Rima International Journal of Education (RIJE), Vol. 3 (No. 2): July 2024; Pg. 254 - 279 ISSN: 2756-6749

ROLE OF PHET INTERACTIVE SIMULATION AS VIRTUAL TECHNOLOGY THAT FACILITATES LEARNING OF CHEMISTRY: A SYSTEMATIC REVIEW OF CHEMICAL CONCEPTS, LEARNING THEORIES, INSTRUCTIONAL MODES AND STRATEGIES

[*1]Hassan Aliyu, [2]Anas Abdullahi, & [3]Aliyu Garba

[*1&2]Department of Science Education,
Faculty of Education,
Sokoto State University, Sokoto
Email: nagoronyo@gmail.com[1] & aliyugarba.ag@gmail.com[2]
ORCID: https://orcid.org/0000-0003-4929-3126[1]

[3]Department of Computer Science,
Faculty of Science,
Sokoto State University, Sokoto
Email: anas.abdullahi@ssu.edu.ng[3]

Abstract

Technology in the classroom is becoming increasingly prevalent, but many educators face challenges when integrating educational technology effectively. With the rapid growth of technological innovations, there are abundant opportunities to engage students in meaningful learning. Thus, for effective integration of technology in the classroom, teachers need to possess relevant technological pedagogical and content knowledge. The study investigated the predominantly employed instructional strategies used by educators when integrating PhET interactive simulations into the teaching and learning of chemical concepts. It also investigated the most learnt chemical concepts and psychological theories guiding the instructions designed by the educators across all levels of education. In order to address these objectives, the study adopted a systematic review of academic research published after the COVID-19 pandemic (2020-2024). After subjecting the obtained data to inclusion and exclusion criteria, 25 articles qualified for the study. The results indicated that the chemical processes/concepts learnt in the classroom with the aid of PhET interactive simulation include "physical chemistry," "chemical bonding," "Three State of Matter (solid, liquid, and gas)," "chemical equilibrium," "general chemistry," and "acid-base concept." It also reveals that the volumetric analysis of acid and base chemistry is the most learnt concept in the laboratory via interactive simulations. The findings also reveal that the predominant instructional strategies used for delivering instruction via PhET interactive simulations include inquiry, problem-based learning, project-based learning, discovery learning, and the Predict-Observe-Explain (POE) method. Finally, constructivism, cognitive load theory, Ausubel's theory of significant learning, and experiential learning theory are predominantly used theories guiding integration of PhET interactive simulation in the teaching and learning of chemistry. The study concluded that chemistry educators focus on using PhET interactive simulation in addressing difficulties in learning abstract concepts of chemistry, especially submicroscopic and microscopic chemical processes.

Keywords: Chemistry, Balancing Chemical Equation, PhET Interactive Simulation, Virtual Learning, Instructional Strategies

Introduction

Because of its adaptability and liveliness, interactive simulation is a powerful tool for conveying ideas, experiences, and activities to learners in a variety of scientific subjects where standard teaching and learning methods are ineffective. An individual can detect interactions that are unclear because of their temporal and spatial distance through the use of interactive simulation (Yassin, 2022). It is also defined by Peperkorn et al. (2024) as a method used by the teacher to clarify scientific facts by bringing the real world closer to the learners. It is a 21st-century tool that helps the student apply the lessons learned in similar scenarios in his life and saves time and effort when conducting experiments compared to real-life laboratories. Additionally, it has a big impact on how well students understand scientific terms and concepts, which increases the drive to improve achievement. Actually, the goal of the interactive simulations is to lessen students rote memorization culture (Rehman et al., 2021; Vandenplas et al., 2021). Thus, technology has made the teaching and learning process easier.

The University of Colorado Boulder is home to the PhET Interactive Simulations project, which was started in 2002 by Nobel Laureate Professor Carl Edwin Wieman ("PhET Interactive Simulations," 2023). PhET, which stands for "Physical Education Technology," is an abbreviation. Numerous audiences are served by its simulations, including faculty members, students in post-secondary education, students in elementary through high school, and even the general public. The simulations are made to work with the majority of hardware and software, such as Macintosh, Linux, and Microsoft Windows. Additionally, it provides operational flexibility, meaning it can be used offline or online.

It was stated that one of the reasons chemistry is such a tough subject to learn is that there are a lot of abstract concepts in it (Rahmawati et al., 2022; Salame & Makki, 2021). However, the contending issue is not only difficulty but also difficulty of learning, difficulty for learning, and difficulty in learning chemical concepts. The “difficulty for learning” concern is with the ability to create experience (previous knowledge) that would ease learning of the current chemical concept. Although chemical processes continuously occur around us, it is difficult to explain those processes in chemical terms because only the product of the whole process became obvious to us while the actual mechanisms that resulted in that product were invisible. It took decades before chemists realised the existence of unanimous chemical processes like conformation of substances, symmetry, isotopes, etc. To date, atomicity is taught to students using assumptions, imagination, and modelling, and this has been one of the causes of “difficulty in learning” about chemical rocesses. Many chemistry teachers tried integrating instructional aids that would facilitate both the teaching and learning of chemical processes. These aids include courseware (Talib, Aliyu, Malik, et al., 2018), instructional videos like dance chemistry (Talib et al., 2017), PowerPoint presentations (Mojica & Upmacis, 2022), documentaries, posters, interactive games (H. Aliyu et al., 2021), web-based resources (Talib, Aliyu, Ali, et al., 2018), virtual resources (Aliyu et al., 2021), etc.

Consequently, difficulty has not been the only issue, but even those learners who easily understand chemical processes misunderstand the chemical idea. Thus, misconception is another critical issue that deters students understanding. Rahmawati et al. (2022), stated that the inability of students to make the connections between the symbolic, macroscopic, and sub-microscopic levels of comprehension in chemistry might lead to misconceptions. Understanding and being able to interact with the macroscopic, symbolic, and sub-microscopic levels of representation are necessary for chemistry. (Gong et al., 2023; Johnstone, 1991). Because of the student's inability to visualise sub-microscopic entities, interactions, and behaviours, the researchers were motivated to investigate the use of PhET Interactive Simulations to describe chemical processes.

Objectives of the Study

Recently, chemistry education has undergone a revolution that embraces technologies to visualise mechanisms that trigger chemical processes. Although it started before the outbreak of COVID-19, the pandemic helped portray the benefits of virtual laboratories for learning chemistry to both teachers and learners. Today, after the pandemic, virtual laboratories are used all over the world because of their ability to present invisible components of chemical processes visually. Research continues to investigate the varying issues and successes recorded by chemistry teachers using interactive simulation tools after the COVID-19 pandemic. One of these virtual tools is the PhET interactive simulation. Thus, this study investigated the implications recorded by researchers when delivering chemistry instructions in the classroom and laboratory. The navigating points of the investigation include:

I. To investigate the chemical processes/concepts that are predominantly learned in the classroom via a PhET interactive simulation

II. To investigate the chemistry processes/concepts that are predominantly learned in the laboratory via PhET interactive simulation

III. To find out the predominant instructional strategies used by researchers in integrating PhET interactive simulation into the teaching and learning of chemical concepts

IV. To find out the predominant learning theories that guide researchers on the integration of PhET interactive simulation in the teaching and learning of chemistry

V. To find out the benefit of integrating PhET interactive simulation in remote learning of chemical concepts

Research Questions

The following are the research questions guiding the study:

I. Which chemical processes/concepts are predominantly learned in the classroom via a PhET interactive simulation?

II. Which chemical processes/concepts are predominantly learned in the laboratory via a PhET interactive simulation?

III. What are the predominant instructional strategies used by researchers in integrating PhET interactive simulation into the teaching and learning of chemical concepts?

IV. What are the predominant learning theories that guide researchers on the integration of PhET interactive simulation in the teaching and learning of chemistry?

V. What are the benefits of integrating PhET interactive simulation in remote learning of chemical concepts?

Methodology

The study assesses the role of PhET interactive simulation in chemistry education. It tries to address questions regarding the integration of PhET in the teaching and learning of chemical concepts in the classroom and laboratory; what is the implication of integrating PhET interactive simulation in chemistry education? Which concepts, methods, instructional strategies, and learning theories are predominantly used by chemistry teachers?. To answer these questions, the study employs a systematic review of related research components executed during and after the COVID-19 pandemic. It reviews studies conducted in the past five years, from 2020 to 2024. The review process includes a search of databases and journals, inclusion and exclusion criteria, and a final sample.

Search from Database

The search used electronic databases and journals with the keywords "PhET," “Physics Education Technology," "Chemistry," "Simulation," “Virtual Lab," “Virtual Laboratory,” etc. This search was carried out on electronic media that publish quality research works globally. These electronic publishing media include, Journal of Chemical Education, Thinking Skills and Creativity Journal, Journal of Educational Research and Evaluation, Journal of Science and Education (JSE), International Journal of Creative Research Thought (IJCRT), Journal of Science Education and Technology, Royal Chemical Society, International Journal of Emerging Technologies in Learning (iJET), International Journal of Education in Mathematics, Science, and Technology (IJEMST), Journal of Science Education and Practice (JSEP), Chimica didactica acta, Jurnal Penelitian dan Pengembangan Pendidikan, Brazilian Journal of Education, Technology and Society (BRAJETS), International Journal for Research in Applied Science & Engineering Technology (IJRASET), Jurnal Pendidikan Sains (JPS), Interdisciplinary Journal of Environmental and Science Education, International Journal of Membrane Science and Technology, International Journal of Instruction, Google scholar, Scopus, Elsevier, Web of Science, Science Direct etc.

