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INTEGRATION OF INTERACTIVE COMPUTER SIMULATIONS IN TEACHING AND LEARNING CHEMICAL REACTION: STUDENTS' PERFORMANCE AND CONCEPT RETENTION

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Abstract

This current study presents the effects of interactive computer simulations on students' performance and concept retention in the unit of chemical reactions. Purposive sampling was used to select four schools with a sample population of 320. The Achievement test on chemical reactions was developed, validated, and checked for reliability. The participating students were in grade 8. The collected data was analyzed in MS Excel and SPSS. The independent sample t-tests were computed to compare the groups and reveal the effectiveness of interactive computer simulations. After the intervention, the experimental groups' post-test means achievement scores of (8.67) were higher than that of the control groups (6.69). The difference between the two mean scores was statistically significant: t (318) = 6.3, p= .000. The experimental group also had higher mean post-retention-test scores of (M = 8.07, α = .29) than that of the control group (M =5.58, α = .19) which was statistically significant at t (318) = 7.28, p = .000. Therefore, it is concluded that interactive computer simulations enhance students' performance and improve their concept retention. The study recommends that simulations should be used to supplement the teaching and learning of chemistry and other science subjects in general.

Keywords – Interactive computer simulations, Students' performance, Concept retention, Chemical reactions.

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1. Introduction

The application of chemistry is almost in all fields, such as food production, engineering, and medicine among others (Cohen & Kelly, 2019; Thummathong & Thathong, 2018). Regardless of the importance of this application of skills and knowledge students acquire from learning chemistry, some available studies related to chemistry education indicate that students' performance in the subject is not satisfactory (Bhure, Welu, See & Ota, 2021; Byusa, Kampire & Mwesigye, 2020; Mohammed, 2021; Ibitomi, Oyelekan & Olorundare, 2022; Musengimana, Kampire & Ntawiha, 2021). Some reasons reported by researchers that may cause this dissatisfaction include the abstract nature of chemistry concepts, inadequate laboratory facilities, poor instructional strategies, and non-availability of teaching materials. In addition, the unsatisfactory in chemistry education is also attributed to some textbooks used that do not separate and distinguish each of the three fundamental levels of representation(macroscopic, microscopic, and symbolic) but rather allow the teacher to shift to another level without clear understanding (Bhure et al., 2021; Tou, Kee, Koh, Camiré & Chow,, 2020; Watson, Dubrovskiy & Peters, 2020), hence leads to the formation of a shared misunderstanding regarding the transmission of macroscopic to microscopic level. As a result, both teachers and students find it extremely difficult to explain and understand all three levels clearly (Zendler & Greiner, 2020). Focus on the effectiveness of chemistry education can prevent students from experiencing low academic performance, loss of interest and desire in the subject, and lack of persistence when dealing with difficult concepts (Kunnath & Kriek, 2018; Musa, Achor & Ellah, 2021).

Students in countries like Pakistan, Nigeria, and South Africa experienced difficulties in chemistry topics (Ali, 2012; Chukwu & Adolphus, 2022; Ramnarain & Joseph, 2012). These findings show that students from these countries share the same difficulties in learning the topics of reaction mechanism, reaction rate, chemical bonds, chemical formula, chemical equations, and balancing equations. Another studies by Ali (2012) Chukwu and Adolphus (2022), and Ramnarain and Joseph (2012) reported that most students always misunderstand chemical reactions at the redox reaction stage to a considerable level of understanding or possibly do not get them anymore. The term redox reaction makes the topic more challenging. This because it demands a shift in perspective focusing on electron transfer and balancing both mass and charge. Studies on science education show that when science educators employ technological teaching tools to supplement traditional instruction, students' learning experience and engagement in science education increases (Watson et al., 2020). For instance, the study conducted by Muniandy, Kandasamy, Subramaniam and Farashaiyan (2022) on how multimedia websites impact students learning reveal that computer-assisted science simulations impact positively students' learning outcomes. In a study on meta-analysis of 62 science simulation instruction reflected on how computerized science simulations impact significantly students' science learning (Watson et al., 2020). The studies further recommend numerous initiatives emphasizing innovative teaching tools that have been developed aimed at providing excellence in teaching to a large student population. These tools include interactive computer simulations. Other authors, Yuliati, Riantoni and Mufti (2018) define interactive computer simulations as software programs that allow students to examine complicated interactions among dynamic variables that replicate real-life situations. Interactive computer simulations help students to see the movement of atoms and molecules, observe changes in properties (macroscopic), and witness electron transfer or molecular rearrangement(microscopic) (Asedillas & Quimbo, 2019). This visual representation enhancing their comprehension in these representations. In other studies (Beichumila, Bahati & Kafanabo, 2022; Mohafa, Qhobela & George, 2022; Ouahi, Lamri, Hassouni & Al Ibrahmi, 2022) reveals the potential advantages of using interactive computer simulations in teaching science such as enable students to explore, experiment in a dynamic virtual learning environment, and improving their scientific processing skills. To measure learning outcomes, its essential to take into account factors such as performance and concept retention among others. Performance and concept retention are intertwining terms that defines differently by different scholars. Ibitomi et al. (2022); Ogunkola and Samuel (2011) argue that, these two aspects are all about how well students achieve their academic goals and are able to apply their skills and knowledge.

