.uew.edu.gh

connections between theoretical concepts and their practical applications in the real world. This supports the contention that simulation-based learning is potentially a good answer to improving concept knowledge and student performance in the challenging subject matter of chemistry.

Salame and Makki (2021) also discussed the broader implications of their research to science education. The utilization of PhET simulations during lessons was perceived to enhance academic performance alongside fostering a positive attitude toward learning science. From the study, it was evident that learners are more inspired and self-assured if they can be encouraged more to utilize challenging material and continue learning the subject. Therefore, the study focuses on adopting technology-supported pedagogical methods like PhET simulations in progressing towards enabling ease in achieving science literacy and critical thinking among students.

In totality, Salame and Makki (2021) research offers strong evidence that PhET simulation use can enhance students' conceptual understanding of chemistry while developing positive attitudes towards science learning at the same time. This suggests the potential of simulations as an empowering influence on science learning with the capability to influence cognitive and affective learning outcomes as well.

Moore and Perkins (2018) discussed the creation of PhET interactive simulations, more particularly their interoperability and accessibility, within the context of their integration into science and engineering education. In their chapter, they discussed how PhET simulations have emerged as an increasingly effective and accessible means of teaching complicated scientific concepts. The authors talked about the technological advancements that have made PhET simulations more platform-independent and accessible to more students regardless of their individual needs.

University of Education,Winneba http://ir.uew.edu.gh

One of the significant advances covered in the paper was the increased interoperability of PhET simulations. These have been made device-compatible over the years with various devices, such as desktops and tablets, and can now be easily integrated into various learning management systems (LMS) and learning platforms. This is convenient for incorporating PhET simulations into various learning environments, so that the simulations can be used just as well in regular classrooms as in online learning setups.

Moreover, Moore and Perkins (2018) reported how PhET simulations are increasingly being made available for students with disabilities. The authors penned the use of universal design principles in creating the simulations so that they are made inclusive for students with diverse learning requirements. For example, they noted that most simulations today have alternative text descriptions for blind students, along with adjustable sound and vision functions to suit students with different senses. These add-on features also made PhET simulations an inclusive tool because students with different abilities are all catered for to use and learn from them.

The other main section of the chapter was the description of how the innovations affected education. According to the authors, in offering access and interoperability, PhET simulations are an increasingly effective way of engaging students and improving educational outcomes. Through the simulations, students are able to interact with and experience scientific phenomena actively, and learn dynamically, with an emphasis on active learning and inquiry pedagogies. By permitting the students to manipulate variables and observe the results in real time, the simulations facilitate a deeper understanding of scientific principles.

University of Education,Winneba http://ir.uew.edu.gh

Moore and Perkins (2018) also spoke about the increasing application of PhET simulations in physics and engineering education, where they have been utilized for teaching a wide variety of subjects, ranging from introductory physics to more specialized subjects like electromagnetism and thermodynamics. The authors expounded that the simulations allow learners to visualize phenomena that would be difficult to visualize under normal classroom settings, which allows them to develop more intuitive, conceptual understanding.

Lastly, Moore and Perkins (2018) noted that the evolution of PhET simulations has made them more powerful, accessible, and flexible for more students. The enhancements guarantee that the simulations can be used to facilitate learning experiences in a range of learning environments and for students with varying needs, and are thus a vital tool in the modern science and engineering classroom.

Mashami, Kurniasih, and Khery (2023) tested the potential for PhET simulations to serve as a virtual lab tool to facilitate students' scientific problem-solving abilities in science learning. In the Jurnal Penelitian Pendidikan IPA, the research emphasizes how PhET simulations possess the potential to cover gaps in traditional science teaching methods, particularly when there is limited physical lab equipment. In their study, the researchers were concerned with the ways in which these simulations impacted students' problem-solving ability in physics through an interactive and engaging environment in which the student can control variables and observe the effect of his or her actions on the system in real time.

Among the key findings of this study was that PhET simulations, through their ability to engage students in experimental-type learning activities, played a significant role in cultivating problem-solving abilities. Different from text or lectured learning where

University of Education,Winneba http://ir.uew.edu.gh

abstract concepts were normally presented without context, the simulations provided more experiential learning. Students could manipulate different variables, test their hypotheses, and immediately observe how changing variables affected the system. Through this active experimenting and immediate feedback, students gained a greater appreciation of scientific principles and the problem-solving process needed to apply those principles.

Moreover, the study revealed that the immediate feedback that came with the simulations was key to students' ability to detect and repair misconceptions. Under regular instruction, students may not realize their mistakes until down the line in the process. With PhET simulations, however, students could experiment, do things wrong, and see immediately the impact of their actions. This led to a more immediate understanding of their errors and allowed for timely corrections, fostering an environment of continual learning and improvement.

The virtual nature of PhET simulations also offered students a unique opportunity for self-directed learning. Students could work at their own pace, revisiting different parts of the simulation or trying various scenarios to explore different outcomes. This autonomy led to the students being accountable for learning, therefore, they were in a position to study the content in a more profound way and with more passion. Doing it on their own with less pressure helped students feel secure about their ability to fix problems. By finishing the simulations, students had the sense of having mastery over the concepts provided and hence reinforced their physics knowledge.

Besides, the study put forth that the PhET simulations could be utilized in both solitary and collaborative learning settings. While students would benefit from solitary learning, where they could experiment and explore independently, the simulations were

University of Education,Winneba http://ir.uew.edu.gh

also conducive to collaborative learning. In group settings, students could share information, compare results, and work together to solve problems. This collaborative element also enriched their learning experience through collaboration, communication skills, and advanced group problem-solving.

Mashami, Kurniasih, and Khery (2023) further emphasized that the ease of accessibility of PhET simulations rendered them especially effective in learning settings where physical laboratory facilities were limited. For example, in a lot of schools, access to advanced lab equipment is limited due to financial constraints, and hence, students cannot readily engage in the kind of hands-on experiments it would take to fully understand specific physics concepts. Under such conditions, PhET simulations offer an affordable alternative that can replicate results from real experiments, allowing students to engage with complicated concepts meaningfully.

The study also investigated if PhET simulations would enhance students' critical thinking abilities by requiring them to hypothesize, test, and examine the outcome of their actions. By engaging with the simulations, the students were not simply passively receiving information; instead, they were actively participating in learning, honing their ability to think critically about the way variables interact and affect each other. This inquiry-based learning experience helped to hone the evaluation and analysis skills of the students, which are important in real-world problem-solving.

Generally, Mashami, Kurniasih, and Khery (2023) found that utilizing PhET simulations as a virtual laboratory immensely improved the problem-solving skills of the students. The interactive, immersive, dynamic setting that the simulations provided allowed students to advance understanding and apply complex scientific concepts. Also, the ability to work independently, along with instantaneous feedback, made it

University of Education,Winneba http://ir.uew.edu.gh

easy for learners to rectify misconceptions early enough and develop enhanced confidence in solving problems. Research stated that PhET simulations have the potential of enhancing the process of science teaching and learning, especially in areas where access to the traditional apparatus of a lab is limited, and that the ability of students in problem-solving, critical thinking, and concept-based knowledge of physics can be significantly enhanced by PhET simulations.

Taibu, Mataka, and Shekoyan (2021) explored how PhET simulations assist in fostering the scientific attitude and aptitude of students in community colleges. In their research, the authors believed that interactive PhET simulations widely used in science education can contribute to not only scientific technical aptitude but also science learning interest.

The study was guided by the assumption that PhET simulations, through providing a visual and interactive learning platform, would significantly affect students' participation in science content and their ability to apply scientific concepts. Researchers noted that PhET simulation-enhanced students' ability to carry out scientific inquiries, analyze data, and understand scientific phenomena. This success was attributed to the power of simulations to simplify complicated things by charting the scientific principles that otherwise became cumbersome and thus arriving at an elevated level of comprehension.

Secondly, studies attested to the impact that PhET simulations had on the attitude of the students towards science. Traditional education requires that most students have had to live with the intangibility of science and thus view science negatively. But with the effect of performing the simulations, students gained greater confidence in science skills, with greater interest in science and a positive attitude towards learning. The

University of Education,Winneba http://ir.uew.edu.gh

interactivity of the simulations offered room for students to experiment with different variables and conditions, allowing them to feel in control of exploring scientific problems at their own pace and within a low-stakes, risk-free setting.

Taibu, Mataka, and Shekoyan (2021) also observed that PhET simulations created an excellent context for active learning. The learners were not passive recipients of facts but were forced to engage with the content by way of hypothesis testing, reading results, and drawing inferences. By doing so, they turned into critical thinkers and thought scientifically. Additionally, the learners had the ability to revisit the simulations countless times to repeat and consolidate learning, which contributed to scientific knowledge consolidation.

The second significant finding of the research was enhanced students' collaborative abilities. Although PhET simulations facilitated individual learning, they nevertheless offered a platform for collaborative learning from others. Through collaboration, the students could exchange information acquired, exchange ideas, and learn from one another, in the process learning teamwork and collaborative problem-solving.

The project also proposed that the PhET simulations would be most effective at the community college level, where students could have varied background and preparation for studying science. The flexibility and accessibility of the simulations allowed the students to learn at their own rates, with the potential of filling in weak spots and developing a solid foundation in scientific principles before moving on to more advanced material.

Overall, Taibu, Mataka, and Shekoyan (2021) have found that PhET simulations enhanced the scientific abilities of the community college students as well as the

University of Education,Winneba http://ir.uew.edu.gh

attitudes towards learning science. Beyond reinforcing students' conceptual science understanding, PhET simulations also allowed for positive and constructive attitudes towards learning science. Enabling students with interactive learning spaces, critical thinking spaces, and collaboration, the PhET simulations were a priceless tool in support of science education in the community college setting.

Perkins and Moore (2017) discuss the activities and constraints associated with increasing access for students with disabilities to PhET simulations. In their paper at the Physics Education Research Conference (PERC), they described the progress made thus far, the obstacles faced, and the possible solutions available for increasing access of PhET simulations, in high demand in science education, to students with various disabilities.

Authors have stated that PhET simulations, being interactive, visual, and dynamic simulations, have been an effective pedagogical tool to facilitate one in acquiring scientific concepts. Disabled students, e.g., the visually impaired, physically or motor-disability-impaired, or cognitively impaired students, however, are at a significant disadvantage when trying to utilize such simulations. Perkins and Moore (2017) further stated that even though the PhET simulations are designed to be interactive and engaging to a significant degree, the lack of accessibility options for students with disabilities could, in effect, render them less useful to students with disabilities.

Some of the most critical interests in the paper was understanding how such difficulties were tackled. Perkins and Moore (2017) pointed out that a lot of efforts had been put to increase the accessibility of PhET simulations, particularly for visual disabilities. This was by adding support for screen reading, descriptions via alternative text, and

University of Education,Winneba http://ir.uew.edu.gh

high contrast visual modes. The modifications facilitated the visually impaired students to use the information at ease and grasp the associated scientific concepts.

Apart from this, the researchers have also attempted to use other forms of input, say, voice or keyboard navigation, to aid handicapped students who have motor handicaps. This was performed in a bid to make the simulations accessible to handicapped students through the use of the standard mouse-based inputs. In turn, Perkins and Moore (2017) emphasized the ongoing collaboration between researchers, instructors, and developers to enhance the accessibility functions to develop and change according to the requirements of students with disabilities.

Despite these updates, Perkins and Moore (2017) pointed out that there were still hindrances to making all PhET simulations universally available. They clarified that most of the simulations lacked the amenities required to enable their use by students with disabilities of the cognitive kind, including simpler instructions or difficulty level settings. Moreover, complete accessibility of PhET simulations for an array of disabilities is an ongoing process of evaluation and adjustment to the software, which is not cost-free.

The article also showed a set of potential solutions to these problems. Perkins and Moore (2017) suggested that developers would be more integrated with disability advocacy organizations and special education experts so that they might learn about the individual needs of students with disabilities more clearly. They also suggested incorporating a more systematic process of accessibility to guide subsequent simulations and education technology development.

University of Education,Winneba http://ir.uew.edu.gh

Finally, Perkins and Moore (2017) emphasized the need to enable PhET simulations to reach all students, including those with disabilities, to ensure optimal learning outcomes. They embraced attempts made in enhancing accessibility but asserted that more effort was needed to enable these simulations to be potentially useful for all students regardless of ability. By resolving these issues and integrating inclusive design principles, PhET simulations would be more likely to meet their potential as a successful and equitable science education resource for a wider population of students. Moore et al. (2014) examined the efficacy of PhET simulations as novel pedagogical resources to learn chemistry. The article took into account the possibility of PhET simulations in revolutionizing how chemistry concepts are instructed and acquired, particularly with regard to providing more available and engaging access to abstractions by students.

The authors provided an overview of how PhET interactive simulations, which are designed to be visually interactive and easy to use, help to provide a more dynamic and interactive learning environment. The simulations allow students to adjust variables in a virtual laboratory setting, allowing them to view the immediate consequence of their own actions and to understand chemical processes better.

Among the strengths of educating students in chemistry through PhET simulations, according to Moore et al. (2014) is that it reduces the distance between theory and practice. The learners have generally been unable to picture and grasp chemical reactions and processes, e.g., molecule movement or atoms interacting, as these phenomena cannot normally be witnessed within a typical schoolroom or lab environment. PhET simulations provide one way of bypassing this restriction by

University of Education,Winneba http://ir.uew.edu.gh

providing learners with interactive depictions of chemical systems that are controllable and viewable in real time.

The study also added that the PhET simulations offer a student-centered learning method where students are free to experiment and learn at their own convenience. This conforms to the principles of constructivist learning that put a strong focus on active learning and knowledge construction by experience and investigation. Through experiencing the simulations, students are encouraged to experiment, generate hypotheses, and test them, thereby resulting in deeper conceptual understanding.

Moore et al. (2014) similarly identified the use of PhET simulations in countering misconceptions in learning chemistry. The simulation facilitates visual feedback and direct variable control, both of which serve to assist the student in formulating their mental models and doing away with misconceptions. There is interactive refinement through this practice, which benefits the achievement of greater learning since students are no longer passively receiving information but are actively experimenting with it and constructing their understanding.

Furthermore, the researchers also talked about scaling PhET simulations to different learning environments. The simulations are designed to be general and accessible and, therefore, are suited to every type of classroom setup, ranging from large lectures and small group discussion to independent study. Moore et al. (2014) also noted that PhET simulations were easy to integrate into traditional classroom teaching as well as e-learning, and an extremely flexible learning environment that suits different teaching approaches and students' needs.

University of Education,Winneba http://ir.uew.edu.gh

Thus, Moore et al. (2014) determined that PhET simulations are new teaching tools for chemistry because they enable students to be taught hands-on, graphical, and dynamic representations of chemistry concepts in which they can participate fully in content. The simulation addresses existing teaching hypotheses, e.g., constructivism and inquiry learning, as it facilitates active learning while allowing students to explore concepts in an experiential way. Therefore, PhET simulations can be an effective addition to traditional teaching to enhance understanding and retention of complex chemistry concepts.

Rahmawati, E. N., & Astuti, D. P. (2020) developed an e-handout with PhET simulations based on a problem-based learning (PBL) model to enhance students' conceptual understanding of the law of conservation of momentum and collisions.

Their overall objective was to explore the effectiveness of integrating PhET simulations and the PBL model in strengthening students' understanding of intricate concepts of physics, such as momentum conservation and collisions. PhET simulations enabled students to have a hands-on experience of interactive graphical representations of physical processes otherwise challenging to understand using conventional teaching methods. These simulations allowed the students to attempt different situations and observe the impact of different variables in real-time, which facilitated their conceptual understanding of such subjects.

The PBL model of student-instruction through real-world problem-solving was integrated with the PhET simulations to augment active learning. This procedure enabled the students to experience a hands-on approach to learning about conservation of momentum and collisions, which are basic topics of classical mechanics. PBL provided the students with an opportunity to address real-life problems, formulate

University of Education,Winneba http://ir.uew.edu.gh

hypotheses, conduct experiments, and conclude. The exercise encouraged problem-solving and critical thinking, and allowed the students to gain more insight into the underlying physics principles.

Perhaps one of the most valuable advantages of such an activity is that it allowed students the freedom to relate abstractions to real things. They were able, through the use of the PhET simulations, to immediately see the effects on momentum conservation of changing different parameters, and how various situations affected the collision dynamics. This was very helpful when dealing with inelastic and elastic collisions, where looking at resultant outcomes of changing factors might be hard without such similar simulating tools.

Apart from that, the study found that the application of an e-handout as a supporting tool helped in the process of learning consolidation. The e-handout included step-by-step instructions, terminologies, and references to the PhET simulations that helped the students follow the PBL activities. The electronic material also helped the students in reading the material outside the classroom, thereby making learning convenient.

In general, Rahmawati and Astuti (2020) found that the combination of PhET simulations and the PBL model was effective in building students' conceptual understanding of the principle of the law of conservation of momentum and collision. The interactivity of the simulation and problem-solving approach to teaching by PBL allowed students to visualize and implement abstract ideas to build their conceptual understandings of key principles of physics. The research emphasized the possibilities of such hybrid mode learning strategies in facilitating difficult abstract physics concepts to be simpler and more interesting to learn for the students.

University of Education,Winneba http://ir.uew.edu.gh

Batuyong and Antonio (2018), researched the effectiveness of PhET interactive simulations in improving the performance and learning experience of students, specifically in the topic of electromagnetism, one of the challenging topics in physics. The research aimed at determining if PhET simulations can help students learn challenging topics in physics and improve their comprehension of the topic.

In the research, a quasi-experimental design was employed where two groups of students were used: one for learning physics in the normal way and the other for using PhET simulations as part of learning. It sought to comprehend whether the utilization of PhET simulations as part of learning can result in evident enhancement in the performance and conceptualization of students compared to traditional classroom instruction.