Over forty-seven thousand, two hundred and eighty-one (47,281) articles are obtained from the search results of all databases. This figure is extremely large, and it contains articles that may not cover chemistry or PhET simulation. Thus, there is a need for inclusion and exclusion criteria.

Inclusion and Exclusion Criteria

At this stage, researchers excluded any study that was not conducted under a chemical concept, was not delivered via interactive simulation, was conducted before the outbreak of COVID-19, was not published after a conference presentation, was a book chapter or book itself, or involved a single author. After executing these exclusion criteria, the search result was reduced to two hundred and thirteen (2,013) articles. Consequently, some of the articles used simulation tools different from PhET, thus the need for inclusion criteria.

Studies of chemical concepts that employed PhET interactive simulations are the only articles included. This means that the focus is only on chemistry and interactive simulation. We obtained sixty-one (61) studies from these inclusion criteria.

Final Sample

In the end, the sixty-one (61) articles were subjected to thorough scrutiny, and studies that had content different from the title were excluded. Similarly, further exclusions include those articles that had no clear objectives or whose results did not address the stated objectives. Moreover, methodology holds a crucial place in every study as it increases the credibility of research by making the process transparent and reproducible. All studies whose methodology was not comprehensive and clear were excluded, focusing on only those articles that were rich in their content and appealing in their titles. The result of the whole search is twenty-three (23) articles. These articles are carefully and systematically reviewed to address the research questions of the study.

Result

The role of PhET interactive simulation in facilitating and enhancing learning of secondary school science subjects (biology, chemistry, and physics) was perceived by many people all over the world recently. One of the most relevant examples of such awareness was demonstrated in the study conducted by Rahayu & Sartika (2020) to describe the influence of PhET Interactive Simulations on the motivation of learning and understanding the concept of natural science subject matter (like biology, chemistry, and physics). The researchers concluded that PhET Interactive Simulations affects the motivation and understanding of the concept of natural science in a positive manner. Similarly, Toma (2023) reported that Bangladesh science teachers recognised PhET simulations' potential as a supplement to hands-on activities for Bangladeshi secondary science education. The teachers believed that PhET simulations could enhance student learning and increase student interest and engagement in STEM education.

Table 1: Result of the search that qualified for analysis after exclusion and inclusion criteria

SN	Authors	Title of the article	Objectives	Sample	Chemical Concept	Method of teaching	Research Method	Result
1	Casa-coila et al. (2023b)	Model Chemlab and Phet Simulator: A Didactic Resource for Chemistry Learning in Undergraduate Students	To determine the incidence of the application of the Model Chemlab and PhET simulator as a didactic resource to improve learning achievement in the Chemistry Laboratory course in undergraduate students	sample of 14 students (6 women and 8 men)	Acid-Base by titration; Gravimetric analysis of chlorides etc.	Inquiry	pre-experimental design	The results showed a significant improvement, with a t-value of 17.393 and a significance level of ρ=0.000 these findings indicate that the students achieved an efficient use and management of the simulators, which favored their learning in the Chemistry Laboratory course
2	Efendi & Budi (2021)	The Effect of Distance Learning Practicum based on PhET Interactive Simulations on Science Process Skills of Secondary School Students	To describe the influence and significant influence of PhET Interactive Simulation-based distance practicum learning on the science process skills of junior high school students.	40 students JSS	Practical of physical chemistry	Interactive Simulation	Quasi-experimental Design	The result indicated that there is an influence of PhET interactive simulation-based distance practicum learning on the science process skills of junior high school students.
3	Toma (2023)	The Pedagogical Opportunities of PhET Interactive Simulations in Secondary Science Education in Bangladesh	To explores the challenges Bangladeshi teachers face in learning to implement PhET-enhanced pedagogies and examines teachers' views of the pedagogical opportunities for PhET simulations in secondary schools	129 students (42 in-service and 87 pre-service teachers)	Chemistry bonding structures	inquiry-based active learning approaches	explanatory mixed-method approach	Results suggested that teachers encountered several challenges when implementing PhET simulations: Inadequate Technological, Pedagogical, and Content Knowledge; Overcrowded Classrooms; Time Constraints, Teacher Workload, and Exam Pressure.
4	Lahlali et al. (2023)	The Effect of Integrating Interactive Simulations on the Development of Students' Motivation, Engagement, Interaction and School Results	To improve students' motivation, engagement, interaction and school results by integrating interactive simulations into the teaching-learning process of chemical bonding concepts	sample of 56 students	Chemical bonding	Interactive Simulation	Experimental	The results showed that students in the experimental group working with PhET interactive simulations scored significantly higher ($p<.01$) than students in the control group after the post-test

5	Sebatana & Dudu (2023)	The Utilisation of Interactive Simulations in the Teaching and Learning of a Grade 10 Chemistry Topic: A Case in the North West province of South Africa	To utilize PhET interactive simulations in the teaching and learning of sub-microscopic behaviour of particles in Three States of Matter (TSM)	40 teachers	three state of matter (solids, liquid and gas) CHM	Guided Inquiry Learning	exploratory and interpretive case study	The result showed that, despite the advantages of PhET interactive simulations to promote conceptual understanding and allowing for the administration of TSM laboratory experiments, interactive simulations may result in misconceptions
6	Ouahi et al. (2021)	Opinions of Moroccan teachers towards the use of PhET simulations in teaching and learning physics – chemistry	To study the views of secondary and high school physics-chemistry teachers regarding the use of PhET(Physics Education Technology) simulations in the teaching and learning of students.	78 responses (38 middle schools and 40 high schools)	General Chemistry	Interactive Simulation	Qualitative research	The result of the survey reveals that most of the simulation tools teachers used are meant to help students develop understanding of chemical concepts through engagement in the scientific process. It also shows that interactive simulation is a flexible tool for learning chemistry
7	Taibu et al. (2021)	Using PhET simulations to improve scientific skills and attitudes of community college students	To explored the gain in students‟ scientific skills and perceptions of using PhET simulations	61 Students	Gas Properties	Collaborative inquiry-based	Mixed methods design	The result reveals that there is gain in lab skills by all participants. It also revealed considerable positive students‟ experiences of the PhET simulations (88% of students indicated positive satisfaction)
8	Rahmawati et al. (2022)	Students' Conceptula Understanding in Chemistry Learning using PhET Interactive Simulations	To analyse students' conceptual understanding of chemical equilibrium matter using Physics Education Technology (PhET) Interactive Simulations	108 students	Chemical equilibrium matter	Interactive Simulation	Quantitative research method	The analysis of interviews about chemical equilibrium showed that students had difficulty determining: (i) the effect of temperature on the equilibrium shift and the equilibrium constant and (ii) the catalyst's effect on the forward and the reverse reaction rates
9	Salame & Makki (2021)	Examining the Use of PhET Simulations on Students' Attitudes and Learning in General Chemistry II	To investigate the students' perceptions on the impact of PhET simulations on their learning and attitudes and to identify PhET's most helpful features	158 participants	General Chemistry II	Interactive Simulation	Survey	PhET interactive simulations have an overall positive impact on students' attitudes and perceptions about learning, and it promote and facilitate learning and understanding of abstract concepts, it furnish learning opportunities that otherwise cannot be attained in a

								traditional laboratory setting
10	Ulhaq et al. (2023)	The Effect of Using PhET Simulations Virtual Lab on the Understanding of the Acid-Base Concept	To investigate the impact of using the PhET virtual lab on chemistry education students' understanding of the acid-base concept	Population of 72, sampled 28 participants	Acid-base Concept	Interactive Simulation	Quasi-experimental approach with a one-shot case study	The result indicated that students responded positively to the use of the PhET virtual lab, with 41% rating it as good and 40% rating it as very good
11	Cruz et al. (2022)	Experimental Activities Using Virtual Simulators to Learn Chemistry During Covid-19 Pandemic	To learn physical properties of substances based on the type of chemical bonds and obtaining binary and ternary compounds.	Population of 188 students, sample 102 students	practical of physical chemistry	Interactive Simulation	Quantitative study	The results showed that the simulation works in a similar way to the experimental method, "despite operating at different cognitive levels
12	Rayan et al. (2023)	Integrating PhET Simulations into Elementary Science Education: A Qualitative Analysis	To evaluate how the use of these digital simulations influenced students' conceiving of scientific concepts, focusing on "States of Matter and Phase Changes" and "Solubility and Saturation"	observed 19 students	Matter and Phase Changes" and "Solubility and Saturation"	Interactive Simulation	Qualitative research approach	The result reveal that in the "Remembering" phase, students demonstrated a tendency to relate personal experiences to simulations, underscoring real-life context's role in learning; "Understanding" phase highlighted how PhET simulations facilitated deeper comprehension, with students making insightful observations; the "Application" phase showcased the effective translation of simulation-derived knowledge into practical scenarios, bridging theoretical and real-world understanding; and simulations supported Grade 3 students in their learning processes of scientific concepts

