p-ISSN 2549-9947
e-ISSN 2614-1426
doi: 10.20885/ijcer.vol10.iss1.art8

Effect of Computer-Based Visualization Model on Students' Academic Achievement in the Periodic Table Concept in Chemistry

Edima Sylvanus Sunday [a, *], Felicia Imeh Umanah [b], George Johnson Ntegwung [c], Enobong Imoh Akpan [d]

[a] Department of Science Education, University of Uyo, Uyo, Akwa Ibom State, