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PhET SIMULATION: A PLATFORM TO IMPROVE STUDENTS PERFORMANCE IN CHEMISTRY CONTENT

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Abstract

This research investigates the impact of PhET simulations on improving students' performance in Chemistry. A quasi-experimental design was employed, involving pre-test, post-test, and control groups. The study targeted senior secondary school students in Kwara State, Nigeria, using purposively selected intact classes from two schools. Students were grouped based on their prior academic performance. To assess learning outcomes, PhET simulations and a Chemistry Performance Test (CPT) were utilized. The instruments underwent expert validation for accuracy, and their reliability of 0.79 was confirmed through Cronbach's Alpha. Findings revealed that the experimental group showed a marked improvement in post-test scores compared to the control group, highlighting the effectiveness of PhET simulations in improving students' understanding and retention of Chemistry concepts.

Keywords: PhET Simulation, Chemistry Education, Student Performance

Abstrak

Penelitian ini menyelidiki dampak simulasi PhET terhadap peningkatan kinerja siswa dalam Kimia. Desain eksperimen semu digunakan, yang melibatkan kelompok pre-test, post-test, dan kontrol. Penelitian ini menargetkan siswa sekolah menengah atas di Negara Bagian Kwara, Nigeria, menggunakan kelas utuh yang dipilih secara sengaja dari dua sekolah. Siswa dikelompokkan berdasarkan kinerja akademik mereka sebelumnya. Pada proses penilaian menggunakan simulasi PhET dan Chemistry Performance Test (CPT). Instrumen telah menjalani validasi ahli untuk akurasi, dan reliabilitasnya sebesar 0,79 dikonfirmasi melalui Cronbach's Alpha. Temuan mengungkapkan bahwa kelompok eksperimen menunjukkan peningkatan yang nyata dalam skor post-test dibandingkan dengan kelompok kontrol, menyoroti efektivitas simulasi PhET dalam meningkatkan pemahaman siswa dan retensi konsep-konsep Kimia.

Kata Kunci: Simulasi PhET, Pendidikan Kimia, Kinerja Siswa

PENDAHULUAN

In the realm of science education, technology integration has become increasingly indispensable for fostering deeper understanding and engagement among chemistry students. Technological tools can be used to learn chemistry content, which is undoubtedly advantageous for developing nations (Najib et al., 2022). Therefore, technology is the application of scientific skills through the production of machines and equipment which is essential to greatly enhance instruction, teaching and learning (Bongomin et al., 2020). Learning and teaching of students can take place by employing the use of technology, and teachers are urged to be innovative in the twenty-first century and to make use of all the technology at their disposal. Since technology increases student involvement in the classroom and encourages participation in both teaching and learning, it is the only resource that can be used to draw students' attention during the teaching and learning process (Uwambajimana et al., 2023).

Many online technological tools can be used to inculcate chemistry content in senior secondary school which can improve chemistry students' performance (Oladejo et al., 2021). One of these online technological tools that can be used to inculcate chemistry content which can improve the students' performance is simulation. The term "simulation" refers to dynamic environments that represent concepts, correlations, systems, or phenomena and enable users to interact with models within those environments (Keykhaei et al., 2024). Simulation is a technology that converts theoretical knowledge into practical applications by streamlining abstract, challenging tasks and giving them a realistic, time-efficient resolution (Atalan & Donmez, 2019). Simulation is also the application of a subject, system, or phenomenon model in a computer environment to support learning, and it is a vital part of preparing people for life (Talan, 2021).

Put differently, simulation refers to the process of employing computers to create realistic (virtual) representations of natural and actual situations. Training students on a realistic model is the most efficient method, particularly in situations when training them in an actual setting with actual tools would be challenging, risky, and expensive. Grandiosity and potential mishaps are thus avoided. Additionally, simulation provides more permanent and quick learning environments (Talan, 2021). A simulation is a program that builds dynamic, interactive, game-like environments to tie real-world occurrences to the underlying scientific principles. In this procedure, experts' and scientists' conceptual and visual models are simplified so that learners may understand them (Ajijolajesu et al., 2019). Benjelloun (2023) asserts that computer simulations help students grasp concepts. They can also have a favourable impact on students' initiative, involvement, and contentment.