The study aimed at a lesson in electromagnetism that covers basic topics such as electric fields, magnetic fields, and electromagnetic induction. Researchers used pre-tests and post-tests to measure the performance of students prior to and after solving the lessons. This was a way of identifying whether students in the experimental group, who used the PhET simulations, learned more in these topics compared to students in the control group.

PhET simulations enabled students to interact with dynamic visualizations of abstract phenomena so that they could alter parameters and experiment with different situations. Through this interactivity, students were able to visualize phenomena that would otherwise be difficult to visualize in the classroom environment, like electric and magnetic fields moving in real-time.

University of Education,Winneba http://ir.uew.edu.gh

In addition, surveys and interviews of the students were administered in the research to solicit qualitative data about the students' learning experience. The instruments that were used were student self-reports on participation, motivation, and whether or not the PhET simulations supported them well in understanding complicated information. The researchers were curious to know if using PhET simulations led to a more and engaging learning experience compared to other instruction.

The findings of the study were favorable, and the experimental group of students, who had been exposed to the PhET simulations, outscored the control group in the post-tests. The experimental group of students mastered basic concepts of electromagnetism more, and this was an indication that PhET simulations were effective for enhancing conceptual understanding in physics.

Not only did the experimental group perform higher in grades, but they also had better experiences throughout the learning process. The interactive simulation made the students visualize the complicated physical phenomena, abstract concepts being more tangible and comprehensible. Students liked the fact that they could experiment with the simulations, where they could test different situations and observe results without consequences. This applied learning experience also seemed to hugely increase their confidence in their ability to problem-solve and theorize.

Furthermore, the simulations provided levels of personalization that were impossible to attain with typical lectures. The students were able to learn at their own rate, revisit concepts where they had difficulty, and experiment with different sets of the simulations to see the effects of changes on the system. This autonomy likely accounted for the increased motivation and interest that the students indicated because they were more in control of their learning.

University of Education,Winneba http://ir.uew.edu.gh

One of the most robust findings of the study was heightened student engagement. Students in the experimental group expressed more interest and motivation when learning with PhET simulations compared to regular classroom instruction. They believed that the simulations were a more interactive and fun learning experience since it allowed them to manipulate and explore concepts visually and dynamically.

The ability to visualize abstract notions such as electric and magnetic fields—notations that are inherently hard to understand in a conventional lecture hall—was the most significant addition to introduce more interactivity. The simulations enabled students to form a more concrete idea of this phenomenon, which is essential if one is to have a solid understanding of complex physics ideas.

The article confirms that the use of PhET interactive simulations can make a tremendous difference in terms of students' attainment and motivation in learning electromagnetism. The authors confirm that the interactive and visual nature of PhET simulations provides students with a better medium for understanding difficult physics concepts than teaching methodologies.

In addition, the research implies that the integration of PhET simulations into the learning of physics has the potential to create a constructivist learning environment, in which the learners are actively involved with the subject, conducting tests of hypotheses regarding various variables, and developing their own understanding of the concepts. The simulations also facilitate learning that is scaffolded, in which the learners learn a concept at their own pace and review material as needed.

The findings of the study announce that PhET simulations play an important role in enhancing students' motivation, more conceptual and deeper conceptual understanding,

University of Education,Winneba http://ir.uew.edu.gh

and improving academic performance in physics. Based on the success of the study, researchers recommend that teachers utilize PhET simulations in teaching lessons, particularly in tackling abstract or complex physics ideas. By doing this, they will be in a position to lead students towards a more interactive, meaningful, and more productive learning process.

In conclusion, the study by Batuyong and Antonio illustrates the wide-ranging impact that PhET simulations can have on students' understanding of difficult concepts in physics, motivation, and achievement. The interactive nature of the simulations offers students an engaging learning resource that can be integrated with regular instruction to achieve more, active understanding of physics.

2.5.6 Using PhET Simulations in Improving Students Performance

PhET project is examined by (Perkins et al., 2006) which aims at developing interactive simulations that can be used in teaching physics. These PhET simulations can be animated and game-like to help students explore ideas about physics faster.

Another focus of this effort is to make the links between everyday occurrences and underlying scientific principles more straightforward for learners. Based on research, the PhET project has adopted a design strategy making use of previous studies as well as iterative assessment for coming up with simulation tools that aid in enhancing student engagement and comprehension.

It is important to note that these simulations are geared towards providing models visual and conceptual models reflecting those held by experts in the field of physics, thus making it easier for learners to grasp complicated ideas around this discipline. It seeks to establish an environment where students can actively engage their senses with these

University of Education,Winneba http://ir.uew.edu.gh

simulators so as to understand key concepts underpinning basic physics aspects. The PhET project has made its resources available freely via its website thereby enabling both educators and their learners access them without limitation.

The impact of PhET simulations on Baybay City Senior High School STEM students' performance in electrodynamics was investigated by (Yunzal Jr & Casinillo, 2020). They wanted to see if using PhET simulations would increase students' understanding and performance in the subject.

In particular, a quasi-experimental design was used that divided seventy-two (72) STEM students into two groups – control group and experimental group. On an hourly basis daily during their free time, the experimental group interacted with PhET simulations while the control group did not have any intervention concerning electrodynamics as mentioned above.

The results showed that the mean scores were not significantly different between the control and the experimental groups even though students found simulations interesting. The study concludes that, although the simulations were captivating, they did not contribute to large improvement in the student's performance. One possible explanation for these out comes is that perhaps students would derive greater benefits from simulations intrinsically linked with their lecture contents and course material. The small improvement in the performance of the experimental group underscores that PhET simulations can be effective only if their incorporation into broader educational systems is done adequately.

The impact of PhET Interactive Simulation-Based Activities on students' performance and learning experiences in electromagnetism, was investigated by Batuyong and

University of Education,Winneba http://ir.uew.edu.gh

Antonio (2018). Their research aimed at assessing the effectiveness of these simulations in enhancing physics education.

To gain insight into various aspects of the PhET interactive simulation-based activities, a panel of experts was asked to evaluate them. Later, the simulations were administered to 200 Grade 10 learners using a quasi-experimental design with a one-group pretest-posttest setup. Various statistical analyses such as frequency distribution, mean, standard deviation and t-test for correlated samples were used to assess the effectiveness of these simulations.

The results revealed that PhET interactive simulation-based activities are highly valid regarding learning outcomes as well as instructional characteristics and evaluation. Academic achievement in physics especially on electromagnetism has improved significantly among students. Informal interviews and student feedback indicated three major themes: physics lessons were perceived as enjoyable, realistic and uncomplicated. These positive encounters validate how much easier it becomes to understand complex principles when they become more accessible or engaging through simulating them.

The study's general conclusion is that PhET interactive simulation-based activities are effective teaching tools in physics, they offer valuable learning experiences and improve students' understanding of electromagnetism. The positive responses and greatly improved performance indicate that these simulations work well for diverse learners and must be incorporated into classroom instruction.

The effect of PhET simulations in electrodynamics on the performance of SMA high school students was examined by Jayanagara and Lukita (2023) .

University of Education,Winneba http://ir.uew.edu.gh

The study's purpose was to see whether PhETs would be useful in improving students' knowledge and skills within this physics area.

This research used a quasi-experimental design with 72 SMA students. Based on their class sections, the students were divided into two groups: control group and experimental group. In their free times, the experimental group was subjected to one-hour daily sessions involving the PhET simulations while no extra activities took place for the control group.

Pre and post-tests which involved multiple choice questions were used to determine performance levels. However, despite an apparent interest among learners in the simulations, results indicated that there were no statistically significant differences between mean scores of control and experimental groups. Nevertheless, there was a slight improvement in performance after exposure to PhET simulations, but it did not reach a level that could be considered statistically significant according to the research findings.

The study suggests that while PhET simulations are interesting and captivating, their effects on performance may be minimal if they are not blended with the regular lecturing materials. The discoveries call for more holistic approaches to harnessing simulations in physics education for better student results.

The study by (Mallari & Lumanog, 2020) was on whether the incorporation of PhET interactive simulation-based activities increased academic performance in science among seventh-grade students. The intention of the researchers was to alleviate the challenges faced by science teachers due to demands imposed by modern education and technological advancements.

University of Education,Winneba http://ir.uew.edu.gh

83 seventh grade students were involved in this study using a quasi-experimental design. While the control group used traditional teaching methods, the experimental group employed PhET interactive simulation-based activities. Standardized tests were used to assess academic performance before and after intervention.

According to pre-test results, there was a slight difference between control (mean=13.28) and experimental groups (mean = 14.26), but it did not reach statistical significance ($t=1.99$, $p>.05$). Subsequent modification of teaching approaches saw an improvement in their scores with control group growing up to (mean = 22.65). On the other hand, experimental group's mean score increased from (mean = 13.28) to (mean = 26.23), a much more significant gain, which was statistically confirmed between two groups as well as for three different types of prosthesis: $t = 2.0$; $p<0.05$.

The results showed that the performance of the control group was slightly higher initially, however, PhET interactive simulations led to greater improvements in academic performance among the experimental group. The findings mean that there can be great improvement on students' performance and understanding by simply integrating interactive simulations into science education which further brings out the advantages of new educational technologies.

The effectiveness of PhET simulation software-based learning was examined by Haryadi & Pujiastuti (2020), to improve science process skills in the area of temperature and heat. The main aim of this research work is to evaluate the impact using PhET simulations has on students' comprehension as well as their ability to do tasks concerning physics in these areas.

University of Education,Winneba http://ir.uew.edu.gh

In this study, a randomized control group pre-test post-test design was employed which involved all 11th-grade students at Sekolah Menengah Atas Yayasan Pendidikan (SMAYP) Serang consisting of five classes where one class was experimental group and used PhET simulation software for learning while another class was control group and received traditional direct instruction.

The results showed that the use of PhET simulations in teaching resulted in a 37% higher N-gain value than when traditional direct instruction was used as control. This huge increase suggests that PhET based e-learning is better at enhancing learners' scientific process skills.

This study concluded that interactive teaching with the use of innovative tools like PhET simulations not only improved students' understanding on heat and temperature but also promote their scientific process skills significantly. Therefore, incorporating simulation into physics classes could be an effective way to improve learning outcomes and skill development.

Potane and Bayeta Jr (2018) researched how effective virtual learning through PhET interactive simulations is in stimulating students' academic achievement in science. The study was designed to determine the influence of this teaching strategy on student performance and learning experience among both urban and rural schools.

The research design used descriptive, which included both qualitative and quantitative analysis. It involved putting into use an offline version of PhET interactive simulations as a part of DepEd Computerization Program (DCP) for the school year 2016-1017. Randomly selected schools within Cagayan de Oro City Division composed the sample for the study.

University of Education,Winneba http://ir.uew.edu.gh

PhET software, strategic intervention materials, pretest-posttest achievement test, and deep interviews conducted to gather qualitative data about students' learning experience were used as instruments in this study.

The findings showed a good performance of the students in the academic field after using PhET simulations during virtual learning. The pre-test posttest results showed significant improvements in both urban and rural areas. Nonetheless, there was no noticeable variation between posttest scores for rural and urban schools.

It is therefore concluded that virtual learning through PhET simulations can effectively improve student's knowledge and skills, thereby motivating students to learn with enjoyment. As a result, the researchers suggested science teachers should include PhET simulations into their teaching approach to enhance primary conceptual understanding, procedural skills and technical competence of students.

Gani et al. (2020) explored the effects of PhET simulations on learners' comprehension and enthusiasm for physics. The research aimed to establish whether PhET simulations could boost students' understanding of physics concepts and their willingness to learn.

The investigation adopted a quantitative design and quasi-experimental method. The target population comprised grade eight (8) students at Madrasah Tsanawiyah (MTs) Insan Qur'ani, with samples drawn from classes VIIIc and VIIId using simple random sampling. Class VIIIc was treated as the experimental group where it was taught using PhET simulations while class VIIId represented the control group whereby traditional lectures were used.

University of Education,Winneba http://ir.uew.edu.gh

The study measured conceptual understanding through fifteen multiple-choice items that were valid and reliable, and motivation by means of a seven-item survey form. Normality, homogeneity, hypothesis testing.

Results showed that the experimental group which used PhET simulations scored an average understanding score of 9.75% unlike 8.81% for the control group. On the other hand, the motivation questionnaire revealed a significant increase in motivation for the experimental group with a mean score of 85.6 compared to 64.6 for the control group implying that students who had exposure to PhET simulations were highly motivated in learning physics as opposed to those who were taught through traditional methods. PhET simulations significantly enhanced both conceptual understanding and student motivation in learning physics according to this research paper's findings. The result therefore implies that use of PhET simulation as a teaching tool has a positive impact on science education performance improvement.

Mashami et al., (2023) conducted a research to assess the usefulness of PhET simulations as a virtual laboratory in enhancing students' problem-solving skills in radiochemistry course. This study was prompted by lack of physical laboratories for conducting practical's hence necessitating use of technology to access educational resources online.

The research design employed both quantitative and qualitative methodologies in this study. The quasi-experimental design with one-group pretest-posttest structure was followed by in-depth interviewing to gain more understanding on the process of student's problem solving. Some of the instruments used were written tests that measured problem solving skills and questionnaires that gathered responses from

University of Education,Winneba http://ir.uew.edu.gh

students while interview guides helped collect qualitative data about the problem-solving process.

Data from problem-solving skills were analyzed quantitatively using the SPSS 22.0 whereas questionnaire surveys and interviews were analyzed descriptively preference. According to Wilcoxon signed-rank test results, there was significant increase in student's ability after applying PhET simulations with p-value less than 0.001. They had three groups including high, medium and low based on their problem-solving capacity whereby high is greater than medium which is also greater than low.

Such positive responses were given by the students who also referred to it as a virtual laboratory meaning it was well-liked and useful in improving their learning. By analyzing interview scripts, it became possible to understand what goes on in the minds of student during chemistry problem solving exercises which suggests the effectiveness of PhET in promoting deep knowledge about complex issues.

PhET simulations therefore evidently enhanced students' ability to solve radiochemistry problems. The students' feedback and qualitative information were detailed enough, which justifies the appropriateness of virtual labs in complementing conventional science learning where there are no practical labs.

The study conducted by Putranta and Kuswanto (2018) aimed at improving students' thinking capabilities in criticality through the use of PhET simulations that support a problem-based learning model. The research sought to create effective physics teaching and researching tools, test how helpful PhET simulations can be in teaching physics, and examine if students' critical thinking abilities have improved.

University of Education,Winneba http://ir.uew.edu.gh

The research employed 62 tenth-grade students using a developmental research approach with reference to the 4D design: Define Design, Develop, and Disseminate. In the define phase, the researchers identified existing problems in physics education and developed appropriate instruments for learning as well as conducting research. The activities included designing these instruments while considering an integrated PBL learning model supported by PhET program. In the develop phase, refinement of instruments was made based on initial designs. Finally, during dissemination stage of this work involved sharing products developed for their incorporation into different uses.

The results showed that the newly developed physics teaching and research tools were valid and reliable in physics education. Additionally, PhET simulations turned out to be effective educational media which led to a significant improvement of students' critical thinking abilities. The study established that the growth in critical thinking skills among students during designing and building classes was considered as moderate. This empirical evidence demonstrates that PBL coupled with PhET simulations has potential for developing critical thinking in physics education.

Najib et al., (2022) conducted research to assess how physics students in high schools could improve on their performance by using PhET interactive simulations. The PhET simulation was to allow learners study physics with the help of computer-based and web-based virtual environments. This study was aimed at evaluating the extent to which these simulations could enhance students' physics achievements.

The research used a quasi-experimental design that involved sixty (60) students divided into two groups: an experimental group that used PhET simulations and a control group that utilized traditional teaching approaches. Each one had thirty 30 individuals. In this

University of Education,Winneba http://ir.uew.edu.gh

regard, the researchers came up with specific module as well as lesson plan for integrating PhET simulations into teaching and learning activities. They used pre-test based on multiple choice questions as well as post-test methods to measure student's progress.

The findings showed improvement in average scores of the experimental group from pretests to posttests indicating that students who used PhET simulations had better physics performance. On the other hand, the control group that did not employ these simulated applications was seen to have no substantial change between their pretest and posttest scores. The results suggest that PhET interactive simulations could really enhance students' physics achievement if they were integrated with well-designed instructional materials and plans.

AlArabi et al., (2022) researched on the effectiveness of teaching Newton's second laws of motion to grade 11 students by use of computer simulations in United Arab Emirates (UAE). The study was quasi-experimental and it compared traditional face-to-face education with Computer Simulations (CSs) on students' understanding of Newton Second Law of Motion (NSLOM).

In this research, a total of (90) students aged between 16-17 years were divided into two girls' classes (40 students), and two boys' classes (50 students). These participants were randomly chosen and tested using the Newton Second Law of Motion Achievement Test (NSLMAT) before and after. Data analysis used both descriptive and inferential statistics.

The Computer Simulations (CSs) significantly improved students' understanding of NSLOM as shown by the results. The simulations being visual and interactive made it

University of Education,Winneba http://ir.uew.edu.gh

easier to understand the ideas and details of Newton Second Law of Motion (NSLOM) than traditional teaching did. Both sexes experienced gains in terms of learning outcomes with respect to the use of Computer Simulations (CSs). Consequently, it has been suggested that physics teachers exploit these simulations for results to improve student achievement.

2.7 Summary

Empirical work presented in aggregate supports the invaluable contribution of PhET interactive simulations toward maximizing the learning of physics, particularly mechanics. In subsection 2.6.1, studies demonstrate simulations to be effective in revealing and remediating students' misconceptions regarding Newtonian mechanics, including force and motion, projectile motion, and energy conservation. Studies such as Müller et al. (2007), Uwayezu & Yadav (2023), and Adegoke (2012) quote conceptual improvement and decreased rates of misconceptions following PhET-supported learning.