They are measured in different ways, such as test scores, grades, and extracurricular activities. Cohen and Kelly, (2019) define the performance as a measurement of students' achievement across all academic subjects. In other studies, define concept retention as ability to grasp and recall stored information rather than facts (Kinyota, 2020; Watson et al., 2020). The study added that, it is very essential in learning process because it helps in application of acquired skills and knowledge to solve problems in any new situation. Thus, the use of interactive computer simulations also impacts positively in students' learning outcomes in learning science subjects in comparison to employing traditional methods (Mohafa et al., 2022), which primarily rely on static images. For example, on the microscopic level, students need to understand the behavior and interaction of individual molecule or atoms that make up the substance involves in the reaction (Asedillas et al., 2019; Ibitomi et al., 2022). consequently, interactive computer simulations serve to convert the abstract concept into a more tangible representations and enabling students to visualize the entire process at all three levels of representation, hence improve their understanding on subject matter.

Largely, the integration of Interactive Computer Simulations (ICS) in chemistry education enhances the social learning environment that assists students in articulating their prior knowledge and presenting what they have learned (Çelik1, 2022; Suratno & Aydawati, 2017), and it is crucial to gain insight into students' learning outcomes regarding the use of ICSs as a teaching tools in the chemistry education. The consulted studies have looked at the positive impact of interactive computer simulations on students' interest and motivation toward learning chemistry. This implies that none discussed students' performance and concept retention in learning chemical reaction concepts which is considered as a challenging topic in the chemistry subject. Due to this viewpoint, the researcher felt interested in exploring how students perform and retain the concept while using ICSs in learning chemical reaction concepts during study intervention. Consequently, the major concern of the current study aims to explore students' performance and retention of concepts with the use of interactive computer simulations in the chemistry teaching and learning process at lower secondary schools.

2. Theoretical Framework

The current study used Mayer's cognitive theory of multimedia learning (CTML) which pulls from some factors to describe how learning new concepts occurs and how pedagogy can be modified to produce meaningful learning. This theory serves as the foundation for this study (Mayer & DaPra, 2012), because it support what interactive computer simulations does in an individual learning process through mental organization and coherent cognitive structure. The theory supports the integration of new concept in relation to consider prior knowledge. Studies on use of multimedia tools and their theoretical support from theories such as Mayer's cognitive theory of multimedia learning, found that learning become meaningful when words and visuals facilitate absorption and accommodation (Blut & Wang, 2020; Njiku, Maniraho & Mutarutinya, 2019). It is noted that while teaching chemistry concepts, there is a need for students to understand the macroscopic, microscopic, and symbolic entities (Cohen & Kelly, 2019; Jaber & BouJaoude, 2012). The interconnection of these entities provide a holistic approach to study chemistry, and enhancing students' comprehension of specific challenging topics in chemistry (Ibitomi et al., 2022; Jaber & BouJaoude, 2012; Ogunkola & Samuel, 2011), especially when explaining both microscopic and symbolic levels.

