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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA

# 11<sup>th</sup> HYBRID INTERNATIONAL CONFERENCE

THEME:

**STEAM EDUCATION  
AND ARTIFICIAL INTELLIGENCE (AI):  
BUILDING A SKILLED  
AND INNOVATIVE  
WORKFORCE**



## CONFERENCE PROCEEDINGS

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## **EFFECT OF INTERACTIVE SIMULATIONS ON STUDENTS' ACHIEVEMENT AND CONCEPTUAL MASTERY IN CHEMISTRY IN SECONDARY SCHOOLS IN ABUJA MUNICIPAL AREA COUNCIL, FCT-ABUJA**

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### **Abstract**

*Education is the foundation for personal growth and national development, and science education plays a vital role in building skills, values, and knowledge for a technology-driven world. Yet, Chemistry remains one of the most challenging subjects in Nigerian secondary schools due to its abstract nature, limited laboratory facilities, and reliance on traditional lecture methods that encourage rote memorization rather than deep understanding. This paper explores the potential of interactive simulations, particularly PhET, to address these challenges by making abstract concepts visual, engaging, and student-centered. Evidence from both local and international studies shows that simulations improve comprehension, conceptual mastery, retention, and academic achievement while boosting students' motivation and interest in STEM fields. Although barriers such as inadequate infrastructure and limited teacher training remain, these challenges can be overcome through strategic curriculum reform, professional development, and technology integration. The findings highlight the urgent need to adopt interactive simulations as a practical, affordable, and effective approach to improving Chemistry education in Nigeria.*

**Keywords:** *Chemistry, Interactive-simulation, PhET, Conceptual-Mastery, and Retention*

### **Introduction**

The primary goal of education is to facilitate knowledge transfer through learning activities that drive behavioral change, leading to desired outcomes while fostering holistic development in attitudes, skills, technological proficiency, and knowledge, since education serves as a tool for societal transformation and individual growth (Budhathoki, 2020). Nigeria's Post-Basic Education and Career Development (PBECD) policy (FRN, 2013) emphasizes self-improvement, equal opportunities for further education, and equipping students with sub-professional skills in applied sciences, teaching, and commerce, reflecting education's deliberate and systematic role in transmitting knowledge, values, and skills (Chazan, 2022). Science education, a dynamic field, enhances societal relevance through hands-on experiments, addressing challenges and supporting economic development, with teaching methods and pedagogical practices being crucial to its success (Sshana & Abulibdeh, 2020).

As an essential part of the curriculum, science education cultivates scientific literacy, process skills, and values, empowering students to thrive in a rapidly evolving society (Esu *et al.*, 2020). At the senior secondary school level, science education includes Biology, Chemistry, Physics, and Mathematics, with Chemistry being important for anyone who intends to pursue STEM related career (Usselman & Rocke, 2024). Despite the importance of Chemistry in fields like medicine, engineering, and food production, it is often perceived as a difficult subject because of its abstract concepts, and students struggle to link theory with real-world applications. Oyelekan (2016)

maintained that effective learning requires hands-on laboratory activities, yet many teachers rely on traditional lecture-based methods, which promote rote memorization over deep and conceptual understanding. This approach fails to cultivate critical thinking or problem-solving skills, leaving students ill-equipped to apply knowledge practically.

Kassaw and Demareva (2023) define academic achievement as the extent to which a student or instructor has met his/her educational objectives, often assessed through regular evaluations. It reflects the abilities acquired by individuals after the learning process, encompassing changes in knowledge, understanding, attitudes, and skills. It also serves as a key indicator of the success or failure of a learning process. Adopting interactive, student-centered teaching approaches is crucial for advancing science education in our knowledge-driven society. Therefore, Interactive simulations have the potential to enhance students' comprehension of complex concepts in Chemistry, and the integration of mastery learning models can simplify science concepts, leading to improved academic achievements and increase their likelihood of pursuing careers in science and technology.