13	Gunawan et al. (2023)	Effectiveness of Deep PhET Interactive Simulation Improving Understanding of the Concept of Material Change	To evaluate the effectiveness of using PhET interactive simulations in increasing students' understanding of the concept of chemical material changes	60 students	Material Change - three state of matter (solids, liquid and gas)	Discovery Learning	Quasi-experimental design	The result illustrates the positive impact of using PhET simulations on improving student understanding
14	Gong et al. (2023b)	Unpacking Chemistry Teachers' Pedagogical Reasoning and Decisions for a PhET Simulation: A TPACK Perspective	To investigate how two chemistry teachers evaluated an interactive simulation and determined pedagogical strategies for integrating the simulation into classroom instruction	two participants	General Chemistry	Interactive Simulation	Comparative case study	It showed that pedagogical reasoning and decisions of the two participants reflected different TPACK components. One teacher mainly utilized TCK and evaluated the simulation from a designer's perspective while the other teacher leveraged TPACK and reasoned from a learner's perspective
15	Yaman & Hand (2024)	Exploring Conditions for Utilizing Representations in Chemistry in an Argument-Based Inquiry Environment: Laboratory Only, Technology Only, or a Combination of Laboratory and Technology	To examines how preservice science teachers (PSTs) use multiple levels of representation in chemistry (macroscopic, microscopic, symbolic, and algebraic) as a result of engaging in argument-based inquiry in three different conditions: laboratory-only, technology-only, and a combination of technology and laboratory	20 PSTs	Acid and base chemistry	Inquiry	Single-case study design	The results reveal that the PSTs prefer engaging in the combination of laboratory and technology conditions in terms of representational use, with this condition being the most beneficial in promoting development of representational competency
16	Vandenplas et al. (2021)	Use of Simulations and Screencasts to Increase Student Understanding of Energy Concepts in Bonding	To investigate the use of simulations alone, versus the use of simulations incorporated into screen-casts, for the teaching and learning of energy changes at the atomic−molecular level	24 students	Force and energy in bonding and intermolecular attractions	Flipped, blended, and online learning	Experimental	The result revealed that the enhanced screencast was able to help students better connect this concept to the phenomena of ATP hydrolysis
17	Dantic & Fularon (2022)	PhET interactive simulation approach in teaching electricity and magnetism	To assess the students' conceptual knowledge in electricity, magnetism, and their perspectives on the	14 preservice science teacher	Electrons in Electricity	Interactive Simulation	Qualitative design	The results have revealed that the conceptual knowledge in Electricity and Magnetism improved to very satisfactory after the application of intervention

		among science teacher education students	effects of the PhET Simulation Approach in teaching the said concepts.					
18	Parthiban & Leo (2024)	Enhancing the Science Process Skills through Phet Simulation	To understand the science process skills among IX standard students with respect to PhET simulation	30 Students	Chemical bonding	Interactive Simulation	Single group design	The result indicated that the level the achievement of science process skills through PhET simulation in posttest is higher than that of Pre-test
19	Cruz et al. (2022)	Experimental Activities using Virtual Simulators to Learn Chemistry During COVID-19 Pandemic	To evaluate the effectiveness of three virtual resources: PhET, Crocodile Chemistry605 and Yenka in learning General Chemistry, Inorganic Chemistry and Chemical Physics	188 students (102 students)	General Chemistry, Inorganic Chemistry and Chemical Physics	Interactive Simulation	quasi-experiment al design	The results show that the activities carried out motivate students to inquire about the contents covered in class, stimulate their participation in the development of activities, but above all contribute to the interpretation of conceptual and procedural contents of the subjects developed in the area of Chemistry
20	Haryanto et al. (2024)	Generic Science Skills: PhET Applications Based On Discovery Learning	To assess the conceptual, procedural feasibility, and efficacy of a groundbreaking educational intervention, the Discovery Learning model-teaching module infused with the innovative PhET application aimed at enhancing students' generic skills proficiency in the domain of chemistry.	60 students and 15 teachers	General Chemistry	Discovery Learning	developme nt method, known as Research and Developme nt (R&D)	The result reveals that the PhET interactive simulation when integrated with discovery learning approach exhibits exceptional validity and practicality and yields tangible improvements in students' generic chemistry science skills.
21	Faizah et al. (2024)	Student Acceptance Study of PhET Simulation with an Expanded Technology Acceptance Model Approach	To assess level of acceptance of PhET interactive simulation on problem-based learning	49 students	General Chemistry	Problem-Based Learning	Quantitativ e design with a descriptive, explanatory type	The result showed that system quality has an effect on perceived usefulness, perceived ease of use has an effect on behavioral intention of use, behavioral intention of use has an effect on actual usage, and there is no relationship between instructor quality on perceived usefulness

22	Komang et al. (2023)	Problem Based Learning Model Assisted by PhET Interactive Simulation Improves Critical Thinking Skills of Elementary School Students	To analyze the effect of the Problem Based Learning model assisted by the phET application on electricity learning materials	Population totaled 192 students, samples is 35 students	Electrons in electricity	Problem Based Learning	quasi-experimental Design	The result indicated that Problem-based Learning assisted by the PhET application could improve the critical thinking ability of fourth grade elementary school students in electricity material
23	Juwairiah et al. (2022)	Digitization of laboratory equipment using PhET simulation media in applied chemistry practicum	To describe the use of PhET Simulation in acid-base practicum,	32 students of State Polytechnic of Creative Media PSDKU	Acid-base practicum of Applied Chemistry	Interactive Simulation	Descriptive method that	Results showed that the application of PhET media was effective in acid and base practicum. Based on student assessments after learning, it was found that students were very happy to learn by using PhET media.

After thorough exclusion and inclusion screening criteria, Table 1 indicated that only 23 articles contain rich information that will be valuable in answering the research question of the study. Although many authors used PhET interactive simulation in 2020, none of their research qualified for the analysis of this study. Consequently, five (5) published articles of 2021 and 2022 each qualified; nine (9) in 2023; and four (4) in 2024 also qualified. The key components of academic research focused by this study include the objective of the study, research methodology, instructional strategies, chemical concept, sample, and the result of the study. All qualified studies aligned their objectives with the methodology, and the findings are reported in a comprehensive and clear manner.

During screening of searched results, authors observed that other interesting studies are conducted in the other areas of science. For example, Efendi & Budi (2021) conducted a study to describe the influence and significant influence of PhET interactive simulation-based distance practicum learning on the science process skills of junior high school students. The study reveals that there is an influence of PhET interactive simulation-based distance practicum learning on the science process skills of junior high school students. It concluded that there is a massive influence between PhET-based remote practicum learning interactive simulations on the science process skills of junior high school students in science subjects. Similarly, Yulianti et al. (2021) used an eight-step guided inquiry framework to explore the description of the guided inquiry learning stages using PhET simulation to train students' critical thinking on vibration and wave topics. These stages are (i) open, (ii) immerse, (iii) explore, (iv) identify, (v) gather, (vi) create, (vii) share, and (viii) evaluate. Twenty-five (25) students were used as the participants of the study. According to researchers, most students were interested in and paid attention to learning starting from the pre-opening to the end. The result indicated that students were able to gain a correct conceptual understanding of classical wave phenomena, which furthermore will make it easier for them to learn more advanced topics, such as quantum physics, in the future.

In order to address research questions, results are presented in a systematic manner that describes each component of the research. The implication of the PhET interactive simulation in teaching and learning of chemical concepts is the first focal point of the study. These implication could come in different manners, but for this study we consider the implication of PhET in teaching and learning of chemical concepts itself, pedagogical approaches implemented for classroom instruction, learning theories, laboratory instruction, and remote learning.

Research Question one: Which chemical processes/concepts are predominantly learned in the classroom via a PhET interactive simulation?

The popular basic chemical concepts include matter, material; solid, liquid, gas, vapour, mixture, substance, solution, solvent, solute; physical physicochemical, chemical, radiochemical, element, compound, allotropy, periodicity, bonding, reaction, electrolysis, electrolytic cell, stoichiometric, nonstoichiometric molecular concepts, atomic and kinetic point of views etc. These formulated the entire macroscopic, sub microscopic, and symbolic level of representation of chemical concepts.

Table 2: Chemical processes/concepts that are predominantly learned in the classroom via a PhET interactive simulation

SN	Researchers	Research Objective	Chemical Concept
1	Casa-coila et al. (2023)	to determine the incidence in which application of those simulators could improve learning achievement in the Chemistry Laboratory course	Physical Chemistry
2	Lahlali et al. (2023)	to understand and relate both chemical systems and what is happening at the sub-microscopic level from the dynamic visualisation, and helps students to overcome learning difficulties and improve academic performance	Chemical Bonding
3	Toma (2023)	to explores the challenges Bangladeshi teachers face in learning to implement PhET with enhanced pedagogies and examines teachers' views of the pedagogical opportunities for PhET simulations in secondary schools.	Chemical Bonding
4	Sebatana & Dudu (2023)	to promote conceptual understanding and allowing for the administration of three state matter (solid, liquid and gas) laboratory experiments, interactive simulations may result in misconceptions.	Three State of Matter (solid, liquid and gas)
5	Rahmawati et al. (2022)	to analyse students' conceptual understanding of chemical equilibrium matter using Physics Education Technology (PhET) Interactive Simulations	Chemical equilibrium
6	Salame & Makki (2021)	to investigate the students' perceptions on the impact of PhET simulations on their learning and attitudes and to identify PhET's most helpful features	General Chemistry
7	Ulhaq et al., (2023)	to investigate the impact of using the PhET virtual lab on chemistry education students' understanding of the acid-base concept	Acid-base Concept
8	Patricia & Cruz, (2022)	to learn physical properties of substances based on the type of chemical bonds and obtaining binary and ternary compounds.	Physical chemistry
9	Rayan et al. (2023)	to evaluate how the use of these digital simulations influenced students' conceiving of scientific concepts, focusing on "States of Matter and Phase Changes" and "Solubility and Saturation"	States of Matter and Phase Changes" and "Solubility and Saturation"
10	Gunawan et al. (2023)	to evaluate the effectiveness of using PhET interactive simulations in increasing students' understanding of the concept of chemical material changes	Material Change – three state of matter (solids, liquid and gas)

Table 2 indicated that some of the chemical processes/concepts learned in the classroom with the aid of PhET interactive simulation include "physical chemistry" (Casa-coila et al., 2023 and Patricia & Cruz, 2022), "chemical bonding" (Lahlali et al., 2023 and Toma, 2023), "Three State of Matter (solid, liquid and gas)" (Gunawan et al., 2023; Rayan et al., 2023 and Sebatana & Dudu, 2023), "chemical equilibrium" (Rahmawati et al., 2022), "general chemistry" (Salame & Makki, 2021), and "acid-base concept" (Ulhaq et al., 2023). Thus, the most learned concept is three states of matter is part of general chemistry.