In studies by Ali (2012), Chukwu and Adolphus (2022), Ramnarain and Joseph (2012), on the challenges students experienced in learning recognized challenging chemistry concepts such as redox reactions are categorized into two primary aspects. They intend to face the challenge of understanding chemical events and connecting the macroscopic, microscopic, and symbolic entities or any combination of these. The primary cause of these misunderstanding is directly link to visualizing the behavior of molecules and atoms. This requires strong spatial reasoning skills, which not all student possess naturally and lack of activities that connect macroscopic, microscopic, and symbolic representations. This direct link of these entities may be limited or absent in some educational settings, hence makes students to formulate incorrect chemical formula and equations. It can be said that the students' difficulties in learning chemistry concepts is due to their inability to visualize concepts in a mental model (Ali, 2012; Chukwu & Adolphus, 2022; Ramnarain & Joseph, 2012).

3. Research Questions

The current study is based on the following research questions:

1. Is there a relationship between interactive computer simulations and students' performance and retention in topics on chemical reactions?
2. Is there a difference in the overall mean scores of male and female students in the simulated classes?

4. Methodology

This study used a quasi-experimental quantitative research design; pre-test and post-test designs with experimental and control groups were used to collect quantitative data. The study's target population was grade 8, N= 320 students, were sampled from four different schools and were purposively chosen. These sampled schools were chosen on account of the accessibility of their computer laboratories that made easier to conduct this study. After randomly assigning two schools to the experimental and two schools to the control group, 80 students participated at each school, and there were two classes with 40 students per class at every sampled school.

The experimental groups (E)	Pre-test	Intervention	Post-test
The Control groups (C)	Pre-test	Normal teaching	Post-test

Table 1. The combined groups of experimental and control groups

4.1. The Four Schools

Before participating in the main study, all students from four schools were given a pre-test. This test was done to establish the equivalence of groups in terms of prior knowledge, so that intervention results could be justified. Teachers in the Experimental Groups were provided three days of training on how to teach chemical reactions using interactive computer simulations. The experimental groups have been taught chemical reactions with the use of simulation methods while the control groups taught chemical reactions with the use of traditional way of teaching. The topics taught in chemical reactions were types of reactions, Classification of chemical reactions, balancing chemical equations, and writing ionic equations. Within twelve weeks of normal teaching, the intervention took 6 weeks. The control group and experimental group have been taught with the same teachers but with different teaching methods. In the 5th week of teaching, the items from the pre-test were rearranged for them not looking similar in numbered format and distributed to both experimental and control groups as a post-test, to enabling a comparison of the effectiveness of the provided instructions in each group. To test concept retention among students of both groups, a delayed post-retention-test was administered after 3 weeks later.

4.2. Instrument

The researcher developed a Chemical Reactions Achievement Test (CRAT) used as the primary assessment instrument for the study. The questionnaire was in line with specific learning objectives for the unit of categories of chemical reactions as outlined in the ordinary chemistry syllabus. To confirm the content validity and reliability, the CRAT was shared with the chemistry teachers at piloted schools with the same features as the schools under the study and two experts in research and innovation from the University College of Education for their review to check whether it fits participants' context. The validators disqualify some questions which was not fit. Then after, the author adjusted the instrument and removed 3 items. The total items become 10 from 13 items in number, the time allocated for the post-test was increased from 30 min to 40 min after realizing that students can not complete the test at the same time as they used during the pre-test. The sample questions for both pre-test and post-test on balancing chemical equations is:

$$Zn\ (s) + HCl\ (l) \rightarrow ZnCl_2\ (aq) + H_2\ (g) \text{ and } Fe\ (s) + HNO_3\ (l) \rightarrow Fe\ (NO_3)_2\ (aq) + H_2\ (g)$$

Furthermore, during this intervention on side of experimental groups, students in pair were encouraged to explore problems, making hypothesis, conduct experiments, making observations and interpretation and share conclusions. For instance, students explored the type of chemical reactions such as synthesis, decomposition, combustion, displacement, and redox reactions. Figure 1, 2, and 3 display the screenshot of one of performed activities. The learning activities were structured in way that encouraged individual participation and provided a chance for them to reflect on their learning experiences.