Computer simulations improved student engagement and instructor instruction by inspiring creativity and motivation and by generating an engaging learning environment (Isiaq & Jamil, 2018). The most promising teaching methods are thought to be simulations for institutional learning or distance teaching (Zulfiqar et al., 2021). Chemikova et al (2020) showed that simulation-based learning removed the constraints of real-world learning and allowed students to practice complex skills during instruction. Simulation was also shown to have a positive impact on learning and be a useful tool for helping students acquires complex skills. Simulations can help students employ a variety of representations, assist their efforts to increase their knowledge, highlight conceptual ideas, and give them immediate feedback (Falloon, 2019). Furthermore, Najib et al (2022) state that to improve comprehension of students' actions, the simulation makes use of a behavioural model.

Given that simulations encourage real-world scenarios, predictions about students who utilize them frequently can be formed (Law, 2022). Both the teacher's method and student learning can be enhanced by the use of simulations in the classroom. A simulator must be constructed before simulation software can be made. Cybernetics, which mimics or can be defined as comparative studies of human control mechanisms and electromechanical systems like computers, is generally the foundation for the construction of simulators (Najib et al., 2022). Experts agree that simulation is a good design since it can replicate real-world circumstances quite well (Law, 2022). Kibga and Olurinola (2024) assert that while teaching chemistry in secondary schools by conventional techniques may increase students' motivation, it is not nearly as engaging as teaching chemistry through a well-thought-out simulation.

This learning approach, when combined with an appropriate simulator design and simulation program, can help students grasp concepts more easily, become more motivated to learn, and perform better on specific chemistry topics (Najib et al., 2022). Arici and Yilmaz (2023) contend that the usage of simulations in educational settings is advantageous because they engage students and help them develop their problem-solving and decision-making abilities. Simulations make learning more engaging for students, prevent abstract knowledge from being taught, and guarantee that students learn by doing and experiencing (Arici & Yilmaz, 2023). It also includes a plethora of multisensory applications, like as graphs, nimations, sounds, and videos, which can facilitate learning. Arici and Yilmaz (2023) state that these are the justifications for using simulations in learning environments, as seen in Figure 1.

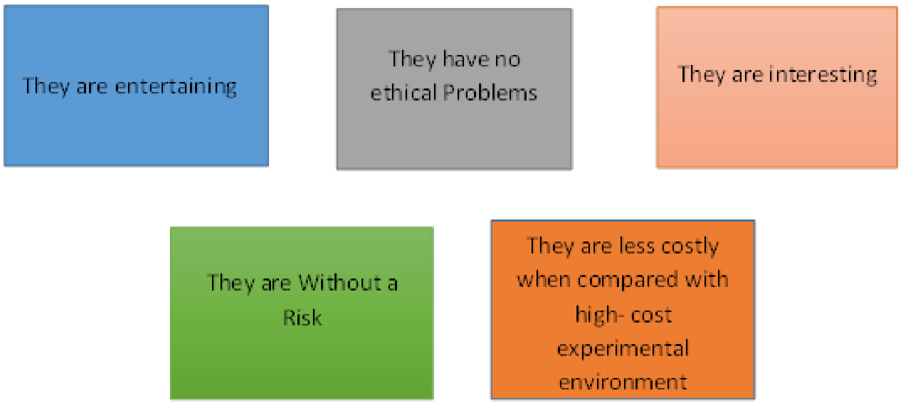

Figure 1. Reasons for Simulation Use

The goal of science education is for pupils to grasp things accurately. Unfortunately, in some scientific fields like abstract concepts, therefore this goal cannot be met to the required extent (Arici & Yilmaz, 2023). For this reason, how abstract ideas can be made concrete is one of the topics that scientific education scholars study the most. In scientific classes, using methods or resources that represent abstract ideas produces good learning outcomes (Puspitarini & Hanif, 2019). Interactive simulations are one resource used to teach chemical principles (Arici & Yilmaz, 2023). Ellizar et al (2019) contend that creating appropriate learning activities is a useful way to create learning modules that effectively teach chemistry concepts. Through a variety of learning activities, this will encourage students' active learning processes and help them retain what they have taught (Ellizar et al., 2019). To increase the effectiveness of the learning and teaching process via simulation, instructors and students should create well-designed modules and daily lesson plans (DLPs) (Najib et al., 2022). One example of this simulation that can be used to inculcate chemistry content is PhET simulation.