Section 2.6.2 stresses that PhET simulations reduce the students' cognitive load by giving them interactive and reduced visual models of abstract concepts. Testimonies from Magana et al. (2022), Salame & Makki (2021), and Banda & Nzabahimana (2021) support that students improve their retention and have less cognitive overloads when they learn mechanics through PhET tools.

IBL with PhET in 2.6.3 is seen as a good pedagogical approach. The research of Yuliati et al. (2018), Fan's research (2015), and Amri et al.'s research (2024) demonstrate how students who were taught through guided inquiry using PhET simulations improved critical thinking, problem-solving, and better conceptual understanding of physical phenomena.

University of Education,Winneba http://ir.uew.edu.gh

Section 2.6.4 presents empirical evidence that hybrid learning models integrating PhET simulations (e.g., Benta & Wiyanto, 2024; Kurniadi et al., 2023; Najib et al., 2022) raise student achievement and motivation, especially in environments where there is demand for fully virtual or hybrid education.

Section 2.6.5 offers challenges in implementation, including a lack of teacher training, infrastructure issues, issues with internet connectivity, and incorporating simulations into existing curricula. Studies like Gloria & Ramnarain (2021) and Perkins & Moore (2017) suggest institutional support and professional development in achieving PhET's full potential.

Finally, section 2.6.6 also concludes with findings on the impact of PhET on student performance, with consistent academic improvement in diverse global studies. In Asia, Africa, or North America, PhET simulations have been discovered to have significantly enhanced students' test scores, levels of understanding, and problem-solving abilities. Briefly, PhET interactive simulations are a good and valuable solution to correcting misconceptions in mechanics as well as enhancing learning outcomes in physics, but only when supported by good pedagogy and institutional support.

University of Education,Winneba http://ir.uew.edu.gh

CHAPTER THREE

METHODOLOGY

3.0 Overview

The main purpose of this chapter is to describe the methods used in this research, which are aimed at addressing student misunderstandings about some mechanics concepts through PhET simulations. It involves an elaborate account of the research design, target population and sample size, data collection tools along with their procedures, ways by which the intervention was facilitated, methods of analyzing the information collected as well as how valid and reliable it is, ethical concerns that arise in the course of study and finally its restrictions.

3.1 Introduction

It discusses about the methods that indicate how the research was conducted. Additionally, through proper methodology design researchers can address their research questions effectively thus contributing to overall rigor and credibility of the study.

In this study a developmental action research design was employed to determine the effectiveness of using PhET simulations as a teaching method for rectifying students' misconceptions in some selected topics in mechanics. In order to assess changes in students' understanding of these particular concepts an intervention was carried out. The action research design is appropriate for this study for a number of reasons.

First, pretesting is helpful in revealing misunderstandings such as students' misperception of some selected mechanics topics which seems to be too difficult for most students to master accurately. In order to rectify these misconceptions, PhET

University of Education,Winneba http://ir.uew.edu.gh

simulations are added to the intervention define process as a technique of learning. These simulate and teach practices that are interactive visual, and hands on, thus holding and improving the understanding of children on the subjects at hand. Lastly, the post-test is administered to help identify any changes in understanding by drawing comparisons of students' knowledge before and after intervention. This comparison is done to determine if the PhET simulation model has in any way helped in correcting the misconception that existed before the pretest assessment.

Given that it would be difficult to randomize learners into groups (Creswell, 2021), we chose a quasi-experimental design because it helped us to investigate what happens during an actual classroom situation when assigning pupils haphazardly might not be practical. This study informs on whether the use of PhET simulations can better explain Newton's first motion law for teaching purposes and therefore promote student's conceptual knowledge development.

3.2 Research Design

The study employs action research design. In this design, before and after intervention, form two students were assessed to measure the changes of their understanding towards some mechanics concepts. A pretest was administered during the baseline establishment period where the students' existing knowledge and misconceptions were measured. After this stage, an intervention using PhET simulations was conducted. Thereafter, a post test was carried out to assess any differences in student understanding.

For real-world educational settings where such randomization may be impractical, quasi-experimental design does not involve random assignment of participants to different groups (Bhattacharjee et al., 2020). Rather than having different groups for

University of Education,Winneba http://ir.uew.edu.gh

pretest and posttest measurements, the same group of students is used so that one can easily compare how they performed before and after the intervention.

For a number of reasons, action research which utilized a one-group pretest-posttest design is more relevant for this study. First of all, it is concerned with practicalities, which in most cases goes beyond ethical considerations, defining random assignment in educational contexts is usually difficult. Same students were used for both pretest and posttest which makes the research easier. This is useful in measuring the effectiveness of PhET simulations on a group of students where the comparison is made via the repeated measures within the group. Finally, a direct evaluation of student understanding is possible due to comparison of results before and after the intervention. Some of the misconceptions held by students about some topics in mechanics through administering a pretest at the beginning of this study were stated. Specific areas where there are misconceptions could be identified by analyzing these preliminary findings.

In this case, PhET simulations are used as an intervention strategy that involves interaction with the physical concepts represented visually. These interactive simulations have been integrated within instruction aimed at addressing and correcting such misconceptions.

The post-intervention test measures how the students' understanding has changed. The intervention effectiveness can be evaluated by comparing pretest and posttest results to determine if PhET simulations can also rectify misconceptions and enhance comprehension of learners.

When random allocation is not possible, a quasi-experimental design is appropriate (Creswell, 2021) because it enables researchers to compare pretest and posttest results

University of Education,Winneba http://ir.uew.edu.gh

in order to determine whether or not an intervention had any effect on a single group. This kind of design will provide invaluable information concerning how much mechanics concepts could be taught using PhET simulations alone as well as demonstration their ability to improve students' conceptions about it.

3.3 Population of the study

Those units that the study finding is supposed to be apply to are called target population (Casteel & Bridier, 2021). For this research, the target population consists of students from Mankessim Senior High and Technical School. It provides both academic and technical training and serves a diverse set of learners in terms of the social-economic status of their parents; or guardians. Concentration is on current enrollment at Physics classes which practically involve activities done by some mechanics topics. This group includes students from different grades mostly second year as well as boys as well as girls from different socio-economic levels. One hundred (100) students were used in this research.

3.4 Sample and sampling Technique

According to Pandey and Pandey (2021), sampling involves choosing some subjects from a particular population so as to represent the population. It serves to ensure that accurate and reliable information about the population is available at minimal cost in terms of time and effort and establish the limits of accuracy of such estimates. Sometimes it makes it possible to have all-inclusive and intensive research with much lower resource costs such as time, money, materials (Pandey & Pandey, 2021) .

This study utilized purposive sampling as a method of data collection. Purposive sampling entails selecting participants who are specifically relevant for the objectives of the research. In this case, this method facilitates an adequate representation of sample

University of Education,Winneba http://ir.uew.edu.gh

which consist students who harbor misconceptions towards some mechanics topics. The opposite is true because purposive sampling has been found to be most common in educational studies where investigators focus on particular traits or happenings within a definite group like among learners (Campbell et al., 2020).

This study had a sample size of one (100) student. This number is significant since it allows for an in-depth understanding of the misconceptions and how effective PhET simulations are in addressing them. Therefore, the school setting can handle such a number of participants allowing meaningful data analysis to take place. In this case, the need to include a large representative sample is balanced with practical constraints like room capacity and available resources.

The following selection criteria were used:

Only students enrolled in physics at present were considered as candidates for the research. This guarantees that all participants have some knowledge on the topic being investigated thus making them pertinent to this study.

Second year science students at Mankessim Senior High and Technical School were included since these are the likeliest grade levels to have learned about Newton's laws of motion. Students were chosen on the basis of their willfulness to participate, thus making it voluntary and conforming with ethical standards.

The study made efforts to incorporate a broad range of female, boys, those who are poor and others of high economic status as well as people from different academic spheres so as to obtain results that would be representative of student population at large. By using purposive sampling, the researcher was able to ensure that only those participants who could be useful in meeting the objectives of the research were selected

University of Education,Winneba http://ir.uew.edu.gh

hence making it more concise in terms of population experiencing certain misconceptions (Campbell et al., 2020). This makes it possible for researchers to concentrate on a specific group within this larger sample size who can recover from this mistake.

3.5 Data Collection Instruments

3.5.1 Interview

The interview was primarily meant to identify student's wrong conceptions concerning mechanics concepts before the intervention. So as to obtain an idea of student's wrong or incomplete understanding this interview served as the starting point.

This interview was a set of questions that were designed for finding out common misconceptions among students. These misconceptions are mentioned in some choices to get deeper ideas on how they think.

For reliability, the interview question tests were pre-tested with a small sample size from other schools in similar socio-economic settings but not partaking in the main study. The findings were examined so that discrepancies or confusions can be identified and rectified accordingly. Furthermore, validity was obtained from expert reviews conducted by physics educators and subject matter experts who critiqued the content of the tests for their accuracy in measuring students' comprehension of mechanics. (See the interview questions at appendix D)

3.5.2 Pre-tests and Post-tests

The intention of the pre-tests and post-tests was to assess students' grasp of mechanics concepts prior to and after the intervention respectively using PhET simulations. Ultimately, such tests were instrumental in appraising the efficiency behind the

University of Education,Winneba http://ir.uew.edu.gh

intervention. Both pre-tests and post-tests were included in this study with comparable formats and contents to ensure that they are comparable. They all contain a mix of multiple-choice items, true/false statements, short answer questions, and problem-solving exercises. Multiple choice questions are designed to test students' knowledge base; short answer questions and problem-solving tasks measure their ability to apply concepts in different contexts.

Reliability was assessed through internal consistency measures such as Cronbach's alpha which the value was calculated to be 0.8. Validity was determined by content validity of these tests which involved having physics educators review them for completeness and adequacy in covering essential aspects related to mechanics.

3.5.3 Student Questionnaire

This made possible acquiring an understanding of the students' viewpoint on the effectiveness of this intervention and their involvement in the course.

The survey was constructed to contain both open-ended questions and closed-ended ones. Closed ended questions usually utilize Likert scales in order to measure students' agreement or satisfaction levels concerning different PhET simulations. The open-ended questions were meant for students to express their thoughts, feelings and suggestions in their own words.

The questionnaire's reliability was assessed through internal consistency analysis after its pilot administration.

Gani et al. (2020) also ensured that the instruments are reliable and valid by piloting them and having them reviewed by experts. Pilot testing helps to spot any problem s in the tools through small-scale administering these tools to a subset of subject who are similar to those involved in study sample, thereby helping make necessary adjustments

University of Education,Winneba http://ir.uew.edu.gh

where appropriate. In expert reviews of this nature, specialists will appraise if these materials really test what they are supposed to do without biasing their results or not.

3.6 Data Collection Procedures

The data collection process was partitioned into three parts: pre-intervention phase, intervention phase and post-intervention phase.

3.6.1 Pre-intervention Phase

In the first phase, interview was conducted to participants. These questionnaires were made in a manner that would help identify wrong ideas students have about the mechanics. The questionnaire was done within a controlled classroom to enhance consistency.

After the questionnaire, a pre-test was conducted to determine the baseline level of understanding of mechanics concepts among the students. The pre-tests comprised multiple choice questions, short answers and problem-solving tasks which emphasized on overall understanding rather than misconceptions.

3.6.2 Intervention Phase (PhET Simulation Implementation)

In the intervention process, PhET simulation was utilized as a teaching tool in order to correct the misconceptions of students. These programs provide interactive and visual experiences that make students come to grips with mechanics concepts.

The simulation was held over several sessions with each set of simulations lasting roughly 45 minutes, which corresponds to the length of a typical class lesson. These sessions were conducted twice a week for only three weeks. In each of these sessions, the students first received a brief overview of the simulation platform, then most of the time was spent on practical work, that is, working with the simulator. The researchers

University of Education,Winneba http://ir.uew.edu.gh

assisted with the completion of some given tasks and answering some selected questions, which was done by the students during the sessions. The students worked in pairs or in small groups which were meant to promote idea sharing and discussion of relevant concepts. In order to help the students concentrate on key points, they were given directed questions and handouts, which made it easier for them to see how these concepts could be useful in real life. (Details of the lesson plan to this intervention phase can be seen at the appendix F)

3.6.2.1 Description of Lessons organised with PhET Simulations and How the Process Correct Misconceptions

The intervention was comprised of six structured lessons, spread across three weeks, to address misconceptions regarding some concepts of mechanics among SHS 2 Physics students. All lessons had a focus on interactive learning, PhET simulations, and guided discovery, facilitating incremental conceptual understanding of forces and motion.

Lesson 1: Diagnostic Test and Introduction to some selected mechanics concepts

The first lesson was employed to present mechanics concepts and to assess prior misconceptions. The lesson began with an investigation of how things move and stop moving, which provided the formal definition of the law. Through the PhET "Forces and Motion: Basics" simulation, students observed the effect of applying and removing force on motion. A diagnostic quiz was administered to reveal common misconceptions.

These initial observations formed a basis for further instructional planning.

University of Education,Winneba http://ir.uew.edu.gh

Lesson 2: Guided Exploration to Address Misconceptions

Lesson 2 set out to address the misconceptions, which had been formed in Lesson 1. The learners were placed in small groups and manipulated variables such as friction and force during the PhET simulation. They explored questions such as:

- What happens when there is no friction?
- Does motion need constant application of force?

Through these investigations, students discovered that in a frictionless environment, an object continues to move without the need for an external force-painfully facing their initial misconceptions. The class discussions and teacher cues helped in solidifying the proper interpretation of Newton's First Law.

Lesson 3: Applying some mechanics topics to Real-World Contexts

To reach a level of deeper conceptual understanding, the lesson applied the law to real-life situations. Students viewed video recordings (e.g., vehicle crashes) and modeled the same using PhET. After reflection and discussion, students identified the need for seatbelts and realized that inertia makes passengers keep going even when the vehicle halts. This physical connection to reality reinforced comprehension and allowed them to soak up the idea that bodies resist changes in their motion except under the influence of a force.

Lesson 4: Ideal Conditions and Frictionless Motion

Through this lesson, students learned about frictionless conditions using PhET simulations. Conditions like traveling in outer space or on ice were used to illustrate how Newton's First Law operates in ideal conditions. The lack of friction allowed students to distinguish between the effect of force on movement and further question their assumption that there has to be constant force for constant motion.

University of Education,Winneba http://ir.uew.edu.gh

Group discussions helped students to articulate new ideas and rule out false concepts such as, "motion always stops if force is not provided."

Lesson 5: Student-Led Simulation Design

This lesson enabled students to make their own PhET simulation designs and utilize mechanics concepts in imaginative terms. In class, they used group simulations for phenomena including traveling in space, sliding bodies, and friction-free surfaces. Through this design component, there was active learning where students had to interpret the law in creating suitable simulations.

By writing and explaining their simulations, students had demonstrated they could now apply some mechanics concepts to a variety of situations, with significant conceptual progress.

Lesson 6: Presentations and Post-Test Assessment

The final lesson included presentations of student simulation projects and a post-test to measure learning. Students described confidently:

- How motion is maintained unless interrupted by force
- How friction and mass impact motion
- How misconceptions were eliminated by engaging simulations

Through peer evaluation and self-testing, students reported deeper understanding and appreciation of the ways in which PhET simulations helped them "see" concepts at work.

How the Process Worked to Correct Misconceptions

1. Visual and Interactive Learning:

PhET simulations made invisible forces and motions observable, allowing students to bridge gaps between abstract theory and concrete experience.

University of Education,Winneba http://ir.uew.edu.gh

2. Conceptual Conflict:

Misconceptions were uncovered and questioned by controlled experiments within the simulations. For example, when a block moved forever in a frictionless environment, students were forced to rethink their belief that movement requires constant force.

3.Scaffolded Learning:

Use of worksheets, guided questions, and teacher facilitation ensured that students were guided to find out and articulate the correct concepts on their own.

4.Collaborative Exploration:

Peer learning in groups caused students to talk through and sharpen concepts, replacing mistaken ideas with scientifically accurate ones.

5. Real-World Connections:

Making the law applicable to real-life situations (e.g., seatbelts, skating, space travel) caused students to see the applicability and concreteness of Newton's First Law at work.

6. Constructivist Approach:

Students were not passive receivers of information. They actively built knowledge, eradicating their own misconceptions through discovery and explanation.

3.6.3 Post-intervention Phase

After the intervention stage was over, students sat for posttests to measure their understanding of mechanics. The format of the post-tests was similar to that of pre-tests, this allowed for direct comparison and assessment of how PhET simulations were effective.

Data Collection Timeline:

Week 1: Questionnaire and pre-tests administered

Weeks 2-5: PhET simulations implemented (twice weekly)

Week 6: Post-tests administered and student feedback taken.

University of Education,Winneba http://ir.uew.edu.gh

An ethical issue has been addressed. Some key ethical issues include:

All participants were given informed consent form before participating in the exercise and they were also told about the objectives of the study, data collection methods and procedures involved, as well as their right to withdraw from the study without being punished at any time.

Participants' identities remained undisclosed while data was anonymised and stored safely. Only the researcher had access to the raw data.

Nobody was forced or coerced into taking part in this study since it required a voluntary participation from within its targeted population.

At end of study participants were shown findings from them and general aim of work. Additionally, they provided some individual performance input asked for.

3.7 Intervention (PhET Simulations)

PhET simulations are interactive, web-based simulations that were built with an aim of teaching different scientific concepts. The University of Colorado Boulder developed these simulations which animate and provide interactive means to understand scientific phenomena. For this research, specific PhET simulations related to mechanics was used. Such simulation enables students to change variables, see the results and get involved in inquiry-based education which makes abstract ideas become more tangible. The specific simulations employed in the research include 'Forces and Motion basics' and 'The Moving Man.' The 'Forces and Motion: Basics' simulation is useful in the education of students as it makes it possible for them to experiment or manipulate various forces and see the effects on motion as well as appreciate the interrelation between force, motion and friction. 'The Moving Man' simulation allows the students to examine the effects of different forces, constant or changing, on the motion with respect to time and the conditions leading to this motion.