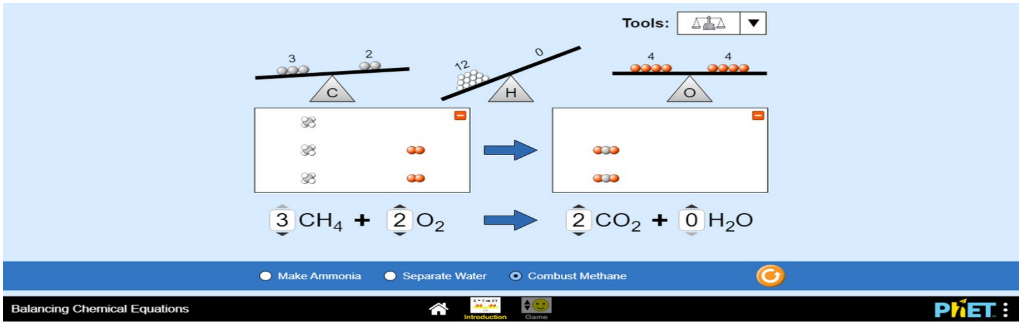

Figure 1. Screenshot of a simulation of the unbalanced chemical equation

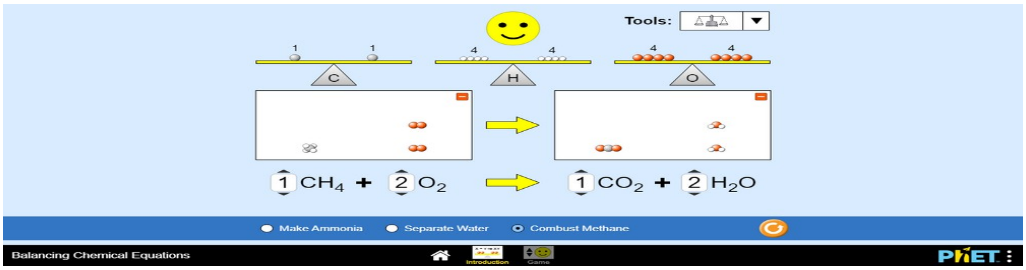

Figure 2. Screenshot of a simulation of a balanced chemical equation

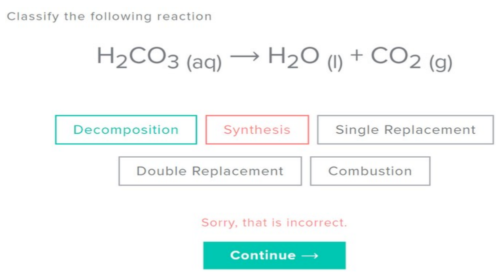

Figure 3. Screenshot of a simulation of classifying types of reaction

4.3. Data Collection and Analysis

Data were collected from both groups; experimental groups and control groups sat for post-test after intervention and scores of individuals combined to produce overall post-test and post-retention-test mean scores of concepts in chemical reactions.

The Statistical Package for Social Science (SPSS) software V.21, the independent sample t-test was used to analyze the data to establish statistical significance for any existing differences between the groups regarding academic performance and retention of concepts. The pre-test analysis was done to determine whether groups had similar prior knowledge in categories of chemical reactions. Then after, a separate analysis was made for two post-test results. The evaluation of students' performance was done immediately after the intervention and three weeks after the intervention was analyzed for evaluating students' concepts retention.

4.3.1. Significance of the Study

The study aims to assess students' performance and retention of concept while using ICSs in learning chemical reaction as one of topics in ordinary level chemistry. These ICSs allow students to manipulate, observe, and experiment with those phenomena in a virtual environment. When students are familiar with use of ICSs will not only help them to enhance their conceptual understanding of abstract concepts but also develop different skills aligned with 21st century skills, such as collaboration, creativity and innovation as far as critical thinking is concerned. This will be done through interaction among universal students and teachers. In a study conducted by Watson et al., (2020) show that teaching approach that encourages students to share their learning experience help them to develop their creativity as well as their appreciation of science and technology. The intention of integrating computers at lower secondary schools is to introduce students to technology that encourage scientific innovation and collaboration among students, create and share their own models, as well as to communicate and cooperate with other students and experts from different countries and cultures (Muniandy et al., 2022). These help students to become more informed and responsible citizens, who makes evidence-based decisions and participate in scientific debates and discussions across the continents.

The study's results are very useful to all professionals working in the field of chemistry education. The produced information informs decision-makers and policymakers, school administrators, and education management on what needs to be done to improve chemistry education. In addition, teachers will know how to select, integrate, and adapt computer simulations to suit their teaching objectives as well as students' needs and preferences are concerned. This also will assist the ministries in charge of education in achieving their objectives, since the results provide platform that enhance and support teaching and learning among schools worldwide. The results will help scholars to understand the opportunities and implications of computer simulations, evaluate the effect of computer simulations on students' learning outcomes, and factors that influence students' learning outcomes during the use of computer simulations. This will also assist researchers to design and conduct more inclusive and effective studies on the effectiveness of using interactive computer simulations in chemistry education.