Technology is also integrated into PhET interactive simulation. PhET (Physics Education Technology) is an interactive simulation that can be used in science classes. The University of Colorado at Boulder developed the PhET project (Ben Ouahi et al., 2022). Free learning simulations in chemistry and other science subjects are available on this website. They can be downloaded for individual or classroom usage (Blacer-Bacolod, 2022). PhET simulations according to Ajijolajesu et al (2019) animate objects that are undetectable to the human eye by combining graphics and intuitive controls like radio buttons, sliders, and click-and-drag manipulation. Under the license, they can be freely used, shared, and distributed. These interactive tools respond instantaneously to user input, effectively exhibiting a variety of linked representations (object motion, graphs, numerical readouts, and more) as well as cause-and-effect interactions (Ajijolajesu et al., 2019). Additionally, these learning simulations can be used with a variety of learning goals, pedagogical approaches, implementation environments, grade levels, and students.

Teachers and students can observe things like atoms, electrons, photons, and electric fields that are not visible with the aid of the PhET interactive simulation (Ben Ouahi et al., 2022). A shared representation between students and teachers who are facilitating all discussions and instructions may also be offered by the PhET interactive simulation (Salame & Makki, 2021). Teachers have several options to create engaging learning experiences with PhET simulations. Their primary characteristic is that they enable students to utilize them to investigate physical events with little to no guidance. They are particularly made to accomplish this goal (Ben Ouahi et al., 2022). PhET simulations can be used in place of risky, unfeasible, or difficult-to-control laboratory operations like dealing with explosives, lightning, or nerve systems (Toma, 2023). The benefit of these simulations is that they allow students to engage with dynamic graphics, concentrate on inquiry-based learning, receive prompt feedback, and gain experience with a variety of representations (Cayvaz et al., 2020).

Using PhET simulation in a natural science class can help students become more creative (Astutik & Prahani, 2018 The sort of technique employed through inquiry-based learning with PhET simulation affects students' ability to solve problems (Yuliati et al., 2018). The versatility and liveliness of this simulation make it an excellent way to teach chemistry ideas, exercises, and experiments. These are concepts that are challenging to teach using traditional approaches (Zuin et al., 2021). Chemistry students can benefit from PhET simulation in several ways, including helping them understand concepts that have proven difficult for them to learn, such as atomic structure, the particulate nature of matter, limiting and excess reagents, stoichiometric quantitative calculations, the mole concept, unit conversion, balancing equations, and more (Mohafa et al., 2022). Teachers are strongly urged to incorporate technology into their lessons (Najib et al., 2022), for instance used Story Bird to teach English to ESL kids in remote areas of Malaysian primary schools, integrating technology into the English language curriculum.

ICT integration in higher education holds great promise. Teachers, particularly those who teach chemistry, are becoming increasingly concerned about the corollary of ICT integration in the teaching and learning process (Najib et al., 2022). According to Batuyong and Antonio (2018), their research has demonstrated that implementing interactive teaching tactics can pique students' interest in enhancing their chemistry education. Previous research has demonstrated the benefits of computer simulation in the field of chemistry. It has been demonstrated to be one of the most useful instruments for learning and teaching (Chemikova et al., 2020). According to a study by Najib et al (2022), the experimental group received higher-quality knowledge and skills from computer simulation than the control group, which received instruction using traditional methods. Computer simulations can be used to enhance instruction and foster higher-order thinking abilities in students as well as improve comprehension (Najib et al., 2022).

Similar research was done by Yaacob et al (2021) who found that using computer simulations to teach students improves their ability to reason scientifically and conceptually.

Anari et al (2023) report that the study's results demonstrated that students in the experimental group that used computer simulation instruction (CSI) had made progress toward mastering chemistry concepts. This demonstrates that the study's conclusions—which state that teaching and studying science through computer simulations will enhance students' achievement and help them comprehend the notion of chemistry are consistent (Oladejo et al., 2021). Based on the study conducted by Alabi et al (2023) aimed to determine the effect of computer simulation on students' performance and retention in the kinetic theory of gas and gas laws in Ilorin, Kwara State.