University of Education,Winneba http://ir.uew.edu.gh

3.7.1 Implementation Process

Each of the sessions began with the researcher giving a brief introduction to the theme for the lesson and outlining the objectives of the lesson. This introduction also included how the current simulation is related with other simulation exercises that revolve around mechanics concepts. The researcher then provided a simulation to the students and explained its important features as well as various controls and options that are available.

After the demonstration, students did tutorial exercises in pairs or small groups, facilitated by the researcher. When the exploration portion was completed, the class was brought back together and the teacher held a discussion with the students about what they had found. The teacher invited the students to think and speak up, as well as ask the things they wished to, during this lesson which was very participatory.

PhET simulations also have an interactive environment where students do not only stand by and watch, but participate in changing and manipulating variables and seeing the results that come from their actions. Within the overall activity, students especially the learners were encouraged to cooperate and form pairs or small groups to brainstorm in order to class learn.

The worksheets had some open-ended and guiding questions which made the learners to be analytical in the simulations and make sense of their observations in terms of theoretical knowledge. The simulations offered instant feedback to the students allowing them to view the consequences of actions they undertook instantly. During the sessions, the role of the researcher was an interventionist where he assisted the students in the operation of the software as well as posing higher order questions aimed at reinforcing their understanding of the concepts. The researcher further observed

University of Education,Winneba http://ir.uew.edu.gh

students' engagement and provided assistance when required ensuring that all learners were participating throughout the activity.

The teacher was there constantly to answer the questions of the students, give the students more information on the concepts brought in the activities through simulation and including mechanics concepts. The intervention activities extended to a period of three weeks with the sessions twice a week with each session lasting for 45 minutes, an average period of a class lesson. Such a timetable gave the learners sufficient opportunity to engage with the simulations, explore the ideas in detail, and practice them repeatedly to strengthen their learning.

3.8 Data Analysis Processing

The study conducted both qualitative and quantitative data analysis.

3.8.1 Quantitative Analysis

To assess the effectiveness of PhET simulations in correcting students' misunderstandings about mechanics concepts, a variety of statistical methods were used for analyzing the pre-test and post test data.

Initially, analyses used encompassed descriptive statistics like means, standard deviations as well as percentages for both pretest and post-test scores. These provide an overview of the data set as a whole and indicated any significant changes in student's conceptions.

Paired t-tests were conducted to determine if there was a statistically significant difference between students' understanding before intervention and after the same. The examination compares average scores obtained from pretests and posttests for each set

University of Education,Winneba http://ir.uew.edu.gh

or group of learners to establish that changes observed are not attributable to chance but rather due to this learning process.

The analysis concentrated on decreased misconceptions identified, and general improvements in comprehending mechanics concepts. This involved comparing responses given to certain standard questions designed to identify misconceptions before and after treatment in order to compare correct versus incorrect frequencies.

3.8.2 Qualitative Analysis

Thematic analysis was used in analyzing the qualitative data from students' questionnaire as well as interviews to gain insights into their experiences with PhET simulations.

The thematic analysis entails coding the qualitative data in order to obtain common themes, patterns and insights regarding students' perceptions of PhET simulations. The first step in the process involved initial coding. This meant going through the answers given to the questionnaires one-by-one with the view of identifying key ideas. After which the codes related to the statements were developed into wider categories in terms of the student's feedback. These were reviewed and revised to ensure a better presentation of the information as collected rather than as an organization of the information. As a result, the final report was composed by restating these categories and supported by extracts of students that reflected their thoughts or experiences towards the topic.

The statistical analysis employed SPSS (Statistical Package for Social Science 29) software, a widely-used package for quantitative data analysis. SPSS offers reliable

University of Education,Winneba http://ir.uew.edu.gh

tools for running descriptive statistics, paired t-tests and other applicable tests that guarantees accuracy and reliability in results.

SPSS software was also employed in performing the qualitative analysis of student questionnaire.

In this regard, SPSS tool is a potent computer program meant for academic research involving all types of study designs including qualitative, quantitative, mixed methods design and other whole systems. By using SPSS for analysis of qualitative data, it therefore assists in implementing an organized coding process that ensures key themes and insights are adequately identified and reported.

Data analysis was done using the methodological approaches recommended by (Creswell, 2021). Quantitative data should be analyzed with appropriate statistical techniques whereas qualitative data need thorough interpretation through rigorous procedures to ensure credible results which are important and meaningful.

3.9 Validity and Reliability

To produce valid and generalizable findings, it is important to consider the authenticity and reliability of the research. The study employed the following techniques in order to enhance internal validity, external validity, and reliability.

3.9.1 Internal Validity

In a controlled classroom setting, this research was carried out to reduce any unwanted impact from extraneous variables on results. In addition, other factors such as the time of day, classroom used and teaching methods were kept constant throughout the intervention. Moreover, potential confounders including students' prior knowledge or different styles of teaching were considered and controlled.

University of Education,Winneba http://ir.uew.edu.gh

PhET simulations made up consistent part of all lessons during sessions. Detailed lesson plans had been developed together with instructional guides so that all learners could benefit equally from these tools while using them uniformly as possible. For instance the researcher underwent training on how PhET simulations should be effectively implemented thus ensuring uniform delivery.

3.9.2 External Validity

To boost the external validity and generalizability of the findings, a varied number of students from Mankessim Senior High and Technical School were involved in the study. The sample includes different academic abilities, socioeconomic backgrounds and gender. Though the study was concentrated on one school, we discussed this insight on its utilization in similar educational establishments as well as various student populations. This was compared with other studies on PhET simulations, besides misconceptions about physics.

3.9.3 Reliability

The reliability of the data collection instruments (questionnaire, pre-tests, post-tests, and student feedback) was ensured through consistent administration procedures. All tests and questionnaire were administered under similar conditions to all participants. Instructions and guidelines were standardized to reduce variability in how the instruments are administered and completed.

Before the main study, the data collection instruments undergo pilot testing with a small group of students similar to the study population. The pilot testing helped identify any ambiguities or issues with the instruments, which was then be revised accordingly. This process ensured that the instruments are reliable and measure what they are intended to measure accurately.

University of Education,Winneba http://ir.uew.edu.gh

Ensuring the reliability and validity of the research instruments and procedures is critical, their guidelines emphasize the importance of thorough preparation and testing of instruments to ensure they provide consistent and accurate measurements.

Cronbach's Alpha was used to ascertain the reliability of the questionnaire and it produced a coefficient of $0.767 \approx 0.8$ which is considered good for this instrument in terms of internal consistency. It shows that the instrument is reliable when measuring students' experiences with PhET simulations.

3.10 Ethical Considerations

During research the ethical issues should be taken into account to protect the rights, dignity, and well-being of all participants. The following were done in order to maintain ethicality throughout the study.

Before commencing on the study, permission was sought from different relevant bodies including Mankessim Senior High and Technical School administration and University of Education, Winneba-Graduate School. By extension, a comprehensive research proposal detailed vital elements such as; methodology, objectives of the study, data collection instruments and ethical considerations. This approval ensures strict adherence to institutional policies and guidelines pertaining to ethics.

One of the major aspects that often come up when talking about ethics research is informed consent. Under this aspect all subjects were provided with materials containing extensive details regarding all aspects of the study which encompassed purpose of it, procedures involved potential risks/benefits among other issues. For example, they were told that participating in their survey was voluntary hence they could withdraw anytime without any repercussions.

University of Education,Winneba http://ir.uew.edu.gh

This sheet provides information like purposes, methods used in collecting data that may include questionnaires or interviews with participants etc., risks involved if any exist, and lastly its benefits available if people participate in it.

The consent form is a document whereby the study participants declared their willingness to take part in the research study. The study instituted steps to protect the participants' privacy by providing anonymity and confidentiality at all stages including data collection and reporting.

In that regard, every source of identification such as names of the participants in this case were deleted and the participants were assigned a number to help in identifying these individuals, which could not have been exposed to individuals not related to that case. There was a limited access to the research data as it was stored in a way such that only the researchers had that access. Also, all information was kept from the public and only aggregate results were given to avoid identity breaches of individuals.

The study put in place measures aimed at minimal risks on participants and ensuring their welfare throughout the research project.

Instruments have been pilot tested to identify and address potential issues that may cause discomfort or stress among respondents.

Participants were told about what support services (counseling) would be available for them if they felt upset during this research period.

For any signs of emotional distress or discomfort among subjects, the observer took immediate action when necessary.

The study was purely voluntary. They were told that during the study they could leave whenever they wished without any repercussions. This was adequately explained

University of Education,Winneba http://ir.uew.edu.gh

during the informed consent procedure and repeated severally in the course of the study.

It is noted that this research adheres to ethical guidelines as well as best practices. By sticking with these ethical principles, it respected and shielded all participants' rights and welfare thus maintaining the study's integrity and credibility.

3.11 Summary

This chapter introduced the methodology used for this study to correct students' misconceptions of mechanics concepts using PhET simulations.

The chapter presented a thorough analysis of some of the key components of the study. The first thing is the introduction that discussed what methodology is all about in research and gave a snapshot of the research design employed. In the section research design, there is a discussion of the one group pretest posttest design recommended for the research and its appropriateness towards achieving the research aim.

This is then followed by giving the population and diversity of sample taking into account giving the target population, the sampling technique used, the number of samples participated and the scope of sample in Mankessim Senior High and Technical School. There was also an outline of the composing data collection tools such as questionnaires, pre-tests, post-tests, and students feedback encouraging the need for internal and external validity.

The procedures instituted for data collection were described with respect to the pre-intervention, intervention, and post-intervention phases with the schedule for data collection and the ethical issues that were addressed during the process. In this regard, the chapter further discussed the theoretical framework of the intervention explaining

University of Education,Winneba http://ir.uew.edu.gh

the role of PhET simulations; including teacher support, teaching approaches and student participation.

In the data analysis section, the chapter detailed the different types of analytical approaches undertaken with the specific attention paid to the PhET simulations and its efficacy in facilitation of learning physics among secondary school students. Additionally, it also included some of the instruments that were used for this analysis. The chapter went further and analyzed the credibility and the reliability of the researched work and outlined various strategies such as pilot study, internal and external validation to reasonably be sure on the results.

Ethical issues were also considered including issues of confidentiality, how the participants were informed and asked for their consent before the research commenced, as well as protective measures employed to reduce negative consequences from revealing the identity of the participants or harm to their emotional or physical well-being.

This chapter serves as a transition to the next and final chapter, which will cover the results, as well as the discussion of the findings of this study. The next chapter will provide information regarding the outcomes from the pre-tests, post-tests, and formative assessments, focusing on students' comprehension of the First Law of Motion and the reduction of alternative conceptions.

Furthermore, the next chapter assessed the ability of PhET simulations in remediating misconceptions and facilitating comprehension of students, and it also looked into the students' feedback regarding their experiences with these simulations and learning. In this manner, the next chapter, which will build upon the strategies already discussed,

University of Education,Winneba http://ir.uew.edu.gh

will without doubt enhance the ability to interpret the existing data and suggest recommendations for both practitioners and researchers.

University of Education,Winneba http://ir.uew.edu.gh

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 Overview

This chapter aims at providing a deep understanding of PhET simulations' usefulness as a tool for addressing misconceptions of mechanics and improving students' performance.

Through data analysis and interpretation, it is possible to know how educational interventions affect learning processes. This investigation would assist in finding out about a percentage of errors made by learners when answering questions; determine if PhET simulations are effective in dealing with these misconceptions; and measure any improvement in student performance. Thus, by analyzing information carefully the research provides evidence-based insights that can be valuable for teaching practices and contribute to expanding knowledge in education.

4.1 Demographic Characteristics of Participants

Table 1.0 analyses the demographic characteristics of the participants in Mankessim Senior High and Technical School. Understanding demographics is important to give context to data and assist in interpreting results correctly.

University of Education,Winneba http://ir.uew.edu.gh

Table 1: Biodata of Participants

Gender	Frequency	Percentage(%)
Male	46	46.0
Female	54	54.0
Total	100	100.0
Age (Years)		
15	14	14.0
16	50	50.0
17	20	20.0
18	12	12.0
19	4	4.0
Total	100	100

Source: field study (2024)

From Table 1.0 and Figure 4.1, it can be seen that, a total of 100 students were involved in the study. Of these, 46 were male which represents 46% of the participants, while 54 were female accounting for 54% of the sample.

The gender distribution is relatively even ensuring that both sexes are represented.

The ages of the respondents ranged from fifteen (15) to nineteen (19) as shown below:

The number of frequency of fifteen (15) years students is fourteen (14), representing 14 percent (14%).

The number of frequency of sixteen (16) years students is fifty representing fifty percent (50%).

The number of frequency of eighteen (18) is twelve representing twelve percentage (12%).

The number of frequencies of nineteen (19) is four representing four percentage (4%).

University of Education,Winneba http://ir.uew.edu.gh

The number of frequencies of seventeen is twenty representing twenty percentage (20%).

These shows that majority of the students made up of teenagers in their mid to late teens who are common among senior high school students.

This statistical result helps in bringing together learners with different familiarity levels with physics mechanics concepts.

4.1.1 Implications of Demographic Data

Besides, the gender balance was considered to ensure that the findings would apply to both male and female students without any gender bias. Similarly, the ages fall within the range typical for senior high school students thus making the outcomes relevant at this level of learning. Moreover, having a mixture of student categories gives insights into variations in preconceptions held by students and how well they are addressed by PhET simulations at various levels.

4.2 Prevalent Misconceptions in Mechanics

Pre-test results were useful in providing insights into the common misconceptions that students hold regarding mechanics concepts. These misconceptions were established through several diagnostic questions that the students answered before PhET simulations started intervening. Table 2.0 shows an in-depth analysis on the most common misconceptions supported by statistical data obtained from responses on the pre-test.

University of Education,Winneba http://ir.uew.edu.gh

4.2.1 Misconceptions Identified

1. Misunderstanding the Concept of Inertia and Its Relationship to Motion:

A large number of students are mistaken when they think that an object's motion needs a force to keep it going. They do not understand inertia, which is defined as an object continuing either at rest or in uniform motion unless acted upon by some outside force. 65 out of 100 students wrongly believed that if a car stops exerting force, it will stop moving illustrating lack of understanding of inertia.

"Once you stop pushing a car, it will come to a halt because it has to have something that keeps it going."

2. Newton's first law of motion Mixed Up for Newton's Second Law of Motion:

Some students do not grasp the difference between Newton's first law and second laws which deals with force, mass and acceleration. As a result, they wrongly think that an object can move due to some external force.

One of the confusing things in the survey was that 55% or in other words, 55 out of 100 students believed that an object requires a net force to be kept moving which is contrasting with Newton's first and second laws.

Illustrative Quote "For an object to keep moving, someone must push or pull it."

3. The belief that constant motion requires Force:

It is a common misunderstanding among most people that, there must be force acting on an object continuously if it is to move at the same speed without changing. This error does not take into account that when there are no counter forces like friction, the body will continue moving even without additional force.

For example, 70% of the students (70/100) believed in continuous use of force on objects for them to remain in constant motion.

University of Education,Winneba http://ir.uew.edu.gh

Illustrative Quote “If you stop pushing a skateboarder his skateboard stops moving.”

4.2.2 Pre-Test Results

The pre-test results are summarized in Table 2.0, to show the prevalence of each misconception among students.

Table 2: Pre-Test Results

Question	Misconception	Correct Answer	Percentage of Students with Misconception	Illustrative Quote
1. The acceleration and velocity of a body are always in the same direction. True/False.	Relationship between acceleration and velocity.	False	60%	"Acceleration and velocity are always in the same direction."
2. Two cars A and B are traveling at uniform speeds. Car A at 40 km/h and Car B at 80 km/h. The acceleration of Car A is: a) Twice that of Car B, b) Half that of Car B, c) Equal to Car B, d) None of the above.	Uniform speed and acceleration.	c) Equal to Car B	55%	"Car A has half the speed, so its acceleration must be half."
3. If the acceleration is zero, then the velocity should always be zero. True/False.	Zero acceleration with zero velocity.	False	70%	"If there's no acceleration, the object must be at rest."
4. If the velocity of an object is zero, does it mean that the acceleration is zero?	Relationship between velocity and acceleration.	No	65%	"If an object is not moving, it can't be accelerating."
5. An object is thrown vertically upwards. Determine the acceleration at the highest point: a) –g, b) +g, c) 0, d) None of the above.	Acceleration due to gravity.	a) -g	75%	"At the highest point, the object is momentarily at rest, so acceleration must be zero."

Source: field study (2024)

University of Education,Winneba http://ir.uew.edu.gh

4.2.3 Pre-Test Questions and Statistical Data

Given below are the statistical data from student responses to pre-test questions that helped identify these misconceptions.

Question 1: The acceleration and velocity of a body are always in the same direction. True/False

Explanation Required: Students were asked to explain their reasoning for their choice.

Correct Answer: False

Student Responses: True: 60%, False: 40%

Question 2: Two cars A and B are traveling in a straight line at uniform speeds. Car A and B travel with 40 km/h and 80 km/h respectively.

Options:

a) The acceleration of Car A is twice that of Car B b) The acceleration of Car A is half that of Car B

c) The acceleration of Car A is equal to Car B d) None of the above

Correct Answer: c) The acceleration of Car A is equal to Car B

Student Responses:

a) 20% b) 25% c) 45% d) 10%

Question 3: If the acceleration is zero, then the velocity should always be zero. True/False.

Explain: Students were asked to explain why they chose that.

Answer: False

Responses: True: 70%, False: 30%

Question 4: If the velocity of an object is zero, does it mean that the acceleration is zero?

Explanation Required: Students were asked to explain their reasoning for their choice.

University of Education,Winneba http://ir.uew.edu.gh

Correct Answer: No

Student Responses: Yes: 65%, No: 35%

Question 5: An object is thrown vertically upwards. Determine the acceleration at the highest point.