4.4. Ethical Consideration

The study's participants ranged in age from 12 to 16 and were from the senior two classes. Before completing the consent papers containing all the information linked to the data collecting process, all participants were given concerned information related to study's objectives. In order to protect the respondents' identity and confidentiality, no information about them was revealed throughout the data collection, analysis, or presentation of the results. They were all made aware that they might withdraw their agreement at any point if it made them uncomfortable. As a result, there was no use of secret cameras, and audio recordings were made to degenerate the respondents' consent. The setting for the interview was confidential. The information was kept on a flash drive, a computer that was coded and locked, and in the researcher's email, which was inaccessible to everyone.

5. Results

This part sequentially presents the results starting with pre-test results. This was made aims at assessing the prior knowledge of both groups concerning selected categories of chemical reaction topics and the determination of students' equivalence before intervention. Then, the academic performance because of the intervention is also presented in this section. The analysis of the groups' equivalency means scores reveals that the four groups had same prior knowledge level of chemical reaction concepts.

5.1. Pre-test Performance Assessment

In the quasi-experimental study, there is a need to assess participants' prior knowledge before intervention for justifying the intervention results. The one-way ANOVA was performed on scores of the four groups, Control (C1 & C2) groups, and Experimental (E1 & E2) groups. Then after, we combined the results of this analysis of the pre-test and are presented in Table 2.

These results show that both experimental and control groups had comparable prior knowledge level of the selected chemical reaction topics. Then we performed the independent sample t-test analysis for statistically significant differences between the mean scores of both groups. The results are presented in Table 3.

	Groups	N	Mean	SD	SE. Mean
Pre-test	Experimental	160	2.01	1.04	.11
	Control	160	2.08	1.16	.12

Table 2. Pre-test mean scores of combined experimental and control groups showing equivalence of groups.

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean diff	SE.diff
Pre-test	Equal variances assumed	2.45	.11	.40	318	.68	.05	.12

Table 3. Results of independent sample t-test on experimental and control groups on the pre-test

The results show that there were no statistically significant differences between the mean scores of controls and experimental groups on the pre-test, t (318) = .40, p = .68. The experimental and control groups were thus appropriate for the investigation since they had equivalent prior knowledge level of chemical reaction concepts.

5.2. Research Question 1

Is there a relationship between interactive simulation and students' performance and retention in topics on chemical reactions?

5.2.1. Students' performance assessment after intervention

Post-test mean scores were analyzed by t-test to determine the differences in mean scores of both experimental and control groups. The combined experimental and control groups' mean scores are presented in Table 4. Then the independent sample t-test was performed to identify the statistically significant differences between groups. The results of these analyses are presented in Table 5.

	Groups	N	Mean	SD	SE. Mean
Post-test	Experimental	160	8.67	3.333	.263
	Control	160	6.69	2.127	.168

Table 4. Post-test mean scores of combined experimental and control groups

These results show that there is a statistically significant differences between the post-test mean scores of the experimental and that of control groups. As a result, the differences are associated with different teaching methodologies. The combined experimental groups' mean scores (M=8.67, б = 3.33) are greater than that of the combined control groups (M= 6.69, = б = 2.12). Table 5 presents the statistically significant differences in the mean scores of the two groups. The observed differences of statistically significantly different at t (318) = 6.34, p =.000), this p-value support other factors such as effect size of the study, and confidence interval to draw the conclusion from this data analysis that the interactive computer simulations positively influence experimental students' performance in chemistry. The findings are consistent with previous research conducted by Benjamin and Berger (2019), which suggested that p-values within the range of .01 to .00 provide supporting evidence for drawing conclusion about positive effects and not rejecting the hypothesis.