The study was a quasi-experimental pre-test, post-test, non-randomized 2×2×2 factorial design. A total of 40 students from two randomly selected senior secondary schools were involved, including 17 students in the experimental group and 23 in the control group. The research instruments were a Physics Education Technology (PhET) simulation developed by the University of Colorado Boulder, a Physics Performance Test (PPT), and a Physics Retention Test (PRT). The reliability of both PPT and PRT was tested using KR-21 with indices values of 0.855 and 0.769, respectively. The research utilized the 5E Instructional model to implement the computer simulation. The research findings revealed that the experimental group had better performance and retention than the control group in the kinetic theory of gas and Gas laws. Also, there was no significant difference in the performance of students taught the kinetic theory of gas and gas laws ($t=1.96$, $p=0.761$, $p>0.05$).

Also, although the experimental group's female students outperformed the male students, there was no significant difference in the students' performance in terms of gender ($f=2.82$, $p=0.115$, $p>0.05$). Even though simulation-based learning is used in chemistry education, it is still not an appropriate technique of instruction. Instructors frequently use teacher-centred instruction, where students mimic and commit chemical principles to memory (Najib et al., 2022). In light of this, the researcher will typically examine how senior school students in Kwara State perform PhET simulations of chemistry content. The researcher will be focusing on four different PhET simulations of Chemistry content such as Matter, Atom, Molecule and Chemical Equations to teach the secondary school chemistry students in Kwara State in other to examine how it improves the chemistry students' performance.

The main purpose of this study is to examine the Chemistry content component of PhET simulation software on how it improves the senior school students' performance in Kwara State. Specifically, the study aims to determine the performance of senior school students in Chemistry content of PhET simulation in Kwara State and determine the significant difference in performance of pretest and posttest results of senior school students exposed to Chemistry content components of PhET simulation; determine the significant difference in the performance of senior school students exposed to Chemistry content components of PhET simulation and those taught through the conventional approach. The following research questions were formulated to guide the study is "what is the performance of Senior School Students in the Chemistry Content component of PhET simulation in Kwara State?"

METODOLOGI

The research design that will be adopted is a quasi-experimental pre-test, post-test, and control group design. The design will adopt a non-randomized sample where the researcher cannot randomly assign subjects, hence intact classes will be used. The population of the study consists of all senior school students in Kwara State, Nigeria enrolled in Chemistry classes. The target population for this study are senior secondary school One (S.S.S. I) students of Chemistry in Kwara State. The rationale for selecting S.S.S. I Chemistry Students is hinged on the selected topics to be taught using PhET Simulation of Chemistry content and due to the willingness of S.S.S I chemistry students to learn using the PhET simulation because they have been perceiving chemistry as a subject that is too abstract and volatile coming from their J.S.S. The sample for this will be drawn from S.S.S. I Chemistry Student at Kwara State. Purposive sampling techniques would be adopted to select two intact classes from two separate schools that will serve as both experimental and control groups accordingly. Based on the National Policy on Education, a ratio of 1:40 is recommended for teacher-student classroom interaction. Therefore, the sample size for this study will be 80 S.S.S. I Chemistry Students with 40 Students in each of the groups (Experimental and Control). Then, Stratified Sampling would be employed to categorize students' performance in the first term examination result and four strata. Thereafter, Proportional Sampling will be adopted to select the 40 participants in each of the school that will constitute both the experimental and control group. The instruments that would be used for data collection in this study are two. The first instrument is the PhET simulation, the second instrument is be Chemistry Performance Test (CPT) which is the Appendix I. The research instruments would be validated by showing the draft copies of the instruments to the seven experts, four lecturers from the Department of Science Education of Al-Hikmah University, Ilorin, Nigeria and three senior secondary schools Chemistry teachers from Government Day Senior Secondary School Adeta Ilorin (GL 10), Hikhi-Wanu Nasirdeen senior secondary school Kuntu Ilorin (GL 12) and Ilorin West senior secondary school Osin Aremu Kwara State (GL 12). The experts would be required to examine the contents of the instruments to ascertain their suitability for the category of students under investigation.