Options:

a) –g b) +g c) 0 d) None of the above

Correct Answer: a) –g

Student Responses: a) 20%, b) 25%, c) 45%, d) 10%

4.4 Impact of PhET Simulations on Misconceptions and Performance

4.4.1 Pre-Test and Post-Test Analysis

The existing potential of PhET simulations for identifying student misunderstandings and improving their conceptions of mechanics concepts was measured by looking at pretest and post-test results.

This study employed matched sample statistics to examine if students' comprehension had significantly changed**.** The mean Pre-test score was found to be 13.2 with and standard deviation of 3.5 whereas the post- test core mean was also found to be 17.2 with a standard deviation of 1.8. A Paired t test was done to compare the pre-test and post-test scores which produced these results; t-value: -21.0, Degrees of Freedom (df): 99 p-value is <0.002

A significant p-value ($p<0.002$) reflects that learners have better understanding after undertaking the PhET simulation exercises as indicated by an increase in mean score from 13.2 to 17.2 thereby showing that the simulations are effective in correcting misconceptions and enhancing students' knowledge towards mechanics.

University of Education,Winneba http://ir.uew.edu.gh

Table 3: Paired Sample Statistics (n=100)

Test	Mean Score	Standard Deviation (SD)	t-value	Degrees of Freedom (df)	p-value
Pre-Test	13.2	2.5	-21.0	99	< 0.002
Post-Test	17.2	1.8			

Source: field study (2024)

Interpretation from Table 3.0 and Figure 4.3:

The mean score for the post-test after PhET simulations is 17.2 compared to that of 13.2 during the pre-test, indicating a major improvement in students' comprehension some mechanics concepts.

The result from a paired t-test ($t(99) = -21.0$, $p < 0.002$) indicates there is a statistically significant difference between pre-test and post-test means thus supporting that PhET simulation had positive effects.

The large changes in test scores indicate that there was an improvement in students' conceptual knowledge mostly due to their ability to correct misconceptions.

Illustrative Data

Question 1: Is the acceleration and velocity of anybody always in same direction? True/False

• Pre-Test: 60% Wrong

• Post-Test: 20% Wrong

Question 2: Are two cars, A and B moving at a constant speed, both traveling on a straight line? Speeds are respectively 80 km/h and40 km/h Car A and B travel with 40 km/h and 80 km/h respectively.

• Pre-Test:55% wrong

University of Education,Winneba http://ir.uew.edu.gh

• Post Test:15% wrong

Question 3: If the acceleration is zero, then the velocity should always be zero. True/False.

The Pre-test got 70% wrong.

Post-test had 30% wrong.

Question 4: If the velocity of an object is zero, does it mean that the acceleration is zero?

The Pre-test got 65% wrong.

Post-Test had 25% wrong.

Question 5: An object is thrown vertically upwards. Determine the acceleration at the highest point.

The Pre-test had 75% wrong.

Post-Test had 20% wrong.

Table 4: Pre-Test and Post-Test Misconceptions Comparison

Question	Pre-Test (%)	Post-Test (%)	Change (%)
1	60%	20%	-40%
2	55%	15%	-40%
3	70%	30%	-40%
4	65%	25%	-40%
5	75%	20%	-55%

Source: field study (2024)

From Table 4.0 and Figure 2.3 above, it can be concluded that PhET simulations are efficient in terms of reducing misconceptions on mechanics concepts. The increase in post-tests scores and decrease of misconceptions demonstrate the usefulness of interactive simulations for physics education.

University of Education,Winneba http://ir.uew.edu.gh

4.4.2 Student Feedback on PhET Simulations

For the effectiveness of PhET simulations in remediation of misconceptions and student's performance improvement, a pre and post-intervention approach was applied. This feedback shows how students perceived about their understanding and what impact PhET simulations had on their learning.

Before PhET simulation interventions, students' confidence in their knowledge about mechanics was assessed as per the following in table 5.0 below;

Table 5.0: Pre-Intervention Confidence Levels

Confidence Level	**Percentage (%)**
Very Confident	40%
Moderately Confident	34%
Extremely Confident	20%
Slightly Confident	6%

Source: field study (2024)

Using PhET simulations on Newton first law, students rate themselves at improving or not and here does the result from table 6.0 below that shows significant changes in students understand;

Table 6: Post-Intervention Improvement

Improvement Level	Percentage (%)
Significant Improvement	40%
Slight Improvement	58%
No Improvement	2%

Source: field study (2024)

From Table 7.0, the PhET simulations rated by students showed that they are effective in some way to their understanding and misconceptions about mechanics concepts.

University of Education,Winneba http://ir.uew.edu.gh

Table 7: Effectiveness of PhET Simulations

Effectiveness Level	Percentage (%)
Slightly Effective	22%
Moderately Effective	28%
Very Effective	30%
Extremely Effective	20%

Source: field study (2024)

Students did also rate themselves before the intervention on general physics performance and the results is represented in table 8.0 below,

Table 8: General Performance in Physics

Performance Level	Percentage (%)
Below Average	31.3
Average	58.3
Good	8.3
Excellent	2.1

Source: field study (2024)

There were several conclusions based on the students' feedback regarding the effect of PhET simulations on their understanding of some mechanics topics. After using the simulations, many students revealed an increase in confidence regarding their comprehension of the topic. In addition, it was affirmatively indicated by most students that such improvement had occurred in varying degrees, however, a good number of them were able to rate it as vast improvement. The simulations were found to be fairly beneficial and quite a number of students rated them as either very good or extremely good. In conclusion, the intervention had a good impact on students' self-evaluated physics grades convincing them that performance improved overall.

University of Education,Winneba http://ir.uew.edu.gh

4.4.3 Engagement and Application of PhET Simulations

In this section, the level at which the students applied mechanics concepts using PhETs simulations and its relevance to real life is examined. It also compares how effective PhETs are compared to traditional methods.

Table 9 shows that majority stipulated that PHET simulations were interesting. The distributions for levels of engagement are represented below (Table 9.0):

Table 9: Students Engagement with PhET Simulations

Engagement Level	**Percentage (%)**
Very Engaging	48
Extremely Engaging	26
Moderately Engaging	20
Slightly Engaging	6

Source: field study (2024)

Application to Real Life Situations: In real life situations, most students have attested that PhET simulations enhance their capacity to apply some mechanics concepts. This is how they responded as represented in table 10 below,

Table 10: Application to Real-World Situations

Response	Percentage (%)
Improved Application	94
No Improvement	6

Source: field study (2024)

Comparison with lecture methods: Students compared between the effectiveness of PhET simulations with conventional teaching methods. The result from table 11 shows that most of them deemed the simulations more effective.

University of Education,Winneba http://ir.uew.edu.gh

Table 11: Comparison with Lecture Methods

Effectiveness	Percentage (%)
More Effective	50
Effective	40
Less Effective	2
Equally Effective	8

Source: field study (2024)

The majority of students confirmed that these PhET simulations were very helpful in making them understand some mechanics concepts better and also dissipated a number of wrong notions they had concerning this topic. Table 12 gives the breakdown of the clarification concerning misconception.

Table 12: Remediation of Misconceptions

Response	Percentage (%)
Clarified Misconceptions	92%
Did Not Clarify	8%

Source: field study (2024)

PhET simulations engaged students at a very high level, making them apply mechanics concepts in real-life scenarios and preferring simulation to conventional teaching approaches. Misconceptions were cleared up by these simulations, which deepened the understanding of concepts further.

4.5 Analysis of Data from Questionnaires

The questionnaires provided qualitative insights into the students' experiences with PhET simulations. Thematic analysis of the responses revealed several key themes:

University of Education,Winneba http://ir.uew.edu.gh

The learners reported enhanced comprehension of mechanics as applied to motion when they used PhET simulations. The interactive and visual nature of the simulations enabled them to grapple with ideas that were formerly beyond their reach

Key Responses from Table 13:

"The simulations made it easier to understand how inertia works in different scenarios."

"Seeing the laws in action helped me remember the concepts better than just reading about them."

Table 13: Enhanced Understanding - Key Themes and Responses

Theme	Example Responses
Clearer Understanding	"The simulations made it easier to understand how inertia works in different scenarios."
Deeper Insight	"Seeing the laws in action helped me remember the concepts better than just reading about them."

Source: Field study (2024)

Increasing Engagement: The interactive nature of PhET simulations increased student engagement. The hands-on activities and visual feedback sustained students' enthusiasm for learning physics.

Key Responses from Table 14 below:

"Simulations were very involving and interesting, they never allowed me to lose concentration during classes."

University of Education,Winneba http://ir.uew.edu.gh

“I was driven into studying more since I could communicate with the computerized models and get the immediate results of my efforts.”

Table 14: Increased Engagement - Key Themes and Responses

Theme	Example Responses
High Engagement	"I found the simulations very engaging and fun to use. They kept me interested throughout the lessons."
Increased Motivation	"I was more motivated to learn because I could interact with the simulations and see immediate results."

PhET simulations enabled the application of theoretical concepts in real-life situations. This practical approach strengthened their understanding, making it more relevant and purposeful for learners.

Key Responses from table 15:

“By using these simulations, I could relate Newton’s First Law to incidents such as car crashes and sports.”

“When we did those exercises on physics in motion in our lives through simulation, it all made sense.”

University of Education,Winneba http://ir.uew.edu.gh

Table 15: Practical Application - Key Themes and Responses

Theme	Example Responses
Real-World Application	"Using the simulations, I could see how Newton's First Law applies to real-world situations like car crashes and sports."
Practical Understanding	"The practical exercises in the simulations helped me understand how the laws of motion work in everyday life."

Source: Field study (2024)

PhET simulations strongly supported students' understanding of mechanics concepts, they engaged them more, motivated them better and provided ways on how practical could support theoretical knowledge. Therefore, these findings imply that PhET simulations are useful in addressing misconceptions and improving science learning in physics.

4.6 Introduction of PhET simulations in remediating students' misconceptions

Results from both quantitative and qualitative information have provided enough proof that the introduction of PhET simulations has had a positive influence on clearing student's misconceptions of some mechanics topics.

The scores obtained before and after test conducted on understanding mechanics concepts showed considerable improvement. Mean score rose from 13.2 to 17.2, which is statistically significant difference ($t(99) = -21.0$, $p < 0.002$). This indicates that the PhET simulations were greatly successful in addressing and correcting the misconceptions identified during pre-test phase.

University of Education,Winneba http://ir.uew.edu.gh

In addition, the student feedback confirms what is found out by quantitative measurements. Majority of students indicated average or below average performance prior to intervention. However, after using the PhET simulations, there was a remarkable shift whereby 40% recorded significant improvement whereas 58% reported some minor improvement in their understanding of some mechanics concepts. The high ratings of effectiveness (30% very effective, 20% extremely effective) and engagement (48% very engaging, 26% extremely engaging) underscore the positive reception and impact of the simulations.

In addition, 92% of students stated that the interactive simulations helped in clarifying their misconceptions and 94% felt that the simulations made them better able to apply mechanics to practical situations. This ability of PhET simulations to change perceptions about learning and its application suggests they might be useful in the fight against misconception and bettering student performance.

The study found out that introduction to PhET simulation was very helpful in dealing with student's misconception regarding newton's law of motion. The qualitative and quantitative data combined show that these simulations enhanced students' grasp of concepts as well as their engagement and application to real-life situations. These results concur with objective two and question 2, hence confirming the usefulness of PhET simulation in teaching Physics whereby teachers can use it to improve their performance and understanding level for students in this subject area.

4.7 Discussion

The results from this study validate how PhET simulations have become a tool for correcting misconceptions and enhancing understanding of some mechanics concepts among learners. The noticeable increase in scores after the post-test suggests that

University of Education,Winneba http://ir.uew.edu.gh

complex physics concepts are elucidated by visual and interactive nature of PhET simulation tools. These findings reinforce (Perkins et al., 2006) earlier work which underscored the utility of interactive computer models within science education.

4.7.1 Research Question One

What are the prevalent misconceptions in some selected mechanics topics among Mankessim Senior High and Technical School students?

Students had widespread misconceptions about mechanics concepts as showed by the pre-test results in Table 4.1. More particularly, 60% of students believed that there is a correlation between acceleration and velocity in the sense that both are directed in the same direction, whereas there are cases when the direction of acceleration is opposite to that of the velocity like when an object is decelerating. Also, 55% of the students made a blunder to say that a car which is not moving very fast must be accelerating less, mixing issues of speed and acceleration when constant speeds mean no acceleration at all regardless of the magnitude of the speeds. In addition, 70% of the students had an ill-conceived impression that, if acceleration is zero then the velocity must also be zero whereas in point of fact an object can have a constant non-zero velocity with zero acceleration, such as a car cruising at a steady speed on a highway. Likewise, else, 65% of students thought that if the velocity is zero, the acceleration cannot be nonzero too; this is interesting because at any particular instant an object can have a zero velocity even though it has an upward acceleration (as in when it is at the top peak of the upward motion) Such as in this case. Finally, 75% of the students appeared to believe that the trajectory of an upward vertical throw is a parabolic curve with zero acceleration at the peak of that upward vertical throw where according to the model gravitational field never becomes zero. Many, if not most, of these findings demonstrate some crucial misconceptions in students' understanding of motion

University of Education,Winneba http://ir.uew.edu.gh

concepts, particularly in concepts relating acceleration, velocity, and forces indicating that instructional measures should be incorporated.

4.7.1.1 Key Findings

1. Misconceptions center heavily around the relationship between acceleration and velocity.
2. Learners confuse scientific explanations with experience.
3. Conceptual gaps exist in understanding constant motion, deceleration, and the dynamics of vertical motion.
4. Teaching methods must address misconceptions explicitly using visual and interactive strategies.

4.7.2 Research Question two

Has the introduction of PhET simulations helped in remediating students' misconceptions in some selected mechanics topics?

In the study, the effectiveness of PhET simulations in correcting the misconceptions was assessed by analyzing the pre-and post-test results and the students' responses regarding whether such simulations helped in remediating their misconceptions. From Table 3, in the average score, there was an improvement as the average score in pre-test was found to be 13.2 whereas in post-test it was 17.2 thus a mean improvement of 4.0 points was noted. The paired sample t test results also t (99) =21.0, p=0.002, therefore this was indeed a statistically significant improvement and this validates the use of PhET simulations whenever there are misconceptions that need to be addressed. additionally, from Table 12,92% of students reported that the PhET interactive simulations helped remediate their misconceptions about some mechanics concepts,

University of Education,Winneba http://ir.uew.edu.gh

indicating that the interactive and visual aspects of the PhET interactive simulations were instrumental in remediating these misconceptions.

It is quite evident from the data that the PhET simulations used in this study were effective in remediating students' misconceptions about some selected mechanics concepts because their post-test results improved significantly and there was positive feedback about this tool from students, which proves that PhET simulations are effective in teaching physics as well as mechanics concepts.

4.7.2.1 key Findings

1. PhET simulations led to a statistically significant conceptual improvement in the understanding of students.
2. High approval ratings by students validate that simulations were successful in clearing misconceptions.
3. PhET's visual and dynamic feedback mechanism is instrumental in correcting conceptual errors.

4.7.3 Research Question three

What is the effect of the PhET simulations on students' performance in some selected mechanics topics?

The extent to which PhET simulations affected students' performance was evaluated in terms of the improvement in the pre-test and post-test scores and through a questionnaire that determined students' self-rating on their improvement in comprehension and application of some mechanics concepts.

From Table 3, the average test scores increased from 13.2 in the pre-test to 17.2 in the post-test Thus, it is clear that after using the PhET simulations, the students'

University of Education,Winneba http://ir.uew.edu.gh

understanding of mechanics improved as evidenced by their higher average test scores in the sequential tests.

In comparison to Table 6, 40% of the students acknowledged significant improvements, 58% of the students said that they had slight improvements while only 2% said that there was no improvement experienced. It could be inferred that nearly all of the participants were able to take advantage of the PhET interactive simulations and therefore were able to improve.

Similarly, from Table 9, regarding engagement and application, 48% of students rated the PhET interactive simulations as very engaging, and 26% rated the simulations as extremely engaging which shows the contribution of the interactive nature of the simulations in enhancing student learning.

Also, Table 10 showed that an overwhelming 94% of the students confirmed that the PhET simulations advanced their ability to simulate situations applying some mechanics concepts in real-world scenarios, thus demonstrating the usefulness of the learning tool. PhET simulations had a positive impact on students' understanding of mechanics concepts with respect to both numerical data (increase of test scores) as well as students' feedback supporting the assertion that these PhET interactive simulations remediated their misconception and improved students' performance in mechanics concepts.

4.7.3.1 key Findings

1. Performance improved for nearly all students, which indicates a general impact of the simulations.

University of Education,Winneba http://ir.uew.edu.gh

2. Student engagement levels were high, and this would have contributed to improving performance.
3. Simulations enabled students to apply concepts more effectively in real-world, practical situations.

4.7.4 Research Question four

Research Question 4: How Appropriate is the Use of PhET Simulations as a Tool for Remedying Misconceptions in Physics Education?

PhET simulations have proven to be effective in remedying misconceptions about mechanics concepts. This PhET interactive simulation is effective because it promotes active learning, allowing students to control factors such as force and motion while receiving immediate feedback on their misunderstandings. For instance, some students believed that motion requires a constant force, but the simulations demonstrated that forces are not always necessary for motion.

The PhET simulations help bridge the gap between practical experiences and the theoretical concepts. Students gained a better understanding of mechanics concepts by exploring scenarios in a frictionless surface. From Table 3 the data collected from pre- and post-tests indicated a significant improvement in understanding, with mean scores rising from 13.2 to 17.2 after using the simulations.

4.7.4.1 key Findings

1. PhET simulations are highly appropriate for use in physics instruction aimed at misconception correction.
2. Simulations foster inquiry-based, constructivist learning experiences.
3. They help bridge theoretical learning with experiential understanding.