Research Question two: which chemical processes/concepts are predominantly learned in the laboratory via a PhET interactive simulation?

According to Patricia & Cruz (2022) laboratory practice constitutes a powerful pedagogical strategy for the construction of conceptual, procedural, and even attitudinal competencies. Chemistry teachers need to understand that thoughtfully designed chemistry laboratories enhance the chemistry experience, practical skills, scientific skills, and general skills vital to any student of science (Tran et al., 2020). Researchers (indicated in Table 3) used PhET simulations to investigate or facilitate learning of chemical concepts in the laboratories.

Table 3: Chemical processes/concepts learned predominantly in the laboratory via PhET interactive Simulations

SN	Researchers	Objective of their Research	Practical Concepts
1	Casa-coila et al. (2023)	To determine the incidence in which application of those simulators could improve learning achievement in the Chemistry Laboratory course	Acid-Base by titration; Gravimetric analysis of chlorides etc.
2	Salame & Makki (2021)	To investigate the students' perceptions on the impact of PhET simulations on their learning and attitudes and to identify PhET's most helpful features.	General Chemistry II
3	Patricia & Cruz (2022)	To learn physical properties of substances based on the type of chemical bonds and obtaining binary and ternary compounds.	Physical chemistry
4	Yaman & Hand (2024)	To examines how preservice science teachers (PSTs) use multiple levels of representation in chemistry (macroscopic, microscopic, symbolic, and algebraic) as a result of engaging in argument-based inquiry in three different conditions: laboratory-only, technology-only, and a combination of technology and laboratory	Acid and base chemistry
5	Dukes (2020)	To move the laboratory portion of our Instrumental Analysis course to an online instruction format	absorption spectroscopy measurement
6	Juwairiah et al.	To describe the use of PhET	acid-base practicum

(2022)	Simulation, knowing the effectiveness of using PhET Simulation media in acid-base practicum, knowing the advantages and disadvantages of using PhET Simulation in acid-base practicum, and the purpose of this study was to see student learning outcomes after the application of PhET media in learning.	of Applied Chemistry

It can be seen from Table 3 that researchers (Casa-coila et al., 2023; Dukes, 2020; Juwairiah et al., 2022; Patricia & Cruz, 2022; Salame & Makki, 2021; Yaman & Hand, 2024) used PhET simulations to investigate or facilitate teaching and learning of chemical concepts in the laboratories, depending on the objective of the researchers. Moreover, it reveals that volumetric analysis of acid-base chemistry is the most learned chemical concepts in the laboratory via PhET interactive simulations.

Research Question three: What are the predominant instructional strategies used by researchers in integrating PhET interactive simulation into the teaching and learning of chemical concepts?

Table 4: Instructional strategies used by researchers in integrating PhET interactive simulation into the teaching and learning of chemical concepts

SN	Researchers	Objective of their Research	Instructional Strategies
1	Komang et al. (2023)	to nalyse the effect of the Problem Based Learning model assisted by the PhET application on electricity learning materials	Problem Based Learning
2	Yulianti et al. (2021)	to explore the stages of inquiry learning approach using PhET, especially on training them to attain their critical thinking skill.	Inquiry-Based Learning
3	Toma (2023)	to explores the challenges Bangladeshi teachers face in learning to implement PhET-enhanced pedagogies and examines teachers' views of the pedagogical opportunities for PhET simulations in secondary schools	Inquiry-Based Learning
4	Makamu and Ramnarain (2022)	To investigate the pedagogical actions of physical sciences teachers when enacting simulations in 5E inquiry-based science teaching for current electricity	5E Inquiry-Based Learning
5	Siswoyo & Muliyati (2021)	to identify students' responses of how they nalyse the relationship between forces and changes in kinetic energy in objects moving in horizontal field	Inquiry-Based Learning
6	Sebatana & Dudu (2023)	to utilise PhET interactive simulations in the teaching and learning of sub-microscopic behaviour of particles in Three States of Matter (TSM)	Guided inquiry
7	Taibu et al.	to explored the gain in students" scientific skills	Collaborative

	(2021)	and perceptions of using PhET simulations	inquiry-based
8	Alfiyanti and Jatmiko (2020)	To assess the effectiveness of the POE model with PhET simulations in enhancing critical thinking skills of senior high school students in Indonesia was investigated	Predict-Observe-Explain (POE) method
9	Çetinkaya and Kırılmazkaya (2022)	explored POE's effect on students' attitudes toward science by reducing students' misconceptions of the concept of greenhouse effect	Predict-Observe-Explain (POE) method
10	Sebatana & Dudu (2023)	to utilise PhET interactive simulations in the teaching and learning of sub-microscopic behaviour of particles in three states of matter (TSM)	Project-Based Learning
11	Gunawan et al. (2023)	to evaluate the effectiveness of using PhET interactive simulations in increasing students' understanding of the concept of chemical material changes	Discovery learning
12	Yaman & Hand (2024)	examines how preservice science teachers (PSTs) use multiple levels of representation in chemistry (macroscopic, microscopic, symbolic, and algebraic) as a result of engaging in argument-based inquiry in three different conditions: laboratory-only, technology-only, and a combination of technology and laboratory	Inquiry
13	Haryanto et al. (2024)	to assess the conceptual, procedural feasibility, and efficacy of a groundbreaking educational intervention, the Discovery Learning model teaching module infused with the innovative PhET application aimed at enhancing students' generic skills proficiency in the domain of chemistry.	Discovery learning
14	Faizah et al. (2024)	to assess level of acceptance of PhET interactive simulation on problem-based learning	Problem-Based Learning

Table 4 represented various instructional strategies used for integrating interactive simulation into teaching and learning of chemical concepts. It has been revealed that the most predominant instructional strategies are "inquiry" (Bonny, 2022; Makamu & Ramnarain, 2022; Siswoyo & Muliyati, 2021 Taibu et al., 2021; Toma, 2023; Yaman & Hand, 2024; Yulianti et al., 2021), "problem-based learning" (Faizah et al., 2024; Komang et al., 2023), "discovery learning" (Gunawan et al., 2023; Haryanto et al., 2024), "project-based learning" (Sebatana & Dudu, 2023), "predict-observe-explain (POE) method" (Alfiyanti & Jatmiko, 2020; and Çetinkaya & Kırılmazkaya, 2022). It indicated that the predominantly used instructional strategies include inquiry, problem-based learning, project-based learning, discovery learning, and Predict-Observe-Explain (POE) method.

Research Question four: What are the predominant learning theories that guide researchers on the integration of PhET interactive simulation in the teaching and learning of chemistry?

Table 5: Learning theories used by researchers in implementing PhET Simulation in Chemistry

SN	Researchers	Objective of their Research	Learning Theories
1	Sebatana & Dudu (2023)	To utilise PhET interactive simulations in the teaching and learning of sub-microscopic behaviour of particles in three states of matter (TSM)	Experiential learning theory
2	Taibu et al. (2021)	To explored the gain in students" scientific skills and perceptions of using PhET simulations	Constructivism
3	Patricia & Cruz (2022)	To learn physical properties of substances based on the type of chemical bonds and obtaining binary and ternary compounds	Ausubel’s theory of meaningful learning
4	Vandenplas et al. (2021)	To investigate the use of simulations alone, versus the use of simulations incorporated into screen- casts, for the teaching and learning of energy changes at the atomic−molecular level	Cognitive Load Theory
5	Cruz et al. (2022)	To evaluate the effectiveness of three virtual resources: PhET, Crocodile Chemistry605 and Yenka in learning General Chemistry, Inorganic Chemistry and Chemical Physics	Ausubel's theory of significant learning

It can be observed from Table 5 that the predominant Psychological theories used by the researchers in integrating interactive simulations in teaching and learning of chemistry include “constructivism” (Taibu et al., 2021), “cognitive load theory” (Eichler, 2022 and Vandenplas et al., 2021), “Ausubel's theory of significant learning” (Cruz et al., 2022), and “experiential learning theory” (Sebatana & Dudu, 2023).

Research Question five: What are the benefits of integrating PhET interactive simulation in remote learning of chemical concepts?