The observations, suggestions and comments made by the experts would be corrected in the final draft copies of the instruments which would be used for pilot study outside the locale to determine the reliability of the instrument and a reliability test was carried out for the instrument using Cronbach Alpha. Afterwards, the researcher and two other research assistants who have already been trained by the researcher would administer pre-test assessments to both the experimental and control groups to measure their initial understanding of chemistry content which includes Matter, Atom, Molecules and Chemical Equation. Immediately after the administration of the pretest, the researcher would introduce the PhET simulations into the chemistry content for the experimental group. The teaching of the control group would also take place after the exposure of the experimental group to the PhET simulation of Chemistry contents which both experimental and control groups would last for four weeks. The researcher would conduct a post-test assessment on both groups (experimental and control groups) to measure the impact of PhET simulations on learning outcomes. The responses will be subjected to both inferential and descriptive statistics. Research questions would be answered using mean, frequency count and standard deviation. All research hypotheses will be tested using a t-test.

TEMUAN DAN PEMBAHASAN

The demographic data on gender in the study evaluation of PhET simulations of Chemistry content on senior school students' performance in Kwara State reveals an equal number of male and female participants. Both the pretest and posttest included 40 male and 40 female students, each making up 50% of the group. This even distribution indicates that the study took steps to include both genders equally, ensuring that the results are free from gender bias in evaluating the PhET simulation's effectiveness. Additionally, there was no dropout in the posttest, with all participants completing the study, which adds to the credibility of the findings.

Table 1. Gender of the Participants

Pretest			**Posttest**	
Male	Female	Total	Male	Female
40	40	80	40	40
50%	50%	100%	50%	

Note: Low Performance (0-49%), Average Performance (50-65%), High Performance (66-100%). Table 1 shows that the lowest mark that students got from the Biology Performance test (BPT) was 50% and the highest mark was 99%. The expected highest mark was 100% while the lowest mark score was 0%. The mean score on the post-test was (M=73.54; SD=11.50) while the mean score on the post-posttest was (M=72.39; SD=11.16) respectively. This indicates there were differences in the scoring level of the biology students.

Researcher question 2 "what is the difference in the scoring levels of male and female students when taught using the Concept Mapping Instructional Strategy?"

Table 2. Difference in The Scoring Levels of Male and Female Biology Students with The Use of Concept Mapping Instructional Strategy to Teach Cell Division

Academic Performance		
	Male	**Female**
Lowest Score	47.00	45.00
Highest Score	99.00	99.00
Mean	68.5250	64.9500
Std. Deviation	9.32802	9.68478

Note: Performance was rated low (0-49%), Average Performance (50-65%), High Performance (66-100%). Table 2 shows that the minimum performance score is 45% and the maximum score is 99%. The expected maximum score was 100% while the minimum performance score was 0%. The mean score of males was (M= 68.53; SD=9.33) and the mean score performance of females was (M=64.95; SD=9.68) respectively. This indicates that gender had some influence on the student's performance when Concept Mapping Instructional Strategy was used to teach them Cell Division. The result shows that this positive influence was in favour of male students.

The hypothesis Ho_1 "There is no significant difference in the posttest and post-posttest scoring levels of Biology Students when (CMIS) is used".

Table 3. ANCOVA Of The Difference in The Posttest and Post-Posttest Scoring Level Of Biology Students when Concept Mapping Instructional Strategy is Used in Teaching Cell Division

	Dependent Variable:	Academic Performance			
Source of Variation	**Sum of Squares**	**Df**	**Mean Square**	**F**	**Sig.**
Covariates	4368.952[a]	78	56.012	1.655	.561
Main Effects	118.810	1	118.810	3.510	.312
Posttest	302.168	8	33.574	.992	.658
Post-posttest	752.332	11	62.694	1.852	.523
Residual	33.848	1	33.848		
Explained	4402.800	76			
Total	335162.000	77			
a. R Squared = .992 (Adjusted R Squared = .393)					

Results in Table 3, indicate that the F(11)-calculated value for scoring levels is 1.86, and the critical table value is 1.97 at 5% level of significance. The F(11). calculated of 1.86 is greater than the critical table value of 3.97 at 5% (F_{cal}=3.51 < $F_{0.05,1,176}$=3.97). Therefore, hypothesis one is accepted**.** This implies that there is a significant difference in the posttest and post-posttest scoring levels of the students when concept mapping instructional strategy is used to teach them.