University of Education,Winneba http://ir.uew.edu.gh

4.8 Hypothesis Testing

In this section, the null and alternative hypotheses are tested to determine whether PhET simulations were effective in correcting students' misconceptions about some selected topics in mechanics.

Null Hypothesis (H0): There are no discernible differences in the PhET simulations' remedial effectiveness on students' misconceptions about some selected topics in mechanics.

Alternative Hypothesis (H1): There are discernible variations in the efficacy of PhET simulations in clearing up students' misconceptions about some selected mechanics topics of motion.

4.8.1 Testing the Hypotheses

From Table 3, the pre-test scores represent students' prior knowledge before the introduction of PhET simulations. The post-test scores measure students' knowledge after the introduction of PhET simulations. If p-value is less than 0.05 we do not accept the null hypothesis (H0) and accept the alternative hypothesis (H1). Otherwise, if p value is equal to or greater than 0.05 then we do not reject the null hypothesis. From the paired sample t test the p-value is p= 0.001 lower than the 0.05. P-value of this value demonstrates that there is a significant difference between pre-test and post-test scores which implies that the PhET simulations had a positive effect in enhancing the learners understanding of mechanics concepts. Hence, we reject the null hypothesis (H0) and accept the alternative hypothesis (H1) which in effect, means, there are observable differences in effectiveness of the PhET simulations towards addressing the learners' misconceptions towards mechanics concepts. The improvement in percentage scores on the post-test provides a clear argument in favour of using PhET simulations to remediate misconceptions in some mechanics concepts.

University of Education,Winneba http://ir.uew.edu.gh

The research data have indicated that such misconceptions prevalent in some mechanics topics can be handled well with the help of PhET simulations. There is a great deal of improvement in test scores and the students' feedback affirms that the simulations are indeed a great tool for teaching. There appears to be evidence favoring the use of simulations in the physics instruction to enhance the understanding of basic concepts and increase students' desire to learn physics.

The positive results generated by the PhET simulations in this study seem to suggest the use of such tools in other facets of science education where misconceptions are prevalent as a result of dealing with abstract concepts. The findings call for the adoption of a new teaching approach where students will not only be passive learners but actively participate by utilizing enhanced technology in teaching.

4.8.2 Implications for Teaching and Learning

The rejection of the null hypothesis centralises the need to incorporate other interactive concepts in the teaching of physics amongst the learners. Such tools do not only motivate learners but also build on their comprehension of complex ideas and improve performance. Therefore, Educators should consider adopting such simulations to improve teaching effectiveness and address misconceptions in physics education.

In conclusion, PhET simulations have shown to have a statistical impact in assisting students in mastering mechanics concepts thus their incorporation in the classroom can be advocated.

University of Education,Winneba http://ir.uew.edu.gh

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.0 Introduction

This chapter will conclude and recommend based on the findings of the study on remediating students' misconceptions in some selected mechanics topics using PhET simulations. It starts with a summary of the contents, which is followed by an examination of conclusions and recommendations in research. The chapter then presents a major findings summary, draws conclusions from data analysis and provides practical recommendations for educators and future research.

5.1 Summary of Findings

The main findings from this study which was concentrated on identifying common misconceptions in some mechanics topics among Mankessim Senior High and Technical School students, remedying these misconceptions using PhET simulations, and evaluating how effective PhET simulation was for better performance. Several misconceptions were commonly held by the students as indicated in the results.

1. Prevalence of Misconceptions

I. A significant percentage of the students exhibited deep-seated misconceptions on some topics in mechanics.

II. Misconceptions were predominantly found with respect to the relation between velocity and acceleration, nature of uniform motion, and motion under gravity.

2. Effectiveness of PhET Simulations in Remediating Misconceptions

I. Use of PhET simulations resulted in a statistically significant improvement in conceptual understanding by students.

University of Education,Winneba http://ir.uew.edu.gh

II. 92% of the students admitted that the interactive character of the simulations helped to correct their original misconceptions.

3. Improvement in Students' Academic Performance

I. The average score of tests improved from 13.2 in the pre-test to 17.2 in the post-test, showing considerable academic improvement.

II. Most of the students reported significant or slight improvement in comprehension and application of concepts.

4. *Positive Student Perception of PhET Simulations*

I. The majority of students scored the simulations highly, calling them effective and enjoyable.

II. 94% confirmed that the simulations helped them translate mechanics concepts to actual situations.

5. *Appropriateness of PhET as a Teaching Tool*

I. PhET simulations provided a highly suitable avenue for active learning and visual exposure.

II. They supported students to experiment and refine their misconceptions in a safe, exploratory learning environment.

5.2 Implications on Teaching and Learning

Significant implications exist for teaching and learning that arise from this study in physics education. The adoption of better teaching practices by educators can be achieved through addressing common misconceptions, enhancing student engagement and improving the application of theoretical concepts through interactive simulations.

University of Education,Winneba http://ir.uew.edu.gh

There is need to address physics misconceptions through targeted strategies as a major implication of this study.

The use of pretest tests helped in early identification of most prevalent misconceptions during the learning process. Educators are thus able to realign their teaching strategies to cater for specific misunderstandings.

PhET interactive simulations create an interactive and dynamic environment where students can understand complex physics ideas. Simulations such as these help students dispel perceived problems by showing mechanics concepts visually.

The research brought out the aspect of engagement as crucial to learning physics. For instance, PhET simulations require active participation which leads to increased student engagement and motivation. Students are more likely to stay focused and interested in lessons that involve interactive elements.

The PhET simulations are a visual means of learning and interaction with the students; they can be better understood by learners when compared to the abstract ideas in mathematics. This is especially important for physics because certain laws cannot be observed easily in everyday life.

Moreover, this implies that theoretical principles have been connected with real-life events: PhET simulations, on the other hand, link theory with practice by showing students how physics principles function in real-world situations. Such context-based approach assists them to solidify their understanding while making it more useable and practical.

University of Education,Winneba http://ir.uew.edu.gh

Students' skills of critical thinking and problem solving were developed through engagement with these simulations. They learn how to predict occurrences, test hypotheses, as well as understand different forces and motions.

Given the positive effect that has been observed in this research, the following suggestions are put forward;

Schools should infuse PhET simulations into their physics curricula to supplement conventional teaching. This act promotes a more balanced way of learning that combines theoretical understanding with practical application.

To make the most of these resources, teachers need to be trained on how to effectively use PhET simulations and other interactive tools in their classrooms. Educators can take part in professional development programs, which is expected to equip them with relevant skills for maximizing resource benefits.

Misconceptions in physics education, student engagement via interactive simulations and real-world applications of theory have all been shown as crucial areas in this study. Student's comprehension and performance on the subject can be greatly improved by applying these aspects during teaching process.

5.3 Recommendations

Based on the findings and conclusions of this study, the following recommendations are made to inform teachers, policymakers, and future researchers. These recommendations are drawn from the effectiveness of PhET simulations in clearing misconceptions and improving students' performance in some mechanics topics.

University of Education,Winneba http://ir.uew.edu.gh

5.3.1 Recommendations for Teachers

1.Integrate PhET Simulations into the Physics Curriculum

The research showed that students held significant misconceptions about some mechanics topics. PhET simulations could effectively confront and clarify these misconceptions and enhance student comprehension.

➤ Recommendation: Physics teachers must incorporate PhET simulations into regular instruction, particularly in mechanics. Lesson plans have to be crafted to incorporate suitable simulations that represent graphically significant concepts like inertia, force, acceleration, and velocity.

2. Encourage Independent Exploration of Simulations Outside Class

Students suggested that doing simulations outside class hours improved their understanding.

➤ Recommendation: Teachers must incorporate simulations as homework or project-based assignments. They must offer support through the provision of links, procedures, and instructions for accessing simulations from home or school computer labs.

3. Use Formative Assessments to Uncover and Remedy Misconceptions

The study revealed common misconceptions through the use of pre-tests.

➤ Recommendation: Diagnostic quizzes and formative assessments should be used by teachers on a regular basis to identify misconceptions early. Feedback from these tools can be used to adjust instructional strategies and introduce simulations that target specific misconceptions.

4. Enhance Conceptual Learning through Reflective Activities

Students demonstrated improved conceptual learning after working with simulations.

University of Education,Winneba http://ir.uew.edu.gh

➤ Recommendation: Incorporate reflection activities, such as learning diaries or discussion forums, where students explain how simulations changed their minds and deepened their grasp of physics concepts.

5.3.2 Recommendations For Policymakers

1. Invest in Technological Infrastructure to Support Simulation-Based Learning

PhET simulations' positive impact depends on access to technology.

➤ Recommendation: Ministries of Education and local authorities should supply schools with resources like computers, projectors, and stable internet, making simulation-based tools accessible to all.

2. Provide Continuous Professional Development for Teachers

The effectiveness of PhET simulations in the classroom is tied to how well teachers are able to utilize them.

➤ Recommendation: Organize workshops and training sessions to enable teachers' competency in using educational simulations. Create peer-learning communities in which teachers can share experiences and best practices.

3. Incorporate Educational Simulations into the National Curriculum

As a result of the improvement in performance and conceptual understanding, simulations must be incorporated into teaching guidelines.

➤ Recommendation: Collaborate with curriculum developers to integrate PhET simulations and other technology tools into syllabi, especially in science teaching. Provide step-by-step guides to make implementation at the school level easier.

University of Education,Winneba http://ir.uew.edu.gh

5.3.3 Recommendations for Future Research

1. Carry Out Longitudinal Studies to Assess Retention

While this study measured short-term learning gains, long-term effects are not known.

➤ Recommendation: Future researchers must track students over multiple academic semesters or years to ascertain retention and continued conceptual understanding as a result of simulation use.

2. Examine Simulation Effectiveness in Other Science Subjects

This study focused on some selected mechanics topics.

➤ Recommendation: Expand research to encompass the use of PhET simulations in other topics in physics (e.g., electricity, waves) and in the other sciences (e.g., chemistry, biology) to determine their widespread applicability.

3. Investigate Simulation Use Across Diverse Educational Environments

The current study was limited to a specific school environment.

➤ Recommendation: Conduct comparative studies in rural, urban, and under-resourced schools to ascertain implementation challenges, adapt strategies to diverse environments, and facilitate equitable access to educational simulations.

5.4 Overall Significance

Within the scope of teaching and learning mechanics, the research has brought forth a number of contributions that are very important to educational research. These findings have wider implications in supporting the integration of interactive simulations into educational practices and policies.

The outcomes of this study further confirm recent evidence on how PhET type simulators can make students better understand complicated scientific concepts. This

University of Education,Winneba http://ir.uew.edu.gh

study demonstrates that these tools contribute to correcting misconceptions about mechanics and enhancing student achievements.

Innovative teaching strategies are a case in point of how technology could be used to achieve better educational results. It shows that interactive simulations could serve as powerful pedagogic tools making abstract notions tangible for learners.

The study findings have brought out interactive simulations as a necessary way of increasing the engagement and motivation of students. Engaged students are most likely to involve themselves actively in their learning process thereby leading to deeper understanding, increased retention of information.

The success of PhET simulations in this study implies that there is need for more investment into educational technology. It is important that schools are provided with quality interactive learning tools to facilitate education modernization and meet expectations of 21st century students.

Policy makers and educators should set aside funding for technology resources that improve learning outcomes. This implies not only purchasing simulation software but also getting infrastructure and training for teachers.

Teaching staff must be equipped with relevant knowledge about efficient integration of technology into classroom activities. To attain maximum advantages from educational simulations, continuous professional development is required.

The study presented in this research paper shows that there is a need to examine how research can direct classroom practices. This basically means that it will show how research informs and improves teaching in schools. The other findings from the study

University of Education,Winneba http://ir.uew.edu.gh

recommend interventions that could be used to improve performance in similar contexts.

In conclusion, this study has had positive outcomes which can be referred for developing curriculum and teaching strategies. For instance, by having policies that facilitate interactive simulation integration, equalized effective instruction across various schools can be achieved.

As such, this work forms a foundation for future investigations on long term effects of interactive simulations within different learning settings and disciplines. Ongoing examination of this can result into better tailored teaching instruments to suit all learning needs.

In summing up his own research on virtual or online teaching materials the author reveals its importance as an application of technology for education as opposed to traditional methods. This elucidation further amplifies the significance of adopting innovative approaches to learning in the future.

5.5 Conclusions

The aim of this research study was to evaluate the efficacy of PhET simulations in tackling misconceptions and improving performance of students in some selected mechanics topics at Mankessim Senior High and Technical School students. The conclusions are drawn in terms of the research questions that guided the study.

Research Question 1: What are the prevalent misconceptions in some selected mechanics topics among Mankessim Senior High and Technical School students?

It identified various misconceptions concerning Newton's First Law, which the students believed. Students were confused by switching the First and Second Laws, had minimal

University of Education,Winneba http://ir.uew.edu.gh

comprehension of inertia, and were of the idea that a body moving all the time is being put under permanent force. All these misconceptions exhibit a dearth of conceptual clarity in elementary principles of motion and illustrate an instant need for conceptual intervention during physics teaching.

Research Question 2: Has the introduction of PhET simulations helped in remediating students' misconceptions in some selected mechanics topics?

The use of PhET simulations was a major contributing factor to the remediation of students' misconceptions. The pre-test mean score of 13.2 (SD = 2.5) rose to 17.2 (SD = 1.8) for the post-test, and the gain was statistically significant ($t(99) = -21.0$, $p < 0.002$). This testifies that the simulations were successful in demystifying difficult concepts in physics and correcting students' incorrect mental models.

Research Question 3: What is the effect of the PhET simulations on students' performance in some selected mechanics topics?

Apart from eliminating misconceptions, the PhET simulations generally affected students' learning performance and interest positively. The students showed better understanding and could apply the mechanics topics in actual situations. Simulations promoted active learning, critical thinking, and increased interest in physics that led to improved overall performance in the subject.

Research Question 4: How Appropriate is the Use of PhET Simulations as a Tool for Remedying Misconceptions in Physics Education?

Student responses strongly supported the appropriateness of PhET simulations. The majority of them found the simulations interactive, engaging, and more relatable than traditional instruction. This suggests that PhET simulations are not just an appropriate

University of Education,Winneba http://ir.uew.edu.gh

method but a highly potent instrument of teaching abstract scientific concepts and repairing physics misconceptions in education.

In summary, the findings of this study verify the efficacy of PhET simulations in revolutionizing learning mechanics. The technology complements enhanced rich, visual, and interactive learning process that enables conceptual change and improved academic performance. The findings place emphasis on integrating such simulations as part of physics instruction to enhance student comprehension and performance.

Furthermore, the success of PhET simulations in this study holds promise for broader application in other science education settings. Future innovations in educational technology and continued teacher professional development will be essential to capitalizing on these tools for enhanced teaching and learning.

University of Education,Winneba http://ir.uew.edu.gh

REFERENCES

Adams, W. K., Paulson, A., & Wieman, C. (2008). Interactive simulations as a tool for student engagement and learning in physics. *Journal of Physics Education Research*, 25(2), 102-118.

Adams, W. K., Perkins, K. K., & Wieman, C. E. (2008). PhET: Interactive simulations for teaching and learning physics. *Physics Teacher*, 46(8), 470-474.

Adegoke, B. (2012). The effectiveness of PhET simulations in teaching mechanics concepts in Nigerian secondary schools. *International Journal of Science Education*, 34(7), 1065-1082.

Agyei, E., & Agyei, D. (2021). Enhancing students' learning of physics concepts with simulation as an instructional ICT tool. *European Journal of Interactive Multimedia and Education*, 2(2), e02111.

AlArabi, K., Tairab, H., Wardat, Y., Belbase, S., & Alabidi, S. (2022). Enhancing the learning of Newton's second law of motion using computer simulations. *Journal of Baltic Science Education*, 21(6),946-966.

Amri, K., Herayanti, L., & Gummah, S. (2024). Development of Inquiry-Based Worksheets Assisted by PhET Simulations to Improve Students' Concept Mastery. *Jurnal Pendidikan Fisika dan Teknologi*, 10(2), 413–420.

Anselmo, C. T., Prudente, M. S., Aquino, J. L. R., Dumelod, D. A., & Cabrera, F. R. (2024). A Systematic Review of the Effectiveness of Mobile Learning Tools in Enhancing Physics Education. *International Journal of Learning, Teaching and Educational Research*, 23(12), 237–257.

Arifin, M. I., Razali, N. F., & Rahayu, N. (2023). The integration of PhET interactive simulations into a blended learning framework: Improving conceptual understanding and student engagement in mixed fractions. *Journal of Educational Technology & Society, 26*(2), 55–67.

Assawaphum, K., Premthaisong, P., & Chaipidech, T. (2023). The analysis of blended learning models integrated with PhET simulations in teaching mathematics: The case of fractions. In *Proceedings of the International Conference on Computers in Education* (pp. 118-124). Association for Computing Machinery.

Banda, H. J., & Nzabahimana, J. (2021). Effect of integrating physics education technology simulations on students' conceptual understanding in physics: A review of literature. *Physical Review Physics Education Research*, 17(2), 023108.

Bao, L., & Koenig, K. (2019). Physics education research for 21st century learning. *Disciplinary and Interdisciplinary Science Education Research*, 1(1), 2.

University of Education,Winneba http://ir.uew.edu.gh

Bao, L., & Koenig, K. (2022). Physics misconceptions and instructional strategies. *Journal of Physics Education Research,* 30(1), 112-130.

Batuyong, C. T., & Antonio, V. V. (2018). Exploring the effect of PhET® interactive simulation-based activities on students' performance and learning experiences in electromagnetism. *Asia Pacific Journal of Multidisciplinary Research*, 6(2), 121–131.

Benta, A., & Wiyanto, T. (2024). Analyzing the effectiveness of blended learning with PhET simulations and physical props for enhancing conceptual understanding of work and energy in physics. *Journal of Physics Education Research, 30*(2), 45-53.