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean diff	SE.diff
Post-test	Equal variances assumed	46.99	.000	6.34	318	.000	1.98	.31

Table 5. Results of independent sample t-test on experimental (E) and control (C) groups on the post-test

5.2.2. Students' Concept Retention Assessment

To assess students' concept retention, the students from both groups took a delayed post-test three weeks after post-test, Figure 1 displays the results of the two groups. This selected time duration was based on the fact that for assessing the retention of information or encoding of a particular concept into long-term memory often requires an extended period of time (Barab, Zuiker, Warren, Hickey, Ingram-Goble, Kwon et al., 2007; Chen & Klahr, 1999; Dean & Kuhn, 2007; Zimmerman, 2018).

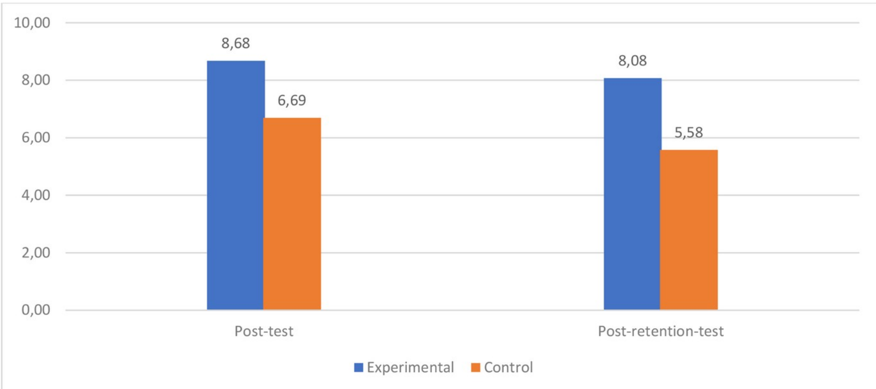

Figure 4. Compare the Post-test and Post-retention-test mean scores of combined experimental and control groups

The results from Figure 2 show that experimental groups had a higher retention mean score (M= 8.08) than the control groups (M = 5.58). The observed differences in post-retention-test mean scores were tested for statistical significance using an independent sample t-test. Table 7 displays the results.

		Levene's Test for Equality of Variances		t-test for Equality of Means				
		F	Sig.	t	df	Sig. (2-tailed)	Mean. Diff	SE.diff
Post-retention-test	Equal variances assumed	66.599	.000	7.284	318	.000	2.49375	.34237

Table 7. Results of independent sample t-test on experimental and control groups on the post-retention-test

Table 6's findings show that there was a statistically significant difference between the experimental and control groups' retention mean scores at t (318) = 7.28, p = .000. This implies that students in the experimental groups had a statistically higher retention mean scores than that of the control groups.

5.3. Research Question 2

Is there a difference in the overall mean scores of male and female students in the simulated classes?

Data presented in Figure 2 show that in experimental groups, the overall mean scores, the female students have a pre-test mean achievement scores of 2.05, post-test of 8.57 and post-retention mean scores of 8.12, while their counterpart male students have a pre-test mean achievement scores of 1.94, post-test of 8.78, and post-retention-test mean score of 8.00. These results indicate that the average scores of female students do not differ significantly from those of male students. This implies that there are no notable differences between the female and male students' performance. As result, gender does not appear to have a significant impact on students' achievement in categories of chemical reactions.

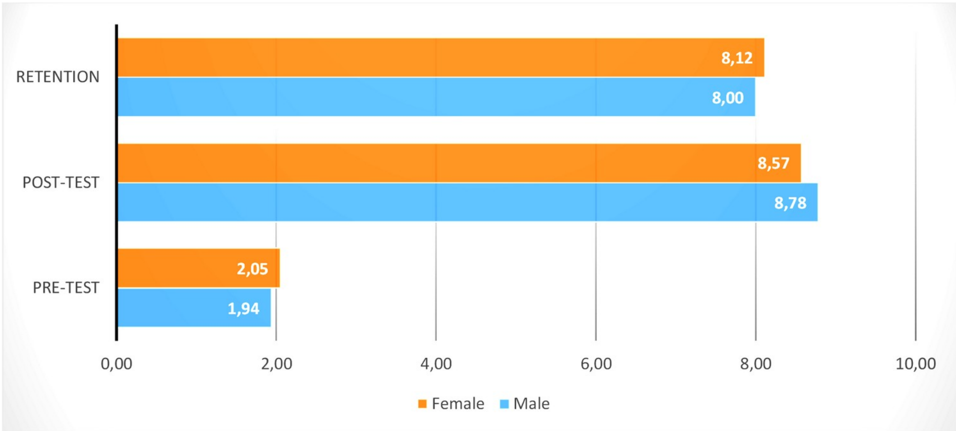

Figure 5. Pre-test, post-test, and post-retention-test mean scores of male and female students in experimental and control groups