Interactive simulations surpass traditional methods by offering immediate feedback, adapting to diverse learning styles, and creating student-centered environments. Technology-enhanced methods, particularly interactive simulations like VR and AR, offer transformative potential by converting abstract concepts into immersive, tangible experiences (Özeren & Top, 2023). These tools, ranging from web platforms to virtual laboratories leverage multimedia elements (sound, visuals, and real-time interaction) to make learning dynamic and accessible (Gambari *et al.*, 2016). One of the most widely used simulation platforms in science education is the Physics Education Technology (PhET) interactive simulations, developed by Nobel Laureate Carl Wieman at the University of Colorado.

PhET interactive platform enables students to visualize molecular structures, explore chemical reactions, and connect sub-microscopic, symbolic, and macroscopic concepts through game-like virtual experiments (Rahmawati *et al.*, 2022). The PhET platform has 166 simulations (including 53 chemistry-specific ones as of 2023), providing risk-free virtual labs where students manipulate variables and validate theories, accelerating conceptual understanding (Kizito & Hassan, 2024). By bridging the gap between abstract concepts and tangible experiences, PhET simulations address chemistry's inherent challenges while preparing students for advanced scientific study. Therefore, conceptual mastery in chemistry requires students to apply core ideas, predict chemical behavior, and translate between different representations skills enhanced by PhET simulations that visualize abstract processes (Palacios *et al.*, 2024). When integrated thoughtfully into inquiry-based activities, these simulations improve comprehension, retention, and academic achievement (Agu & Samuel, 2018).

Retention is the ability to retain and consequently remember things experienced or learned by an individual at a time. It takes place when learning is coded into memory. Retention is a product of meaningful learning when teaching is effective and meaningful to the students (Kamisah & Nur, 2013). However, the nature of the material to be coded are related to the quality of retention in terms of their meaningfulness, familiarity, concreteness and image-evolving characteristics. Thus, achieving conceptual mastery is critical for students' success in Chemistry and their overall

scientific literacy which will lead to positive academic achievement and the ability to retain the concepts learned.

However, despite the proven benefits of interactive simulation, its implementation in Nigerian secondary schools faces significant challenges. Two primary barriers that hinder widespread adoption may include inadequate technological infrastructure, including insufficient computers, projectors and unreliable internet connectivity (Oladejo & Ebisin, 2021), as well as critical shortage of teacher training in digital pedagogies. This study focuses specifically on secondary schools within Abuja Municipal Area Council (AMAC) of Nigeria's Federal Capital Territory (FCT), to examine how PhET interactive simulations, a globally recognized science education platform, can impact students' chemistry learning outcomes.

### **The Concept of Science Education**

In science, students seek solutions to real-life problems, and the discipline of science education is concerned with discovering, developing, and evaluating methods and strategies to be used in teaching science effectively. Oyelekan (2016) defines science education as the process of transferring scientific knowledge, skills, and processes from one person to another. Every nation's growth reflects its scientific progress, and the scientific knowledge of subjects is essential for a nation to develop 21st-century technologies. This means that science literacy is necessary for human comfort, which calls for the necessity of scientific literacy in the Nigerian school with chemistry inclusive. Therefore, science education is essential as it is of immense value in the student's individual life and his life in society.

Since science affects almost every element of human life, science shapes cultural worldviews, conceptions, and thinking habits in many modern countries. Bancong and Song (2020) noted that one of the primary purposes of science education is to prepare students to think critically while solving problems rationally in a variety of ways and make judgments based on relevant information and facts obtained in the course of their study. Sari *et al.* (2020) posited that science learning environments should be arranged in a way that it can provide opportunities for students to explore and discover things by themselves. Therefore, if learning strategies and students' achievement in science have to improve, then the students have to be introduced to more, effective, efficient and appropriate teaching approaches (Jack, 2023<sup>a</sup>).

### **Chemistry as a Science Subject at the Secondary School Level**

Chemistry is one of the five branches of science, which is taught in secondary schools at the senior level is defined as the study of matter, what it is made of, how it behaves, its properties and how it changes during chemical reaction. Zhaobao and Xiaoling (2018), defined Chemistry as a fundamental natural science that investigates the composition, properties, structure and laws of change of substances and their applications at the atomic and molecular levels. Therefore, a significant fact about chemistry education is the understanding of interactions of elements and compounds, and the practical implications of these reactions in our daily lives. Thus, chemistry comprises theories, facts, and laws that have been explored and validated through rigorous experimental procedures.