The use of simulations in chemistry courses has become more frequent, and using them outside of the classroom in an online environment is one mechanism to provide active engagement with concept development at the atomic−molecular level (Vandenplas et al., 2021). Thus, the ability for classes to continue in a remote learning environment would not have been possible without innovative technology. Initially, issues arose due to lack of computers, limitations on sharing computers with other family members, and low-bandwidth internet (Emenike et al., 2020). During COVID-19 lockdown some institutions had to create emergency students funds to so that they could distribute laptops to those in need (Emenike et al., 2020), more training was provided to teachers

Table 6: Benefits of integrating PhET interactive simulation in remote learning of chemical concepts

SN	Researchers	Benefit	Frequency	Percentage
1	Juwairiah et al. (2022) and Sebatana & Dudu (2023)	enhanced student's interest	2	7.1%
2	Vandenplas et al. (2021)	Connect student's experience	1	3.6%
3	Faizah et al. (2024)	perceived usefulness, perceived ease of use	1	3.6%
4	Endrayani et al. (2022); Efendi & Budi (2021); Haryanto et al. (2024); Parthiban & Leo (2024); Taibu et al. (2021)	enhance students' science process skills	4	14.3%
5	Cruz et al. (2022); Cruz et al. (2022)	motivate students	2	7.1%
6	Casa-coila et al. (2023); Nizar et al. (2022); Yassin (2022)	improve academic achievement	3	10.7%
7	Ouahi et al. (2021); Yaman & Hand (2024)	enhanced students' engagement	2	7.1%
8	Dantic & Fularon (2022); Gunawan et al. (2023) Ouahi et al. (2021); Rayan et al., (2023); Rehman et al. (2021); Salame & Makki (2021); Sebatana & Dudu (2023)	improving student conceptual understanding	7	25.0%
9	Komang et al. (2023)	improve critical thinking ability	1	3.6%
10	Yassin, (2022); Lahlali et al. (2023)	enhanced students' academic performance	2	7.1%
11	Salame & Makki, 2021	yield positive impact on students' attitudes and perceptions about learning	1	3.6%
12	Ulhaq et al. (2023)	yield positive development in learning	2	7.1%
	Total		**28**	**100%**

It can be observed from Table 6 that researchers reported several benefits of integrating PhET interactive simulation in remote learning of chemical concepts including that, it help students better connect their experience with the chemical concepts (Vandenplas et al., 2021); enhanced student's interest (Juwairiah et al., 2022; Sebatana & Dudu, 2023); perceived usefulness, perceived ease of use (Faizah et al., 2024); enhance students' science process skills (Efendi & Budi, 2021; Haryanto et al., 2024; Parthiban & Leo, 2024; Taibu et al., 2021); motivate students (Cruz et al., 2022; Patricia & Cruz, 2022); improve academic achievement (Casa-coila et al., 2023; Nizar et al., 2022; Yassin, 2022); enhanced students' engagement (Ouahi et al., 2021; Yaman & Hand, 2024); improving student conceptual understanding (Dantic & Fularon, 2022; Gunawan et al., 2023; Ouahi et al., 2021; Rayan et al., 2023; Rehman et al., 2021; Salame & Makki, 2021; Sebatana & Dudu); improved student's learning (Banda & Nzabahimana, 2023); enhanced problem-solving (Patricia & Cruz, 2022); enhanced students cognitive ability (Patricia & Cruz, 2022); yield positive development in learning (Ulhaq et al., 2023); yield positive impact on students' attitudes and perceptions about learning (Salame & Makki, 2021); enhanced students' academic performance (Ali & Yassin 2021; Lahlali et al., 2023); improve critical thinking ability (Komang et. Al, 2023). The most reported benefits of integrating PhET interactive simulation in remote learning of chemical concepts is that it "improve student conceptual understanding" which represented 25% of the benefits recorded.

Discussion

The study executed systematic review of related articles that represented the integration of interactive simulations for facilitating teaching and learning of chemistry. After thorough exclusion and inclusion, qualified articles are reviewed and the results are discussed in the following subsections thereby addressing research questions of the study.

Predominant chemical processes/concepts learned in the classroom with the aid of PhET interactive simulation

As indicated in Table 2, some of the chemical processes/concepts learned in the classroom with the aid of PhET interactive simulation include "physical chemistry", "chemical bonding", "Three State of Matter (solid, liquid and gas)", "chemical equilibrium", "general chemistry", and "acid-base concept". These concepts are among the fundamental processes that understanding them lead to the understanding of other more complex concepts. Out of all the components of chemistry curriculum (physical, general, organic, inorganic, analytical, environmental, etc.) physical and general chemistry are the predominantly learned concepts in the classroom via interactive simulations. These mean that all learned concepts (three states of matter, chemical equilibrium, acid-base chemistry, chemical bonding) falls within the category of physical and general chemistry.

a. Physical Chemistry

The study of matter's behavior at the atomic or molecular level is the focus of physical chemistry. It also involves the study of the properties of substances at different scales, from the macroscopic scale, which includes particles that are visible to the naked eye, to the subatomic scale, involving extremely small subatomic particles, such as electrons. This area of chemistry employs the concepts and principles of physics to understand chemical systems and reactions. Patricia & Cruz (2022) guide their 102 students to learn physical properties of substances based on the type of chemical bonds and obtaining binary and ternary compounds using PhET interactive simulation. The findings of this action study conducted by Patricia & Cruz (2022) reveals that students fully agree that the use of simulators motivated the development of their skills, encouraged the development of strategies to solve theoretical and practical problems, and fostered a learning environment with meaningful, relevant experiences and constant feedback.

However, from the findings of the study, it is obvious that the three states of matter can be understand to be a concepts found in the physical branch of chemistry. To be precise, the three primary states of matter are the solid, liquid, and gaseous states. These three forms of matter can be converted from one state of matter to another state by changing certain environmental factors (increasing or decreasing pressure and temperature, for instance). According to Sebatana & Dudu (2023), three state of matter is the only topic in Grade 10 Physical Sciences that requires practical laboratory experiments (a heating curve) and is assessed as a formal task that contributes 25% to learners' pass mark in first term. It involves solid, liquid and gas, and their observable features can be difficult to understand, resulting in both teaching and learning challenges. Specifically, what makes this topic difficult is the sub-microscopic level of particles, since it is invisible. Sebatana & Dudu (2023), report that despite the advantages of PhET interactive simulations to promote conceptual understanding and allowing for the administration of three state matter (solid, liquid and gas) laboratory experiments, interactive simulations may result in misconceptions. The authors suggested that PhET interactive simulations should be utilised for effective teaching and learning of abstract concepts and conceptual understanding of sub-microscopic behaviour of particles in three state of matter (solid, liquid and gas).

Other authors that utilized PhET interactive simulation to facilitate learning of three states of matter include: Rayan et al. (2023) who evaluated how the use of these digital simulations influenced students' conceiving of scientific concepts, focusing on "States of Matter and Phase Changes" and "Solubility and Saturation"; and Gunawan et al. (2023) who also evaluated the effectiveness of using PhET interactive simulations in increasing students' understanding of the concept of chemical material changes.

b. General Chemistry

General chemistry is the study of matter, energy, and the interactions between the two. The main topics in chemistry include the gas phase, acids and bases, solutions (solubility), atomic structure, thermochemistry, electrochemistry, periodic table, equilibrium, chemical bonds, chemical kinetics, stoichiometry, and chemical reactions. The finding of the study reveals that while some authors (Salame & Makki, 2021) uses PhET simulation to teach the while general chemistry, others (Lahlali et al., 2023; Rahmawati et al., 2022; Toma, 2023; and Ulhaq et al., 2023) teach some components of general chemistry (chemical boding, equilibrium, acid-base chemistry etc.) via interactive simulation. For example, in a Redox reactions, Salame & Makki (2021), uses PhET simulations as part of their laboratory sessions of teaching general chemistry II in City College of New York, an urban, minority serving, and public college. The researchers use 158 participants to investigate the students' perceptions on the impact of PhET simulations on their learning and attitudes and to identify PhET's most helpful features. The general finding of the study are that PhET interactive simulations have an overall positive impact on students' attitudes and perceptions about learning, PhET simulations promote students' development of conceptual understanding of chemistry concepts and content, PhET simulations seem to promote and facilitate learning and understanding of abstract concepts, and PhET simulations furnish learning opportunities that otherwise cannot be attained in a traditional laboratory setting.

For the chemical bonding, the results of the study conducted by Lahlali et al. (2023) suggest that the teaching-learning of chemistry topics related to chemical bonding can be enhanced using PhET interactive simulations combined with molecular models. The researchers suggested the use of this simulation also allows students to understand and relate both chemical systems and what is happening at the sub-microscopic level from the dynamic visualisation, and helps students to overcome learning difficulties and improve academic performance. Lahlali et al. (2023), reported that the rate of student interaction between peers and with the teacher during the teaching-learning process after the integration of PhET interactive simulations is higher than before the integration of PhET, which mean that the simulation stimulation students' curiosity, engagement and collaboration in learning.

Chemical bonding and structures was also studied by Toma (2023) to explore the challenges Bangladeshi teachers face in learning to implement PhET with enhanced pedagogies and examines teachers' views of the pedagogical opportunities for PhET simulations in secondary schools.

For the equilibrium, Rahmawati et al. (2022), used interactive simulation to analyse students' conceptual understanding of chemical equilibrium matter using Physics Education Technology (PhET) Interactive Simulations. Three basic problems form the reason for the study according to the researchers. These include: students have difficulty connecting sub-microscopic, macroscopic, and symbolic level; students have different prior knowledge based on their everyday life experiences and perceive this as a scientifically acceptable concept; and students have difficulty visualising the chemical equilibrium system as well. Researcher reported that some common misconceptions that experienced by students in equilibrium reactions are that the reaction will occur after all reactants have reacted such as irreversible reaction; some even thought that no reaction occurs in the equilibrium system; increasing the concentration of the reactants will form more reactants; addition of solvents, such as water, will not affect the equilibrium shift. Students did not understand the meaning of enthalpy in the reaction equation and temperature given to the system; they ignored any temperature changes that could impact the distribution of the product and reactant molecules.

For the acid-base chemistry, Ulhaq et al., (2023) used interactive simulation to investigate the impact of using the PhET virtual lab on chemistry education students' understanding of the acid-base concept. About 28 individuals participated in this quasi-experimental approach where a one-shot case study followed by a post-test. The findings suggested that the implementation of PhET Simulation can facilitate students in understanding the concepts of acid-base materials.