The Hypothesis Ho_2 "There is no significant difference in the scoring levels of male and female Biology students taught with (CMIS)".

Table 4. T-Test of the Difference in The Scoring Level of Male and Female Biology Students When Concept Mapping Instructional Strategy is used in Teaching Cell Division

One-Sample Test						
	Test Value = 0.5					
	t	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Male	21.546	53	.000	44.198	40.08	48.31
Female	14.267	26	.000	50.389	43.13	57.65

Results in Table 4, indicate that the t-calculated value for male scoring levels is 21.55, and 14.28 for females. The significance level is .000 at 5% level of significance. The significant level is less than 5% (p.<0.5). Therefore, hypothesis two is rejected**.** This implies that there is a significant difference in the scoring level of male and female students when concept mapping instructional strategy is used to teach them.

Discussion of this research is demonstrates a substantial disparity in the post-test and post-posttest scores of students when the concept mapping instructional strategy is employed. Specifically, the study indicates a notable contrast in the post-test and post-posttest scores of Biology Students when the concept mapping instructional strategy is utilized to teach Cell Division. This suggests that the average scores of participants at the post-test (M= 302.17) and post-posttest (M=752.33) exhibit a significant difference due to the implementation of the concept mapping instructional strategy. Notably, this variance favoured the experimental group participants who achieved higher scores compared to those in the control group. The findings reveal that the concept mapping instructional strategy positively impacted the scores of participants in the experimental group in contrast to those in the control group. These results align with previous studies conducted by Adebisi et al (2021), Maryam et al (2021), Appaw et al (2021), Simpson (2021), Nuru et al (2020), Ebuoh dan Ezeudu (2015) which all underscored that students exposed to the concept mapping instructional strategy achieved higher scores than those taught through conventional methods. This indicates that the utilization of concept mapping assisted experimental group participants in organizing, linking, and comprehending the interconnectedness of concepts in Cell Division compared to those in the control group, thereby contributing to their higher scores.

Furthermore, the research also concludes that a significant discrepancy exists in the scoring levels of students when the concept mapping instructional strategy is employed, particularly favouring male participants. The data suggests that the average scores of male and female participants exhibit a significant difference when the concept mapping instructional strategy is applied, with male participants achieving higher scores than their female counterparts. The results demonstrate that the concept mapping instructional strategy positively impacted the scoring levels of male participants compared to females, aligning with the findings ofToheed et al (2017), Adeniran et al (2018), Lamidi et al (2015), Awofala (2011), dan Martins-Omole et al (2016) all of which indicated that students taught using the concept mapping instructional strategy experienced significant improvements in their retention scores. Male students displayed better retention levels than their female counterparts, indicating that the use of concept mapping facilitated male participants in organizing, linking, and comprehending the interconnected concepts in Cell Division more effectively than their female counterparts, leading to higher retention levels among male participants. Thus, it can be inferred that the exposure to the concept mapping instructional strategy enhanced the retention levels of male participants compared to females. In conclusion, the implementation of the concept mapping instructional strategy yielded positive outcomes in terms of students' performance and retention, particularly benefiting male participants in understanding and retaining the concepts related to Cell Division.

SIMPULAN

Based on the findings, the study concludes that a notable disparity exists in the post-test and post-posttest performance levels of students when the concept mapping instructional approach is employed. Moreover, the study concludes that male students attain higher performance levels compared to their female counterparts when the concept mapping instructional strategy is utilized to teach Cell Division. Author recommendations based on the findings, the study recommends that science education teachers in the field of Biology are encouraged to utilize the concept mapping instructional strategy when teaching students who exhibit lower performance levels. This approach is expected to enhance students' performance levels in Cell Division. Additionally, the study recommends that Biology instructors should pay particular attention to female students when employing concept mapping to teach Cell Division.

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