The study of Chemistry helps students understand the world and produce a progressive society, to apply science concepts and principles to everyday concerns. Through the knowledge of chemistry,

many new substances have been created which have many important applications in our everyday lives, environment and activities, and every substance or object is related to chemical processes (Ahmad *et al.*, 2021). Lin (2023) noted that the difficulty of learning chemistry can be summarized by the inherent nature of science that makes it difficult to reach, and the limitations of traditional teaching. Hence, the advent of technology has profoundly impacted the field of chemistry education, from enhancing experimental accuracy to facilitating comprehensive mastery of complex concepts. Thus, in Nigeria, where access to fully equipped laboratories is limited, interactive simulations offer a cost-effective alternative to quality science education.

### **Traditional/Conventional Methods of Teaching Chemistry**

Teaching is effective when the approach used brings about a desirable change in the behaviour of the learner. As noted by Alnaser and Forawi (2023), learning chemistry cannot be isolated from experiments, which requires mastering knowledge and discovery. However, the usual traditional laboratory experiments fall short of promoting learning and conceptual mastery of chemistry concepts and do not adequately support effective learning (Cooper and Stowe, 2018). Typically, the traditional methods of teaching focus on improving the communication of conceptual knowledge, learning abstract concepts, and using practical experiments to understand applications. This means that the type of teaching method and tools adopted by a teacher greatly impacts on students' concept mastery and understanding, interest and curiosity in learning chemistry and science related subjects in general.

### **Interactive Simulations in Science (Chemistry) Education**

The use of technology in classrooms has been a subject of study in recent years, bringing about a shift in teaching methods and educational processes, as well as reforming curriculum to incorporate more technology integration (Siyam *et al.*, 2022). Following this present concern, a lot of teaching strategies and methods have been recommended by researchers for effective teaching and learning of chemistry. One of the promising methods is the use of interactive simulations, which provide an alternative avenue to traditional laboratory learning. Interactive simulations are virtual environments that mimic the scenario or functioning of a real-life system. Salame and Makki (2021) described simulations as computer-generated educational tools that can promote learning of concepts using simplified models of real-world phenomena through animation, visualization, and interactive learning experience, and observe outcomes in a controlled virtual environment.

Park (2019) noted that the use of technology tools like interactive simulations allows learners to participate in inquiry-based learning, which is a more student-centered approach, thus enhancing learners' representation of real-world scientific ideas. It is a method of teaching and learning for supporting knowledge acquisition, development of skill, test theories, and explore scenarios that may be impractical or impossible to study in real life (Lohmann, 2020). For example, chemistry simulations are designed to enhance students' understanding of complex chemical concepts virtually, by providing a visual and interactive learning experience and illuminating the principles of reactions without the risks associated with real-life experiments. They are also relevance in developing learners' cognitive knowledge (Ogegbo & Ramnarain, 2024).

### **Physics Education Technology (PhET) Interactive Simulation in Chemistry Teaching**

In environments where resources for teaching and learning of chemistry are limited, Physics Education Technology (PhET) simulation can be adopted, which is capable of extending learning beyond the classroom, as student can often access them remotely, enabling them to review and experiment with concepts independently at their own pace. PhET interactive simulation is a project at the University of Colorado (PhET, 2022), which provides an interactive fun way for learning science including chemistry. This software can be run online or downloaded through (<http://phet.colorado.edu>) for free. These simulations are highly interactive, animated and user-friendly, and creates a game-like environment to the students. They allow actions that explain and represent concepts, which would be impossible in the real-world setup. According to Mallory (2023) PhET simulations covers many science subjects like physics, chemistry, math, earth science and biology, with the current PhET website having 166 simulations available as of 2023, out of which 53 are chemistry related.