Chemical processes/concepts are predominantly learned in the laboratory via a PhET interactive simulation

The findings of the study reveals that chemical concepts like volumetric analysis of acid & base (Casa-coila et al., 2023; Juwairiah et al., 2022; Yaman & Hand, 2024), Gravimetric analysis of chlorides, absorption spectroscopy measurement (Dukes, 2020), general chemistry II (Salame & Makki, 2021) and physical chemistry (Patricia & Cruz, 2022) are some of the processes learned in the laboratory via interactive simulations. However, the results of the study reveals that the volumetric analysis of acid & base chemistry is the most learned concept in the laboratory via interactive simulations. These findings are obvious because, Casa-coila et al. (2023) use Model Chemlab and PhET Simulator to determine the incidence in which application of those simulators could improve learning achievement in the Chemistry Laboratory course. Moreover, they use

14 undergraduate students to study volumetric analysis of chemistry practical in nine (9) learning sessions. No instructional approach was indicated by the authors, but the results showed a significant improvement which indicate that the students achieved an efficient scores that favoured their learning in the Chemistry Laboratory course. According to Casa-coila et al. (2023), the application of active experimental strategies is an active learning method that stimulates students to develop competencies through interactions, using simulators in laboratory classrooms.

Juwairiah et al. (2022) uses 32 students of State Polytechnic of Creative Media PSDKU to describe the use of PhET Simulation, knowing the effectiveness of using PhET Simulation media in acid-base practicum, knowing the advantages and disadvantages of using PhET Simulation in acid-base practicum, and the purpose of this study was to see student learning outcomes after the application of PhET media in learning. The results showed that the application of PhET media was effective in acid and base practicum. Based on student assessments after learning, it was found that students were very happy to learn by using PhET media.

Consequently, as an alternative to didactic resource to teach students to learn the practical of physical chemistry, Patricia & Cruz (2022) uses PhET simulator and the virtual laboratories Crocodile Chemistry605 and Yenka to learn physical properties of substances based on the type of chemical bonds and obtaining binary and ternary compounds. The study reviewed properties of gases and their laws (Boyle, Charles and Gay Lussac).

Predominant instructional strategies used by researchers in integrating PhET interactive simulation into the teaching and learning of chemical concepts

Technology in the classroom is becoming increasingly prevalent, but many educators face challenges when integrating educational technology effectively (Toma, 2023). With the rapid growth of technological innovations, there are abundant opportunities to engage students in meaningful learning. Thus, for effective integration of technology in the classroom, teachers need to possess relevant technological pedagogical and content knowledge. According to Ulhaq et al. (2023), PhET simulations bridge the gap between theoretical concepts and real-world application.

The findings of the study reveal that the predominant instructional strategies used for delivering instruction via PhET interactive simulations include inquiry, problem-based learning, project-based learning, discovery learning, and Predict-Observe-Explain (POE) method. Interestingly, the pedagogical advantages of PhET simulations in improving the visualization of abstract scientific concepts have been reported by many researchers (Correia et al., 2019; Price et al., 2019; Salame & Makki, 2021). But, this and other benefits can be achieved only when PhET simulations coupled with appropriate instructional approaches (Toma, 2023). The use of improper instructional strategies has been identified as a significant factor that may hinder the effective use of PhET simulations in the classroom or laboratory (Ouahi et al., 2022). According to Toma (2023), researchers suggested that lecture and guided inquiry are specific strategies that are best suited to PhET simulations. Some of them explored how POE (Predict-Observe-Explain), 5E (Engage-Explore-Explain-Elaborate-Evaluate), and CCL (Collaborative Creativity Learning) models can be used with PhET simulations.

Some researchers (Prima et al., 2018; Toma, 2023) found that students who learn scientific concepts with PhET simulations performed significantly better across four cognitive domains: remembering, understanding, applying, and analysing. Moreover, in an attempt to identify and discuss the views of teachers of physics-chemistry (Ph-Ch) and Life and Earth Sciences (LES) on the use and effectiveness of interactive simulations PhET in student teaching and learning Ouahi et al. (2022) resolved that the use of interactive simulations in investigative science teaching and learning is very effective for both teachers and students, despite the presence of a set of obstacles that hinder the use of classroom simulations.

a. Problem-based Learning

The problem-based learning was used by Faizah et al. (2024) and Komang et al. (2023) to facilitate instruction in a simulation environment. Problem-based learning (PBL) is a pedagogy that uses real-world problems to direct students towards the learning objectives of a course. It is an instructional method helps students to use open-inquiry approach in learning to apply scientific knowledge in real life situations unlike the traditional method where students become passive in the teaching process that does not promote problem-solving and cognitive skills. Solving the problems requires that students build upon their background knowledge and gain new subject knowledge of the material that they have not yet studied. They gain this knowledge on a need to know basis in order to solve the problem. Thus, it was reported that PhET application-assisted problem-based learning enhances critical thinking ability (Komang et al., 2023).

b. Inquiry-Based Learning approaches

Inquiry-based learning has be used by chemistry teachers (Tran et al., 2020) for decades to deliver effective instructions in in the classroom, laboratory or even remote locations. Yulianti et al. (2021), reports that students' critical thinking abilities increase during the implementation of the guided inquiry model in learning. The authors used the nine-step guided inquiry framework (pre-opening, opening, immerse, explore, identify, gather, create, share, evaluate) designed by Kuhlthau et al. (2012) with 25 Indonesian junior high school students. They found out that using PhET simulations in a guided inquiry learning model that emphasized critical thinking helped students acquire the following concepts: wave speed, wavelength, and wave frequency.

Similarly, Toma (2023), argued that inquiry-based active learning approaches have been proven to be more effective teaching strategies of teaching and learning chemistry at all levels of education. This covers not only students but evidence indicated that teachers were also trained using inquiry on how to implement PhET simulations to their classroom. For example, while Makamu and Ramnarain (2022) integrate 5E inquiry-based to develop students' understanding of scientific ideas and concepts, Bonny (2022) use 5E inquiry-based to train science teachers how to use PhET interactive simulations.

Siswoyo & Muliyati (2021), conducted a study to identify students' responses of how they analyze the relationship between forces and changes in kinetic energy in objects moving in horizontal field. The authors used inquiry-based exploration where 36 students play an energy skate simulation experiment by placing the objects on the track. The result indicated that students' interpretation of graph is better after using PhET than before. Students were interested in PhET interactive simulation and actively ask questions during the lesson.

Guided inquiry was used by Sebatana & Dudu (2023) to utilise PhET interactive simulations in the teaching and learning of sub-microscopic behaviour of particles in

Three States of Matter (TSM). The finding of the study showed that, despite the advantages of PhET interactive simulations to promote conceptual understanding and allowing for the administration of TSM laboratory experiments, interactive simulations may result in misconceptions. Collaborative inquiry-based was used by Taibu et al. (2021) to explore the gain in students‟ scientific skills and perceptions of using PhET simulations.

c. Predict-Observe-Explain (POE) method

The effectiveness of the POE model with PhET simulations in enhancing critical thinking skills of senior high school students in Indonesia was investigated by Alfiyanti and Jatmiko (2020) where they found out that the instructional approach with PhET simulations improved students' critical thinking skills and increased the student' level of active learning. This approach was introduced by White and Gunstone (1992), ask students to make predictions about the experiment, make observations, and then explain by comparing their predictions with their observations.

Çetinkaya and Kırılmazkaya (2022) explored POE's effect on students' attitudes toward science by reducing students' misconceptions of the concept of greenhouse effect. The results of the study reveals that students who learned with the POE method supported by PhET simulations had a much better understanding of the greenhouse effect, a positive attitude toward science, and fewer misconceptions.

d. Project-Based Learning

Project-based learning (PBL) is an inquiry-based approach that aims to engage students in challenging, active, and meaningful experiences connected to the world outside the classroom. The strategy is increasingly popular trend in the 21st century. Solving highly complex problems requires that students have both fundamental skills (reading, writing, and math) and 21st century skills (teamwork, problem-solving, research gathering, time management, information synthesizing, utilizing high tech tools). Sebatana & Dudu (2023) used project-based learning to utilise PhET interactive simulations in the teaching and learning of sub-microscopic behaviour of particles in three states of matter (TSM)

e. Discovery Learning

The result of a study conducted by Haryanto et al. (2024), reveals that the PhET interactive simulation when integrated with discovery learning approach exhibits exceptional validity and practicality and yields tangible improvements in students' generic chemistry science skills. The study adopted a development method, known as Research and Development (R&D), to develop and validate educational products called "PhET application- based Discovery Learning module". The model applied is the 4-D Model, which includes the Define, Design, Develop and Disseminate stages. The development of this model was guided according to the stages in the Hannafin and Peck model.