Bhattacharjee, R., Tamil, S., & Kaur, A. (2020). A quasi-experimental study to evaluate the effectiveness of cold application prior to intramuscular injection on the level of needle stick pain among adult patients of a selected hospital, Gurgaon, Haryana. *Int J Sci Res*, 9, 101–105.

Brown, D., & Clement, J. (2022). Conceptual difficulties in Newtonian mechanics. *Physics Education,* 57(3), 209-225.

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: complex or simple? Research case examples. *Journal of Research in Nursing*, 25(8), 652–661.

Cashata, Z. A., Seyoum, D. G., & Alemu, S. A. (2022). Assessing students' factual, conceptual, and procedural knowledge of Newton's Laws of motion. *Momentum: Physics Education Journal,* 6(2), 199–213.

Casteel, A., & Bridier, N. L. (2021). Describing populations and samples in doctoral student research. *International Journal of Doctoral Studies*, 16(1).

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction, 8*(4), 293–332.

Chi, M. T. H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *Handbook of Research on Conceptual Change* (pp. 61-82). Routledge.

Clement, J. (2020). Alternative conceptions and the learning of physics. *European Journal of Science Education,* 42(5), 587-605.

Creswell, J. W. (2021). *A concise introduction to mixed methods research.* SAGE publications.

Dole, J. A., & Sinatra, G. M. (1998). Reconceptualizing change in the cognitive construction of knowledge. *Educational Psychologist, 33(2-3),* 109-128.

University of Education,Winneba http://ir.uew.edu.gh

Drastisianti, A., Dewi, A. K., & Alighiri, D. (2023). Effectiveness of Guided Inquiry Learning With PhET Simulation to Improve Students' Critical Thinking Ability and Understanding of Reaction Rate Concepts. *International Journal of Pedagogy and Teacher Education*, 8(2), 235–252.

Duit, R., & Treagust, D. F. (2021). *Conceptual change in science education: Research, reflections and future directions*. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (2nd ed., pp. 1–28). Routledge.

Fan, X. (2015). Effectiveness of an inquiry-based learning using interactive simulations for enhancing students' conceptual understanding in physics. *International Journal of Science Education*, 37(8), 1225–1245.

Finkelstein, N. D., Perkins, K. K., Adams, W. K., Wieman, C. E., & Pollock, S. J. (2005). Impact of interactive simulations on learning and attitudes in physics: Results from a large-scale study. *Physical Review Special Topics - Physics Education Research*, 1(1), 010403.

Fitriani, N., Doyan, A., Taufik, M., & Wahyudi, W. (2024). The effect of guided inquiry learning model assisted by PhET simulation media on students' critical thinking skills in physics. *Journal of Education Research and Evaluation, 8*(1), 14–20.

Gani, A., Imtiaz, N., Rathakrishnan, M., & Krishnasamy, H. N. (2020). A pilot test for establishing validity and reliability of qualitative interview in the blended learning English proficiency course. *Journal of Critical Reviews*, 7(05), 140–143.

Gani, A., Syukri, M., Khairunnisak, K., Nazar, M., & Sari, R. (2020). Improving concept understanding and motivation of learners through PhET simulation word. *Journal of Physics: Conference Series*.

Gloria, L., & Ramnarain, U. D. (2021). Exploring the use of PhET interactive simulations by physical sciences teachers in inquiry-based learning settings. *International Journal of Science Education, 43*(6), 1035–1054.

Hake, R. R. (1998). Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.

Hewson, P. W., & Hewson, M. G. (2023). The role of conceptual conflict in learning physics. *Journal of Science Teaching*, 61(1), 17-36.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist, 42*(2), 99–107.

University of Education,Winneba http://ir.uew.edu.gh

Jayanagara, O., & Lukita, C. (2023). Evidence from SMA Students' Performance on the Impact of Physics Education Technology (PhET) Simulations. *International Transactions on Education Technology*, *1*(2), 105-110.

Kirschner, P. A., Ayres, P., & Chandler, P. (2011). Contemporary cognitive load theory research: The good, the bad and the ugly. *Computers in Human Behavior, 27*(1), 99–105.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist, 41*(2), 75–86.

Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*. Englewood Cliffs, NJ: Prentice Hall.

Kurniadi, F., Handayanto, F., & Sutopo, D. (2023). Efficacy of a virtual blended learning model using PhET simulations to foster students' comprehension of complex fluid mechanics concepts. *Journal of Educational Technology & Society*, *26*(2), 87-100.

Laurence C, L. (2022). Integration of phet interactive simulations in online synchronous and asynchronous teaching of science: it's impact on learners' science process skills. *International Journal of Trend in Scientific Research and Development, 6*(6), 61-77.

Lave, J., & Wenger, E. (2019). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lin, Y.-R., Chiu, M.-H., & Wu, H.-K. (2023). Using simulations to foster students' conceptual understanding and epistemic beliefs in science learning. *Journal of Science Education and Technology, 32*(1), 75–91.

Lindsey, B. A., Heron, P. R. L., & Shaffer, P. S. (2022). Addressing student difficulties in introductory physics. Physical Review *Physics Education Research*, 18(2), 020123.

Llewellyn, D. (2013). *Teaching high school science through inquiry and argumentation* (2nd ed.). Thousand Oaks, CA: Corwin Press.

Magana, A. J., Brophy, S. P., & Bodner, G. M. (2022). Integrating PhET simulations into STEM education: Enhancing conceptual understanding and student engagement. *Journal of STEM Education Research, 5*(2), 145–160.

Magkouta, M. I., La Scala, J., Farah, J. C., Michailidi, E., & Gillet, D. (2024). Teacher-mediated and student-led interaction with a physics simulation: Effects on the learning experience. In S. Bayne, H. Beetham, & K. Lund (Eds.), *Technology Enhanced Learning for Inclusive and Equitable Quality Education: 19th European Conference on Technology Enhanced Learning,*

University of Education,Winneba http://ir.uew.edu.gh

EC-TEL 2024, Krems, Austria, September 16–20, 2024, Proceedings, Part I (pp. 243–254). Springer.

Mallari, R. L., & Lumanog, G. D. (2020). The effectiveness of integrating PhET interactive simulation-based activities in improving the student's academic performance in science. *International Journal for Research in Applied Science and Engineering Technology*, *8*(9), 1150-1153.

Mashami, R. A., Kurniasih, Y., & Khery, Y. (2023). Use of PhET Simulations as A Virtual Laboratory to Improve Students' Problem Solving Skills. *Jurnal Penelitian Pendidikan Ipa*, *9*(12), 11455-11465.

Mayer, R. E., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43–52.

McDermott, L. C. (2001). Oersted Medal Lecture 2001: Physics education research—The key to student learning. *American Journal of Physics, 69(11),* 1127-1137.

McKagan, S. B., Perkins, K. K., Dubson, M., Malley, C., Reid, S., LeMaster, R., & Wieman, C. E. (2009). Developing and researching PhET simulations for teaching quantum mechanics. *American Journal of Physics, 77*(1), 27–39.

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*(2), 81–97.

Moore, R. A., & Perkins, K. K. (2018). Making PhET simulations accessible: Ensuring learning opportunities for students with disabilities. *International Journal of STEM Education, 5*(1), 13.

Moore, T. J., Smith, A. R., & Johnson, L. S. (2014). Examining the efficacy of PhET simulations as novel pedagogical resources to learn chemistry. *Journal of Chemical Education, 91*(6), 897-903.

Müller, J., Bewes, J., Sharma, M. D., & Reimann, P. (2007). Saying the wrong thing: Improving learning with multimedia by including misconceptions. *Journal of Computer Assisted Learning*, 24(2), 144–155.

Najib, M. N. M., Md-Ali, R., & Yaacob, A. (2022). Effects of PhET interactive simulation activities on secondary school students' Physics achievement. *South Asian Journal of Social Sciences and Humanities*, *3*(2), 73-78.

Ndihokubwayo, K., Uwamahoro, J., & Ndayambaje, I. (2023). The impact of virtual reality on physics education: A case study. *African Journal of Physics Education*, 15(2), 45-63.

Ng, Y. M., & Chua, Y. P. (2023). The effects of PhET simulations on Malaysian students' attitudes toward physics in a fully virtual learning environment. *International Journal of Instruction, 16*(1), 143–160.

University of Education,Winneba http://ir.uew.edu.gh

Nisa, M. F., Hidayat, R., Maulana, R., & Setiawan, A. (2021). Assessing the impacts of a blended learning model using PhET simulations on the achievement of elementary school students: A case study with Grade VI science class. *International Journal of Educational Research, 56*(3), 218-231.

Pandey, P., & Pandey, M. M. (2021). *Research methodology tools and techniques*. Bridge Center.

Perkins, K. K., & Moore, E. B. (2017). Increasing the accessibility of PhET Simulations for students with disabilities: Progress, challenges, and potential. *In proceedings of the Physics Education Research Conference* (PERC) (pp. 1-8).

Perkins, K. K., Adams, W. K., Dubson, M., Finkelstein, N. D., Reid, S., Wieman, C. E., & LeMaster, R. (2006). PhET: Interactive simulations for teaching and learning physics. *The Physics Teacher*, 44(1), 18–23.

Perkins, K., Adams, W., Finkelstein, N., & Wieman, C. (2023). The impact of interactive simulations on conceptual learning. Journal of Interactive Learning Research, 34(1), 87-105.

Potane, J., & Bayeta Jr, R. (2018). Virtual learning through PhET interactive simulation: A proactive approach in improving students' academic achievement in science. *The rapids crossers. An official research journal of the Division of Cagayan de Oro City* https://portal. *issn. org/resource/ISSN/2545-9589*.

Pranata, I. G. P. E. (2023). The effect of guided inquiry learning model assisted by PhET simulation media on students' conceptual understanding of gravitational force material. *Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 12*(1), 79–92.

Pranata, M. (2024). Game-based learning and physics misconceptions: A comparative study. *Journal of Educational Technology & Society*, 27(1), 12-24.

Prince, M., & Felder, R. (2006). Inductive teaching and learning methods: Definitions, comparisons, and research bases. *Journal of Engineering Education, 95*(2), 123–138.

Putranta, H., & Kuswanto, H. (2018). Improving students' critical thinking ability using problem based learning (PBL) learning model based on PhET simulation. *SAR Journal, 1*(3), 77-87.

Radulović, M., Petrović, D., Jovanović, N., & Marković, S. (2023). Investigating the impact of blended learning with PhET simulations on students' motivation in learning physics. *Journal of Educational Technology & Pedagogy, 18*(1), 87-95.

Rahmawati, E. N., & Astuti, D. P. (2020). Development of e-handout assisted by PhET simulation with problem based learning (PBL) model about

University of Education,Winneba http://ir.uew.edu.gh

momentum conservation law and collision to train students' conceptual understanding. In *Journal of Physics: Conference Series* (Vol. 1440, No. 1, p. 012048). IOP Publishing.

Redish, E. F. (2004). A theoretical framework for physics education research: Modeling student thinking. *In Proceedings of the International School of Physics Enrico Fermi (*Vol. 156, pp. 1-63. Italian Physics Society.

Redish, E. F. (2023). Rethinking physics education: A constructivist approach. *Physics Today*, 76(3), 45-61.

Salame, I. I., & Makki, J. (2021). Examining the use of PhET simulations on students' attitudes and learning in general chemistry II. *Interdisciplinary Journal of Environmental and Science Education*, 17(4), e2247.

Salame, I. I., & Samson, D. (2019). Examining the implementation of PhET simulations into general chemistry laboratory. *International Journal of Environmental and Science Education*, *14*(4), 207-217.

Shabani, K. (2020). Constructivist learning theory: A paradigm for teaching and learning. *Journal of Education and Learning, 9*(3), 12–19.

Sitindaon, R. M., Bukit, N., & Turnip, B. (2017). The effect of guided inquiry learning model assisted by PhET simulation media on students' problem-solving ability and critical thinking in physics learning. *Journal of Education and Practice*, *8*(30), 110–116.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257–285. https://doi.org/10.1207/s15516709cog1202_4

Sweller, J. (2011). Cognitive load theory. In J. P. Mestre & B. H. Ross (Eds.), *The psychology of learning and motivation: Vol. 55. Cognition in education* (pp. 37–76). Academic Press.

Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review, 31*(2), 261–292.

Syifa, A., Rahmawati, S., & Fitria, E. (2023). Exploring the impact of PhET virtual simulations on students' cognitive structures in diffraction and light interference concepts. *Journal of Educational Technology, 18*(4), 445-455

Taibu, R., Mataka, L., & Shekoyan, V. (2021). Using PhET simulations to improve scientific skills and attitudes of community college students. *Journal of Science Education and Technology, 30*(3), 457-470.

Tomas, L., Evans, N., Doyle, T., & Skamp, K. (2021). Scaffolding inquiry learning with technology in science classrooms: The role of the Zone of Proximal Development. *Research in Science Education, 51*(2), 359–379.

University of Education,Winneba http://ir.uew.edu.gh

Trowbridge, D. E., & McDermott, L. C. (2021). Investigating student understanding of Newton's laws. *American Journal of Physics*, 89(4), 267-280.

Uwambajimana, J., Uwamahoro, J., & Ndayambaje, I. (2023). The effects of PhET simulations on students' conceptual change in electrostatics. *African Journal of Physics Education*, 15(2), 98-120.

Uwayezu, J. C., & Yadav, L. L. (2023). Effect of computer-simulated teaching tools on Rwandan senior four students' understanding of graphs of projectile motion. *Journal of Mathematics and Science Teacher, 3*(2), em043.

Vosniadou, S. (2013). Conceptual change in learning and instruction: The framework theory approach. In M. S. Khine $ I. M. Saleh (Eds.), *Handbook of Research on Educational Communications and Technology,* (pp. 22-36). Springer.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wambugu, P. W., & Changeiywo, J. M. (2008). Effects of Mastery Learning Approach on Secondary School Students' Physics Achievement. *Eurasian Journal of Mathematics, Science & Technology Education*, 4(3), 293–302.

Wang, X., & Yang, J. (2022). The role of PhET simulations in increasing student motivation and engagement in physics learning. *Journal of Science Education and Technology*, 31(4), 564-579.

Wieman, C. E., & Perkins, K. K. (2005). Transforming physics education. *Physics Today*, *58*(11), 36–41.

Wieman, C. E., Adams, W. K., & Perkins, K. K. (2008). PhET: Simulations that enhance learning. *Science*, 322(5902), 682–683.

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2010). Teaching physics using PhET simulations. *The Physics Teacher, 48*(4), 225–227.

Wu, H. T., Mortezaei, K., Alvelais, T., Henbest, G., Murphy, C., Yezierski, E. J., & Eichler, J. F. (2021). Incorporating concept development activities into a flipped classroom structure: using PhET simulations to put a twist on the flip. *Chemistry Education Research and Practice*, 22(4), 842-854.

Yani, M., & Widiyatmoko, A. (2023). The effectiveness of a PhET-supportive model of creative problem-solving in enhancing students' knowledge of vibration, wave, and sound. *International Journal of Education and Practice, 11*(3), 227-235.

Yulianti, D., Zhafirah, N. M., & Hidayat, T. (2021). The effect of PhET-assisted virtual laboratory on students' conceptual understanding in physics learning during the COVID-19 pandemic. *Jurnal Penelitian dan Pembelajaran IPA, 7*(1), 58–70.

University of Education,Winneba http://ir.uew.edu.gh

Yuliati, L., Riantoni, C., & Mufti, N. (2018). Using PhET simulation to improve students' conceptual understanding and problem-solving skills on electricity. *Journal of Physics: Conference Series, 997*(1), 012015.

Yunzal Jr, A. N., & Casinillo, L. F. (2020). Effect of physics education technology (PhET) simulations: evidence from stem students' performance. *Journal of Education Research and Evaluation*, *4*(3), 221-226.

Zhao, H., Zhang, H., & Lu, Y. (2022). Enhancing inquiry-based learning with technology: A meta-analysis of the effects of simulations and digital tools in science education. *Educational Technology Research and Development, 70*(3), 789–816.

University of Education,Winneba http://ir.uew.edu.gh

APPENDICES

APPENDIX A: TEST ITEM

UNIVERSITY OF EDUCATION, WINNEBA

(TEST ITEM) PRE-TEST AND POST-TEST ITEMS (DURATION 15 MINUTES)

ANSWER THE FOLLOWING QUESTIONS CORRECTLY BY TICKING WHERE NECESSARY

1. The acceleration and velocity of a body are always in the same direction. True/False

   Explain the reason(s) for your choice of answer.

   ……

   ……

   ……

   ……

   ……

   ……

   ……**(5 marks)**

2. Two cars A and B are traveling in a straight line at uniform speeds. Car A and B travel with 40 km/h and 80 km/h respectively.

I. The acceleration of Car A is twice that of Car B

II. The acceleration of Car A is half that of Car B

III. The acceleration of Car A is equal to Car B

A. I and II

B. II and III

C. III only

D. I and III only

University of Education,Winneba http://ir.uew.edu.gh

Explain.

……

……

……..……**(5 marks)**

3. If the acceleration is zero, then the velocity should always be zero. True/False.

Explain the reason(s) for your choice of answer.

……

……

……..……**(5 marks)**

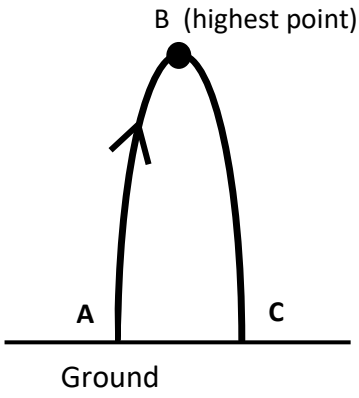
4. If the velocity of an object is zero, does it mean that the acceleration is zero?