This therefore means that PhET interactive simulations provide a type of learning approach whereby students are involved in a guided inquiry-based learning activity through the analysis and interpretation of data (Yuliati *et al.*, 2018). It is designed to develop students' inquiry skills and it is made up of about hundreds of interactive simulations, found free to use. Physics Education Technology (PhET) is a widely recommended simulations for teaching and learning of sciences as an emerging strategy that students engage in scientific-like exploration, resulting in greater and deeper learning of scientific concepts through questioning, making connections, and deducing the rules. O moy (2023) noted that PhET interactive simulation is a student-centered teaching strategy that enables students to fully engage in the learning process, just like they would when playing a video game.

### **Effect of PhET on Mastery of Chemistry Concepts and Academic Achievement**

Conceptual mastery involves not only the memorization of facts or procedures of doing things, but understanding the underlying ideas that connect them, solve problems and adapt to new situations. According to Sausan *et al.* (2020), students' conceptual mastery of a range of chemistry topics could be improved by effective interactive simulations in chemistry in various settings. Conceptual mastery involves deep and meaningful understanding of the fundamental concepts, which is the higher-order thinking and development through manifold active intellectual engagement, aiming at meaning construction through pattern recognition and concept association between different topics in various contexts. These include inquiry, critical-thinking, creative thinking, problem-solving, and metacognitive skills.

Since the main purpose of teaching-learning process is to transfer knowledge to students and bring about behavioral change called learning outcomes or learning achievements. Thus, achieving conceptual mastery in Chemistry concepts is crucial for every student to be able to retain the concepts learned and their overall academic success. Salame and Makki (2021) in their study revealed that PhET interactive simulations have an overall positive impact to promote students' development of conceptual mastery of chemistry concepts and content, thereby facilitating furnishing learning opportunities and understanding abstract concepts that otherwise cannot be attained in a traditional laboratory setting. Diab *et al.* (2024) examined the impact of PhET simulations, and found that students who used the simulations did not just score higher on tests; also, did not just help students memorize facts, but showed a stronger ability to explain the

concepts behind their answers when solving problems and built a deeper understanding of scientific concepts.

### **Effect of PhET on Retention of Chemistry Concept and Academic Achievement**

Retention is the ability to retain and consequently remember things experienced or learned by an individual at a time. It takes place when learning is coded into memory. Appropriate coding of incoming information provides the index that may be consulted so that retention takes place without an elaborate search in the memory lane. However, the nature of the material to be coded contributes to the level of retention. Materials are related to the quality of retention in terms of their meaningfulness, familiarity, concreteness, and image-evolving characteristics.

Nkosi *et al.* (2024) tested whether PhET interactive simulations could help students retain key chemistry concepts better than traditional teaching methods. Their results were clear that students who used the simulations not only understood the concepts better but also retained them for much longer. Also, Jack (2023<sup>b</sup>) in their study revealed that students who were taught using computer simulations demonstrated significantly better long-term retention of the concepts compared to those who learned through traditional methods. The study concluded that using simulations is a highly effective teaching strategy, not only for helping students remember complex topics but also for improving their overall academic achievement in chemistry.

### **Conclusion**

Chemistry is essential for students who aspire to careers in science, medicine, engineering, and technology, but the way it is currently taught often leaves learners discouraged and underprepared. This study has shown that interactive simulations, especially PhET, offer powerful solutions by bridging the gap between theory and practice. They enable students to visualize complex processes, test ideas safely in virtual labs, and retain knowledge more effectively than with traditional teaching methods alone. Research consistently supports their ability to enhance academic achievement, motivation, and long-term conceptual mastery. While infrastructure gaps and limited teacher readiness pose real challenges, these are not insurmountable. With the right policies and training, simulations can complement existing teaching methods and transform Chemistry education in Nigeria.

### **Recommendations**

- i. PhET and similar tools should be formally included in the senior secondary Chemistry curriculum as a complement to laboratory work, and professional development programmes should be organized to equip teachers
- ii. Schools should be supported with affordable tools such as projectors, laptops, and offline versions of PhET to overcome connectivity issues.
- iii. Simulations should be used alongside practical labs where possible thereby, ensuring that students gain both conceptual understanding and hands-on skills.
- iv. Continuous studies should evaluate the impact of simulations on learning outcomes across different contexts and science subjects.

- v. Government and education stakeholders must create clear policies that support the adoption and scaling of interactive technologies in secondary schools.

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