6. Discussion

From the analysis made on this study in relation to respond research questions, it was found that the students in experimental group performed better and retain concept than their counterpart students taught using conventional lecture method. The results also indicate that there are no notable differences between the female and male students' performance. These results are consistence with findings of (Çelik1, 2022; Kaheru & Kriek, 2016). The findings of these studies come to some comparable conclusions. They argued that using computer simulations while delivering a lesson in the classroom has positively impacted students' performance in chemistry. The study's findings also agree with those from (Mohafa et al., 2022) show that students who taught using computer simulations performed at a high mean score than those who taught using traditional methods. These studies concluded that if computer simulations are effectively used while delivering a lesson, it improves students' retention of concept and performance as well. The study's results support those of related studies that assessed students' proficiency in stoichiometry (Mohafa et al., 2022). These findings reveal that students show improvement in their academic performance and retention of concept in some areas. Similar results were found by other researches. For instance, the results of a study that looked at the effectiveness of computer simulations in teaching chemistry show that the experimental groups performed better on post-retention tests right away after the intervention than the control groups students on average (Kifah, Abdullah & Al-qaisi, 2022; Ross, Morrison & Lowther, 2020).

The study' results also align with theory of multimedia learning (Mayer & DaPra, 2012) that explains the channels of processing information includes visual and auditory, it claims that student benefits from multimedia presentations when images and wards are combined. This implies that theory support cognitive process involves in learning. Consequently, computer simulations as a type of multimedia provide interactive and dynamic representations of images and wards of complex phenomena, it helps students to visualize concepts that are otherwise hard to understand. This facilitates students' concept retention through supporting their cognitive process of fixing information in long-term memory and recall them at times of need. We agree that computer simulations enhance experimental students' memory which helped in quickly recall what they learned during post-retention test that made them to outperformed their counterpart of control group who used traditional method in learning.

In the light of gender differences, the results indicate that there are no remarkable differences between the female and male students' performance and retention of concepts. These findings are consistence with those from a study conducted by Kaheru and Kriek, (2016) show that computer simulations make no differences among female and male students in terms of their academic learning outcomes. In a study by Krüger, Höffler, Wahl, Knickmeier and Parchmann (2022) found that male students had similar scores as female students when using computer simulations for the concept of acid-base titration in chemistry. The study also found that not only both female and male students had same acquisition of skills but also had increased at same level of their confidence, engagement, and collaboration.

This support common saying that "I remember what I see". From these perspectives, when theories are logically being together with dynamic images and presented to students, it allows them to fix such presented content in their long-term memory, hence improve their academic goals. The results also added to the existence knowledge that agreed on potential positive impact of computer simulations in promoting students' learning, whereby they provide a chance to individual student to visualize invisible phenomena in domain of chemistry.

7. Conclusion

The study intention was to examine the effectiveness of the use of the interactive computer simulations on student's performance, concept retention as well as gender differences. The results indicate that students taught using computer simulations performed better than those who were taught using traditional methods. The findings also show that not only experimental students outperformed their counterpart but also in terms of retaining concepts were at high rate than those in the control group, and again, there was no any significance differences in average scores among female and male students attributed by the use of computer simulations. Consequently, to achieve quality education in this world of technology, educational professionals need to incorporate instructional technology into education sector. Computer simulations are among of new instructional technologies that available to meet the need of students and serve as a prerequisite for modern market.

8. Limitations and Recommendations

Although the results address the study's objectives, there were some limitations. The first limitation is the sampling method, as all participated students were selected from different rural schools but shared same features of being day scholars. This similarity in school type and geographical location among students may limit the generalizability of the results to other schools such as private and urban schools. The second and lastly limitation was insufficient computers, students did not carry out the manipulation of the simulations individually. Regardless to these limitations, the study's findings still provide insights into simulations as important tools for teaching complex topics as a supplement to conventional methods. Successively, the study findings suggest that science teachers should be innovative and use interactive simulations to increase their variety of teaching and learning strategies.

Declaration of Conflicting Interests

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