……

……

…..……**(5 marks)**

5. An object is thrown vertically upwards. Determine the acceleration at the highest point as indicated in the diagram below.



a) – g

b) +g

c) 0

d) None of the above

Explain the reason(s) for your choice of answer.

……

……

……..…**(5 marks)**

University of Education,Winneba http://ir.uew.edu.gh

ANSWERS

QUESTION 1: False

EXPLANATION: Acceleration and speed are not always in the same direction. For instance, if object speeds up, then acceleration and velocity are in the same direction. If it is slowing down, the reverse happens. Consider a car moving forward but slowing down; its velocity is forward while its acceleration (deceleration) is backward.

QUESTION 2: C) The acceleration of Car A is equal to Car B

EXPLANATION: Explanation: The two cars are moving at the same constant speed making their accelerations equal to zero. Acceleration is a rate of change of velocity, and if both vehicles remain at the same speed, no change will occur in their velocities thereby resulting in null acceleration.

QUESTION 3: FALSE

EXPLANATION: Zero acceleration refers to constant velocity and not necessarily zero speed. When the velocity does not change, it implies that acceleration is zero and the object moves with constant velocity. The velocity can be of any value including non-zero values. For instance if a vehicle is moving at a steady speed of 60 km/h, its acceleration is zero while its speed is not zero.

Question 4: NO

EXPLANATION: Zero acceleration does not necessarily mean zero velocity. At some instant an object may be at rest with zero velocity but still accelerating. For example a ball thrown vertically upwards: when it reaches the apex of its path, the speed will be zero but it will still have the effect of gravity pushing it downwards. From this, one can deduce that while there is no motion (zero velocity), there will still be some changes in acceleration.

University of Education,Winneba http://ir.uew.edu.gh

Question 5: b) +g

Explanation: At the highest point of its trajectory, the object's acceleration is still (g) (the acceleration due to gravity). This acceleration is directed downward and downward acceleration is positive. Even though the velocity of the object is zero at the highest point, it continues to be acted upon by gravity and thus falls back down. Making the acceleration at the highest point be negative zero.

University of Education,Winneba http://ir.uew.edu.gh

APPENDIX B: QUESTIONNAIRE

The aim of this questionnaire is to determine the reasons behind students' poor performance in physics and their knowledge about PhET simulations as an instructional aid.

It consists of two parts, Section A and B.

By responding to this questionnaire, you can be sure that your answers will remain private and be utilized solely for research purposes rather than anything else.

Section A {Bio Data}

1. Sex

   Male { } Female { }

2. Which form are you?

   S.H.S 1 { } S.H.S 2 { } S.H.S 3 { }

3. How old are you?

   ……..

4. Which course do you offer?

   ……..

Section B{consist of both close and open ended }

1. How would you rate your overall performance in physics?

   Below average ☐ Average ☐ Good ☐

   Very Good ☐ Excellent ☐

2. How would you rate your confidence in understanding physics concepts on a scale of 1 to 10?

   ……

University of Education,Winneba http://ir.uew.edu.gh

Do you spend extra time studying for physics outside the class?

Do you have enough resources and support for successful study of Physics?

If yes, list the learning resources you have.

……

……

Do you feel that the way physics is taught in class aligns with your learning style?

Yes ☐ No ☐

If not, what changes do you think should be made?

……

……

What can tutors do to help those students who find it hard to cope with physics?

……

……..

3. Have you ever heard of PhET simulations before?

   Yes ☐ No ☐

4. If yes, how would you describe your familiarity with PhET simulations?

   Very familiar ☐ somewhat familiar ☐ Not familiar ☐

5. Do teachers use PhET simulations as part of their lesson delivery?

   Yes ☐ No ☐

6. If yes, what was your experience with using PhET simulations?

   Helpfulness ☐ Ease of use ☐

   Engagement ☐ All of the above ☐

7. If no, would you be interested in using Phet to aid your learning?

University of Education,Winneba http://ir.uew.edu.gh

.....

.....

Would you prefer using PhET simulations as a supplement to lecture method?

Yes ☐ No ☐

State your reason for your responds.

.....

.....

8. How do you think educators can better support students in learning physics effectively?

.....

.....

University of Education,Winneba http://ir.uew.edu.gh

APPENDIX C: DATA ANALYSIS

BIODATA OF PARTICIPANTS

GENDER	FREQUENCY	PERCENTAGE%
Male	46	46.0
Female	54	54.0
Total	100	100.0
AGE		
15 YEARS	14	14.0
16 YEARS	50	50.0
17 YEARS	20	20.0
18 YEARS	12	12.0
19 YEARS	4	4.0
Total	100	100

Test item

PAIRED SAMPLE STATISTICS			
GROUP	N	MEAN	S.D
PRE-TEST	100	13.2	2.5
POST-TEST	100	17.2	1.8

PAIRED SAMPLE T-TEST						
PRETEST-POSTTEST	MEAN	SD	t	df	P-VALUE	CHROMBACH'S AIPHA
	-4.0	1.9	-21.0	99	0.002	0.767

THE CHROMBACH ALPHA IS 0.767 ≈ 0.8

University of Education,Winneba http://ir.uew.edu.gh

QUESTIONAIRE ON EFFECTIVENESS OF THE PHET SIMULATION

	FREQUENCY	PERCENTAGE (%)
How would you rate your overall performance in physics?		
NOT CHECKED	1	2.1
Below average	15	31.3
Average	28	58.3
GOOD	4	8.3
Total	48	100.0

How comfortable were you with your knowledge of Newton's first law of motion prior to using the PHET simulations?		
SLIGHTLY CONFIDENT	6	6.0
MODERATELY CONFIDENT	34	34.0
VERY CONFIDENT	40	40.0
EXTREMELY CONFIDENT	20	20.0
Total	100	100.0
Have you ever studied physics ideas using PHET simulations?		
YES	82	82
NO	18	18
Total	100	100
How well do you think you understand Newton's first law of motion after utilizing the PHET simulations?		
SIGNIFICANTLY IMPROVED	40	40.0
SLIGHTLY IMPROVED	58	58.0

University of Education,Winneba http://ir.uew.edu.gh

SIGNIFICANTLY WORSENED	2	2.0
Total	100	100.0
Please rate the effectiveness of the PHET simulations in helping you understand Newton's first law of motion.		
SLIGHTLY EFFECTIVE	22	22.0
MODERATELY EFFECTIVE	28	28.0
VERY EFFECTIVE	30	30.0
EXTREMELY EFFECTIVE	20	20.0
Total	100	100.0
Did the PHET simulations help clarify any misconceptions you had about Newton's first law of motion?		
YES	92	92.0
NO	4	4.0
NOT SURE	4	4.0
Total	100	100.0
How engaging did you find the PHET simulations in learning Newton's first law of motion?		
SLIGHTLY ENGAGING	10	10.0
MODERATELY ENGAGING	16	16.0
VERY ENGAGING	48	48.0
EXTREMELY ENGAGING	26	26.0
TOTAL	100	100.0
Did the PHET simulations improve your ability to apply Newton's first law of motion to real-world situations?		
YES	94	94.0
NO	2	2.0
NOT SURE	4	4.0
Total	100	100.0

University of Education,Winneba http://ir.uew.edu.gh

How likely are you to recommend the use of PHET simulations to your peers?		
SLIGHTLY LIKELY	14	14.0
MODERATELY LIKELY	8	8.0
VERY LIKELY	48	48.0
EXTREMELY LIKELY	30	30.0
Total	100	100.0
Compared to traditional teaching methods, do you believe PHET simulations are more effective way to learn about Newton's first law of motion?		
LESS EFFECTIVE	2	2.0
SLIGHTLY LESS EFFECTIVE	8	8.0
EFFECTIVE	40	40.0
MORE EFFECTIVE	50	50.0
Total	100	100.0
Did the PHET simulations make it easier for you to grasp the concepts related to Newton's first law of motion?		
YES	92	92.0
NO	2	2.0
NOT SURE	6	6.0
Total	100	100.0
How would you rate your rate experience with using PHET simulations?		
FAIR	4	4.0
GOOD	44	44.0
VERY GOOD	32	32.0
EXCELLENT	20	20.0
Total	100	100.0

University of Education,Winneba http://ir.uew.edu.gh

APPENDIX D: INTERVIEW QUESTIONS

Basic Understanding of Newton's First Law

Can you state and explain Newton's First Law of Motion in your own words?

What do you think it means if we state that, "an object in motion continues in motion unless an outside force changes this state"?

Force and Motion Relationship:

If a moving object comes to a complete stop all of a sudden, what do you think made it stop?

Do you think that an object in motion does not require a force to be applied on it all the time for its motion to continue? Why, or why not?

Real-World Applications and Examples:

Assume that you were in a moving car which suddenly stopped. Why would you think your body would move forward even though the car had come to a standstill? How is this applicable in Newton's First Law of motion?

Exploring Specific Misconceptions:

Do you think that heavier objects must contain more inertia than their lighter counterparts? What influence does this phenomenon bring on the motion of the objects?

Impact of External Forces:

What is your view on of air resistance in relation to the fall of an object? Is there some violation of Newton's First Law?

Reflection on Learning Experiences:

Was there ever a time which you had difficulty in grasping the ideas presented in Newton's First Law? What do you think caused the difficulties?

University of Education,Winneba http://ir.uew.edu.gh

APPENDIX E: WASSCE RESULTS ANALYSIS

MANKESSIM SENIOR HIGH AND TECHNICAL SCHOOL WASSCE RESULTS ANALYSIS (from 2019 - 2021)								
2019			2020			2021		
A1-C6	D7-E8	FAIL	A1-C6	D7-E8	FAIL	A1-C6	D7-E8	FAIL
31.9%	43.7%	24.4%	39.3%	47.6%	11.8%	27.6%	32.3%	38.9%

University of Education,Winneba http://ir.uew.edu.gh

APPENDIX F: LESSON PLAN FOR THE INTERVENTION

LESSON ONE

Week ending: week one **Day**: Tuesday	**Duration:** 45minutes **Class:** SHS 2 **CLASS SIZE** :100	**Subject**: Physics **Topic:** Motion **Sub-topic:** Newton's first law of motion

Reference: Ministry of Education (2010). *Teaching Syllabus for Integrated Science (Senior High School)*. Accra.

Objective/RPK	**Teacher-Learner Activities**	**Teacher-Learning Resources**	**Core Points**	**Evaluation & Remarks**
Objective To introduce Newton's First Law of Motion and identify common misconceptions about motion and forces. **RPK** Students have a basic understanding of forces and the concept of motion.	**Introduction** Teacher start lesson my discuss with students' about how objects move and stop Explain Newton's First Law and key concepts. **Activities** 1. PhET simulation demo: Use "Forces and Motion: Basics" to show how forces affect motion and rest. 2. Administer a diagnostic quiz to identify misconceptions.	Laptop, PhET Simulation "Forces and Motion: Basics", Projector, Whiteboard, Markers.	Newton's First Law of Motion: An object at rest stays at rest, and an object in motion stays in motion unless acted upon by an external force. **Application** - Real-world examples of inertia (e.g., moving cars, stationary objects).	**Evaluation** 1. What happens to an object when no external force acts on it? 2. Does an object in motion require continuous force to keep moving? **Remarks** The lesson was successfully thought

University of Education,Winneba http://ir.uew.edu.gh

LESSON TWO

Week ending: week one	**Duration:** 45minutes	**Subject:** Physics
Day: Thursday	**Class**: SHS 2	**Topic**: Motion
	CLASS SIZE :100	**Sub-topic:** Newton's first law of motion

Reference: Ministry of Education (2010). *Teaching Syllabus for Integrated Science* (Senior High School). Accra.

Objective/RPK	**Teacher-Learner Activities**	**Teacher-Learning Resources**	**Core Points**	**Evaluation & Remarks**
Objective To use PhET simulations to correct misconceptions about inertia and motion. RPK: Students have misconceptions identified from Session 1 and a basic understanding of force and motion.	**Introduction** Teacher start lesson by Recapping on key points from Session 1 **Activities** 1. PhET simulation activity: In groups, students explore different scenarios, manipulating force and friction using PhET. 2. Group discussion to share findings and correct misconceptions. 3. Summarise with key concepts.	Computer, PhET simulation software, Group discussion guide, White board marker.	No external force is required to maintain an object's motion in a frictionless environment. **Application** Application of Newton's First Law to everyday contexts (example, objects sliding on ice or in space).	**Evaluation** 1. If friction were absent, what would happen to an object in motion? 2. Why does an object at rest stay at rest unless acted upon by a force? **Remarks** The lesson was successfully thought

University of Education,Winneba http://ir.uew.edu.gh

LESSON THREE

Week ending: week two **Day:** Tuesday	**Duration:** 45minutes **Class**: SHS 2 **CLASS SIZE** :100	**Subject:** Physics **Topic**: Motion **Sub-topic:** Newton's first law of motion

Reference: Ministry of Education (2010). *Teaching Syllabus for Integrated Science* (Senior High School). Accra.

Objective/RPK	Teacher-Learner Activities	Teacher-Learning Resources	Core Points	Evaluation & Remarks
Objective To help students apply Newton's First Law to real-world scenarios using PhET simulations. **RPK** Prior knowledge of inertia and forces from Week 1.	**Introduction** Review Newton's First Law and its applications. **Activities** 1. Show video clips of real-world examples to demonstrate Newton's First Law. 2. PhET simulation activity: Students simulate real-world motion (e.g., cars, objects in space) and record their observations. 3. Class discussion on how the law applies to these examples.	Laptop, Video clips (car crashes), PhET simulation software, Worksheets, Whiteboard, Marker.	- Newton's First Law in action (seatbelts in cars). **Application** Applying Newton's First Law to practical real-world examples.	**Evaluation** 1. How does Newton's First Law explain why seatbelts are necessary in cars? 2. What happens to a spacecraft once it leaves Earth's atmosphere? **Remarks** The lesson was successfully thought

University of Education,Winneba http://ir.uew.edu.gh

LESSON FOUR

Week ending: week two	**Duration:** 45minutes	**Subject:** Physics
Day: Thursday	**Class**: SHS 2	**Topic**: Motion
	CLASS SIZE :100	**Sub-topic:** Newton's first law of motion

Reference: Ministry of Education (2010). *Teaching Syllabus for Integrated Science* (Senior High School). Accra.

Objective/RPK	**Teacher-Learner Activities**	**Teacher-Learning Resources**	**Core Points**	**Evaluation & Remarks**
Objective To explore Newton's First Law in situations with minimal external forces (frictionless environments) **RPK** Students should have basic knowledge of Newton's First Law from the previous sessions.	**Introduction** Warm-up discussion on environments where friction is minimal (e.g., outer space, ice rinks). **Activities** 1. PhET simulation: Students explore frictionless motion using the simulation, manipulating forces. 2. Review key findings through group discussion.	Laptop, PhET simulation software, Worksheets, Whiteboard, Marker.	Newton's First Law under ideal conditions, such as frictionless surfaces. **Application** - Application of Newton's First Law to conditions with minimal external forces (e.g., space travel, ice skating).	**Evaluation** 1. How would Newton's First Law apply in space, where friction and air resistance are absent? 2. How does friction affect motion in real life? **Remarks** The lesson was successfully thought

University of Education,Winneba http://ir.uew.edu.gh

LESSON FIVE

Week ending: week three	**Duration:** 45minutes	**Subject:** Physics
Day: Tuesday	**Class**: SHS 2	**Topic**: Motion
	CLASS SIZE :100	**Sub-topic:** Newton's first law of motion

Reference: Ministry of Education (2010). *Teaching Syllabus for Integrated Science* (Senior High School). Accra.

Objective/RPK	**Teacher-Learner Activities**	**Teacher-Learning Resources**	**Core Points**	**Evaluation & Remarks**
Objective To reinforce students' understanding by having them design simulation-based projects that demonstrate Newton's First Law. **RPK** Comprehensive understanding of Newton's First Law from the previous sessions.	**Introduction** Explain the group project: Design a PhET simulation demonstrating Newton's First Law. **Activities** 1. Group work: Students design a simulation scenario (e.g., objects in motion, effects of friction, or space travel) using PhET 2. Groups finalize simulations and prepare for presentation.	Laptop, Projector, PhET simulation software, Worksheets, Whiteboard, Marker.	Newton's First Law applied through simulation. **Application** - Using PhET simulations to create real-life scenarios demonstrating Newton's First Law.	**Evaluation** 1. What forces would be needed in your simulation for an object to change its state of motion? 2. How does Newton's First Law apply in the scenario your group created? **Remarks** The lesson was successfully thought

University of Education,Winneba http://ir.uew.edu.gh

LESSON SIX

Week ending: week three	**Duration:** 45minutes	**Subject:** Physics
Day: Thursday	**Class**: SHS 2	**Topic**: Motion
	CLASS SIZE :100	**Sub-topic:** Newton's first law of motion
Reference: Ministry of Education (2010). *Teaching Syllabus for Integrated Science* (Senior High School). Accra.		

Objective/RPK	**Teacher-Learner Activities**	**Teacher-Learning Resources**	**Core Points**	**Evaluation & Remarks**
Objective To assess students' understanding of Newton's First Law through presentations and a post-test. **RPK** Comprehensive understanding from previous sessions and group project.	**Introduction** Review key points before group presentations **Activities** 1. Group presentations: Each group presents their PhET simulation and explains how it demonstrates Newton's First Law 2. Group presentations: Each group presents their PhET simulation and explains how it demonstrates Newton's First Law 3. Class discussion and reflection on learning	Laptop, Projector, PhET simulation software, Worksheets, Whiteboard, Marker.	Newton's First Law demonstrated through group simulations. **Application** Real-world applications based on student simulations.	**Evaluation** 1. What key aspects of Newton's First Law did your group demonstrate? 2. How has your understanding of Newton's First Law changed from the beginning of the intervention? **Remarks** The lesson was successfully thought