Predominantly learning theories that guide researchers on the integration of PhET interactive simulation in the teaching and learning of chemistry

The findings of the study reveal that researchers predominantly used Constructivism, cognitive load theory, Ausubel's theory of significant learning, and experiential learning theory as a guide integrating PhET interactive simulations into teaching and learning of chemistry. Understanding of the underlying learning theories behind simulation education help teachers in the development of their classroom instructions. According to Babin et al. (2019), the learning theories are the foundation of an effective educational experience. Thus, teachers need to be familiar with these theories in order to enhance their instructional skills.

a. Experiential learning theory

According to Sebatana & Dudu (2023), effective learning takes place when a learner progresses through a cycle of four stages of experiential learning: (i) having a concrete experience; (ii) reflective observation on that experience; (iii) abstract conceptualisation; and (iv) active experimentation. In their study titled "the utilisation of interactive simulations in the teaching and learning of a grade 10 chemistry topic: a case in the North West province of South Africa" Sebatana & Dudu (2023) argued that concrete experience is achieved when the learner actively experiences an activity such as those contained in PhET simulation. Thus, the PhET simulation is proved to be effective in the construction of experience that triggered reflective observation in learning.

b. Constructivism

This theory is based on the idea that people actively construct or make their own knowledge, and that reality is determined by your experiences as a learner. A study conducted by Taibu et al. (2021), to explored the gain in students‟ scientific skills and perceptions of using PhET simulations was guided by the constructivism.

c. Cognitive Load Theory

Cognitive Load Theory was developed by John Sweller in the late 1980s, who argues that human memory has a limited capacity; therefore, instructional procedures need to avoid overloading it with those activities that don't directly enhance learning. When information is entered into human brains, it carries a cognitive load that exerts a processing burden on the brain to provide meaningful learning outcomes to the information. Thus, classroom teachers need to know how they can reduce cognitive load as there are profound implications for learning outcomes. The best learning occurs when the learning environment is aligned with the human cognitive capacity. To investigate the use of simulations alone, versus the use of simulations incorporated into screen- casts, for the teaching and learning of energy changes at the atomic−molecular level, Vandenplas et al. (2021) used cognitive load theory. Flipped, blended, and online learning strategies were employed by the researchers. The result reveals that the enhanced screencast of the simulator was able to help students better connect this concept to the phenomena of ATP hydrolysis.

d. Ausubel's theory of significant learning

According to the theory, a learner needs an established cognitive structure that new concepts can be anchored or subsumed into in order to absorb new concepts from spoken material. If the requisite cognitive structure is not available it can be provided with an advance organizer. Cruz et al. (2022) used Ausubel's theory of significant learning to evaluate the effectiveness of three virtual resources: PhET, Crocodile Chemistry605 and Yenka in learning general chemistry, inorganic chemistry and chemical physics. The findings of the 102 students' quasi-experimental research design demonstrate that the activities conducted encourage students to ask questions about the material covered in class, encourage their involvement in the creation of new activities, but most importantly, they aid in the interpretation of the procedural and conceptual content of the subjects developed in the field of chemistry.

Benefits of integrating PhET interactive simulation in remote learning of chemical concepts

The benefits of integrating interactive simulations in remote learning of chemical concepts. The results of the study revealed that some of the benefits of integrating PhET interactive simulations in remote learning of chemical concepts include, enhancement of student's interest, connect student's experience, it is easy to use, it enhance students' science process skills, motivate students, improve academic achievement, enhanced students' engagement, improved student conceptual understanding, improve critical thinking ability, enhanced students' academic performance, yield positive development in learning, and it yield positive impact on students' attitudes and perceptions about learning. For example, according to Parthiban & Leo (2024) knowledge is a process not a product and we teach chemistry not to produce little living libraries, but rather to get a students to take part in the process of getting knowledge which will enable them acquire science process skills. The author classified process skills in basic process skills (observing, Inferring, classifying, predicting) and integrated process skills (hypothesizing, interpretation data, experimenting, generalizing, manipulating); and both assists to enhance science as a process and never be a product.

Cruz et al. (2022), evaluate the effectiveness of three virtual resources: PhET, Crocodile Chemistry605 and Yenka. Although, Crocodile Chemistry605 and Yenka are programs that must be previously installed and are in the English language, which for some students made their use difficult, they are virtual laboratories that give the student freedom to carry out experimental activities. Similarly, even though, the result indicated that there is no difference in the academic performance of the students when using the three virtual simulators such as PhET, Crocodile Chemistry605 and Yenka, PhET simulator is more effective due to the exceptional facilities it provided including access to it without an internet connection once downloaded and integrated different languages.

Rahmawati et al. (2022), suggested that PhET Interactive Simulations require improvements or additional features to help students better understand conceptual understanding through analogies of product and reactant molecules' movement in the equilibrium system. PhET simulations have been successful in reaching large numbers of users in the K12 or secondary school, colleges and university levels with over 45 million runs per year and usage in all across the 50 states of United States and the entire world (Salame & Makki, 2021). Thus, according to Rahmawati et al., (2022) the use of PhET Interactive Simulations in chemistry provides students with a learning experience where they can explore concepts directly to gain knowledge and experiment in a relatively short time. It offers students the ability to understand and relate both chemical systems and what is happening at the sub-microscopic level through dynamic visualization.

Conclusion

Chemistry is considered difficult for students to learn because many of its concepts are abstract in nature and require visualisation at the sub-microscopic level of representation. And due to the nature of these abstract chemical concepts, students often experience multiple problems with understanding the lessons taught. The study investigated the most employed instructional strategies used by educators when integrating PhET interactive simulation. It also investigated the most learnt chemical concepts and psychological theories guiding the instruction design by the educators. In order to address these objectives, the study adopted a systematic review of academic research published after the COVID-19 pandemic (2020-2024). After subjecting the obtained data to inclusion and exclusion criteria, 25 articles qualified for the study. The results indicated that the chemical processes/concepts learnt in the classroom with the aid of PhET interactive simulation include “physical chemistry," “chemical bonding," “Three State of Matter (solid, liquid, and gas)," “chemical equilibrium," “general chemistry," and “acid-base concept." It also reveals that the volumetric analysis of acid and base chemistry is the most learnt concept in the laboratory via interactive simulations. The findings also reveal that the predominant instructional strategies used for delivering instruction via PhET interactive simulations include inquiry, problem-based learning, project-based learning, discovery learning, and the Predict-Observe-Explain (POE) method. Finally, constructivism, cognitive load theory, Ausubel's theory of significant learning, and experiential learning theory are predominantly used theories guiding integration of PhET interactive simulation in the teaching and learning of chemistry.

Interactive simulations help learners to repeat experimental simulations several times and subsequently assist in the realisation of scientific phenomena. Simulations help learners grasp real-world data through multiple representations. Simulations give students the opportunity to visualise and experience things that would be impossible to handle in the laboratory, such as manipulating an object. Interactive simulations are the enhancement of motivation and creativity.

Recommendation

The study recommended that governments across all continents should endeavour to overcome the problem of shortage of equipment and capabilities, fund experiments, and provide security and protection for learners from health, physical, and environmental risks when carrying out experiments. Teachers should assist learners to link the theoretical side and the applied side.

References

Aliyu, F., Talib, C. A., & Aliyu, H. (2021). Multi-Dimensional Visualization Support Mechanism and Students ’ Achievement in Chemical Bonding and Structures. *4th ASEAN International Conference on Education and Social Sciences*, 1–13.

Aliyu, H., Raman, Y., & Talib, C. A. (2021). Enhancing Cognitive Development in Learning Chemical Symbol and Periodicity through Instructional Game. *International Journal of Asian Education*, *2*(3), 285–295. https://doi.org/10.46966/ijae.v2i3.115

Casa-coila, M. D., Mamani-vilca, P. S., Tisnado-mamani, L. M., Pari-achata, D., & Vilca-apaza, H. M. (2023). Model Chemlab and PhET Simulator: A Didactic Resource for Chemistry Learning in Undergraduate Students. *International Journal of Membrane Science and Technology*, *10*(5), 59–75. https://doi.org/10.15379/ijmst.v10i5.2420

Cruz, E. P. U., Salcán, N. de J. S., & Riofrío, M. C. O. (2022). Experimental Activities using Virtual Simulators to Learn Chemistry During COVID-19 Pandemic. *SciELO Preprints*, *22*(1), 122–137. https://doi.org/https://doi.org/10.1590/SciELOPreprints.3668

Dantic, M. J. P., & Fularon, A. R. (2022). PhET interactive simulation approach in teaching electricity and magnetism among science teacher education students. *Journal of Science and Education (JSE)*, *2*(2), 88–98. https://doi.org/10.56003/jse.v2i2.101

Dukes, A. D. (2020). Teaching an Instrumental Analysis Laboratory Course without Instruments during the COVID-19 Pandemic. *Journal of Chemical Education*, *97*(9), 2967–2970. https://doi.org/https://doi.org/10.1021/acs.jchemed.0c00648

Efendi, N., & Budi, S. (2021). The Effect of Distance Learning Practicum based on PhET Interactive Simulations on Science Process Skills of Secondary School Students. *Jurnal Pendidikan Sains (JPS)*, *9*(1), 91–96. https://doi.org/https://doi.org/10.26714/jps.9.1.2021.91-96

Eichler, J. F. (2022). Future of the Flipped Classroom in Chemistry Education: Recognizing the Value of Independent Preclass Learning and Promoting Deeper Understanding of Chemical Ways of Thinking During In-Person Instruction. *Journal of Chemical Education*, *99*(11), 1503–1580. https://doi.org/https://doi.org/10.1021/acs.jchemed.1c01115

Emenike, M. E., Schick, C. P., Van Duzor, A. G., Sabella, M. S., Hendrickson, S. M., & Langdon, L. S. (2020). Leveraging undergraduate learning assistants to engage students during remote instruction: Strategies and lessons learned from four institutions. *Journal of Chemical Education*, *97*(9), 2502–2511. https://doi.org/10.1021/acs.jchemed.0c00779

Endrayani, I., Efendi, A., & Yamtinah, S. (2022). Identification of the Need for PhET Simulation-based Interactive Media for Learning in Vocational High Schools. *Journal of Educational Research and Evaluation*, *6*(3), 667–677. https://doi.org/https://doi.org/10.23887/jere.v6i4.53040

Faizah, S. N., Dina, L. N. A. B., Kartiko, A., Ma'arif, M. A., & Hasan, M. S. (2024). Student Acceptance Study of PhET Simulation with an Expanded Technology Acceptance Model Approach. *Journal of Applied Engineering and Technological Science (JAETS)*, *5*(1), 279–290. https://doi.org/10.37385/jaets.v5i1.3041

Gong, X., Wei, B., Bergey, B. W., & Shockley, E. T. (2023a). Unpacking Chemistry Teachers' Pedagogical Reasoning and Decisions for a PhET Simulation: A TPACK Perspective. *Journal of Chemical Education*, *100*(1), 34–44. https://doi.org/https://doi.10.1021/acs.jchemed.2c00397

Gong, X., Wei, B., Bergey, B. W., & Shockley, E. T. (2023b). Unpacking Chemistry Teachers' Pedagogical Reasoning and Decisions for a PhET Simulation: A TPACK Perspective. *Journal of Chemical Education*, *100*(1), 34–44. https://doi.org/hpps://doi.org.10.1021/acs.jchemed.2c00397

Gunawan, A., Heliawati, L., & Permanasari, A. (2023). Effectiveness of Deep PhET Interactive Simulation Improving Understanding of the Concept of Material Change. *Journal of Science Education and Practice (JSEP)*, *7*(2), 92–102. https://doi.org/https://journal.unpak.ac.id/index.php/jsep

Haryanto, Asrial, Sanova, A., Widowati, A., & Saputra, A. (2024). Generic Science Skills: PhET Applications Based On Discovery Learning. *Jurnal Ilmiah Ilmu Terapan Universitas Jambi*, *8*(1), 158–169. https://doi.org/10.22437/jiituj.v8i1.32441

Juwairiah, Riana, M., & Windiani. (2022). Digitization of laboratory equipment using PhET simulation media in applied chemistry practicum. *International Journal of Trends in Mathematics Education Research*, *5*(2), 169–173. https://doi.org/https://doi.org/10.33122/ijtmer.v5i2.131

Komang, I. G., Angga, A., Widiarta, P., Wahyu, I. G., Antara, S., & Dewantara, A. K. (2023). Problem Based Learning Model Assisted by PhET Interactive Simulation Improves Critical Thinking Skills of Elementary School Students. *Thinking Skills and Creativity Journal*, *6*(1), 1–8.

Lahlali, A., Chafiq, N., Radid, M., Moundy, K., & Srour, C. (2023). The Effect of Integrating Interactive Simulations on the Development of Students' Motivation, Engagement, Interaction and School Results. *International Journal of Emerging Technologies in Learning (IJET)*, *18*(12), 193–207. https://doi.org/10.3991/ijet.v18i12.39755

Mojica, E. E., & Upmacis, R. K. (2022). Challenges Encountered and Students ' Reactions to Practices Utilized in a General Chemistry Laboratory Course During the COVID-19 Pandemic. *Journal of Chemical Education*. https://doi.org/10.1021/acs.jchemed.1c00838

Nizar, M., Najib, 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 & Humanities*, *3*(2), 73–88. https://doi.org/https://10.48165/sajssh.2022.3204

Ouahi, M. Ben, Hou, M. A., Hassouni, T., & Al Ibrahim, E. M. (2021). Opinions of Moroccan teachers towards the use of PhET simulations in teaching and learning physics – chemistry. *IEEE Xplore*, 274–278. https://doi.org/10.1109/CiSt49399.2021.9357174

Ouahi, M. Ben, Lamri, D., Hassouni, T., & Al-Ibrahmi, E. M. (2022). Science Teachers ' Views on the Use and Effectiveness of Interactive Simulations in Science Teaching and Learning. *International Journal of Instruction*, *15*(1), 277–292. https://doi.org/https://doi.org/10.29333/iji.2022.15116a

Parthiban, J., & Leo, S. S. (2024). Enhancing the Science Process Skills through Phet Simulation. *International Research Journal on Advanced Engineering and Management*, *2*(3), 432–435. https://doi.org/https://doi.org/10.47392/IRJAEM.2024.0060

Patricia, E., & Cruz, U. (2022). Experimental Activities Using Virtual Simulators to Learn Chemistry During Covid-19 Pandemic. *CHAKIÑAN. Revista de Ciencias Sociales y Humanidades*, 122–137. https://doi.org/https://doi.org/10.37135/chk.002.17.08

Peperkorn, Y., Buschmann, J., & Schwedler, S. (2024). Comparing drawing tasks and elaborate single-choice questions in simulation-based learning: How do they facilitate students' conceptual understanding on chemical equilibria? *Chemistry Education Research and Practice*. https://doi.org/10.1039/D3RP00113J

Rahayu, C. D., & Sartika, S. B. (2020). Students Learning Motivation and Concepts Understanding of Science through the Use of PhET Interactive Simulations Motivasi Belajar dan Pemahaman Konsep IPA. *Science Education Journal (SEJ)*, *4*(1), 63–76. https://doi.org/10.21070/sej.v4i1.750

Rahmawati, Y., Hartanto, O., Falani, I., & Iriyadi, D. (2022). Students' Conceptula Understanding in Chemistry Learning using PhET Interactive Simulations. *Journal of Technology and Science Education*, *12*(2), 303–326. https://doi.org/https://doi.org/10.3926/jotse.1597

Rayan, B., Daher, W., Diab, H., & Issa, N. (2023). Integrating PhET Simulations into Elementary Science Education: A Qualitative Analysis. *Edu. Sci.*, *13*(884), 1–17. https://doi.org/https://doi.org/10.3390/educsci13090884

Rehman, N., Mahmood, A., Zhang, W., & Alam, F. (2021). Teaching Phyics with Interactive Computer Simulation at Secondary Level. *Brazilian Journal of Education, Technology and Society (BRAJETS)*, *14*(1), 127–141. https://doi.org/http://dx.doi.org/10.14571/brajets.v14.n1

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), 1–9. https://doi.org/https://doi.org/10.21601/ijese/10966

Sebatana, M. J., & Dudu, W. T. (2023). The Utilisation of Interactive Simulations in the Teaching and Learning of a Grade 10 Chemistry Topic: A Case in the North West province of South Africa. *14th International Conference on Education Technology and Computers (ICETC 2022)*, 182–188. https://doi.org/https://doi.org/10.1145/3572549.3572579

Siswoyo, S., & Muliyati, D. (2021). Teaching high school physics using PhET interactive simulation. *The 2nd Science and Mathematics International Conference (SMIC 2020)*, *030003*(April), 030003-1–7. https://doi.org/https://doi.org/10.1063/5.0041657

Taibu, R., Mataka, L., & Shekoyan, V. (2021). Using PhET simulations to improve scientific skills and attitudes of community college students. *International Journal of Education in Mathematics, Science, and Technology (IJEMST)*, *9*(3), 353–370. https://doi.org/https://doi.org/10.46328/ijemst.1214

Talib, C. A., Ali, M., Zawadzki, R., Baharuddin, N. S., Thoe, N. K., & Aliyu, H. (2017). Video-Based Learning in Chemistry Education: Exemplars, Issues and Challenges. *Learning Science and Mathematics Journal*, *12*, 35–51. http://www.recsam.edu.my/lsm/2017/(4)CAT p35-51_final.pdf

Talib, C. A., Aliyu, H., Ali, M., Malik, A. M. A., & Siang, K. H. (2018). Is Sakai Online

Visual Learning Suitable for Cultivating Thinking Skills in Malaysia's Higher Education? *Learning Science and Mathematics Journal*, *33*, 87–97.

Talib, C. A., Aliyu, H., Malik, A. M. A., Siang, K. H., & Ali, M. (2018). Interactive Courseware as an effective strategy to overcome misconceptions in Acid-base Chemistry. *2018 IEEE 10th International Conference on Engineering Education (ICEED)*, 240–245.

Toma, M. J. (2023). *The Pedagogical Opportunities of PhET Interactive Simulations in Secondary Science Education in Bangladesh*. University of British Columbia.

Tran, K., Beshir, A., & Vaze, A. (2020). A Tale of Two Lab Courses: An Account and Re fl ection on the Teaching Challenges Experienced by Organic and Analytical Chemistry Laboratories During the COVID-19 Period. *Journal of Chemical Education*. https://doi.org/https://dx.doi.org/10.1021/acs.jchemed.0c00649

Ulhaq, D., Hanum, L., & Habibatia. (2023). The Effect of Using PhET Simulations Virtual Lab on the Understanding of the Acid-Base Concept (A Case Study at Chemistry Education Department, Syiah Kuala University). *Chimica Didactica Acta*, *11*(1), 8–14. https://doi.org/https://doi:10.24815/jcd.v11i1.28257

Vandenplas, J. R., Herrington, D. G., Shrode, A. D., & Sweeder, R. D. (2021). Use of Simulations and Screencasts to Increase Student Understanding of Energy Concepts in Bonding. *Journal of Chemical Education*, *98*(3), 730–744. https://doi.org/10.1021/acs.jchemed.0c00470

Yaman, F., & Hand, B. (2024). Exploring Conditions for Utilizing Representations in Chemistry in an Argument-Based Inquiry Environment: Laboratory Only, Technology Only, or a Combination of Laboratory and Technology. *Journal of Chemical Education*. https://doi.org/https://doi.org/10.1021/acs.jchemed.3c01136

Yassin, A. A. B. (2022). The Effect of Using Interactive Simulation (PhET) and Virtual Laboratories (Praxilabs) on Tenth- Grade Students' Achievement in Physics. *Britain International of Linguistics, Arts and Education (BIoLAE) Journal*, *4*(2), 58–72. https://doi.org/https://doi.org/10.33258/biolae.v4i2.693 -58-

Yulianti, E., Zhafirah, N. N., & Hidayat, N. (2021). Exploring Guided Inquiry Learning with PhET Simulation to Train Junior High School Students Think Critically. *Berkala Ilmiah Pendidikan Fisika*, *9*(1), 96–104. https://doi.org/10.20527/bipf.v9i1.9617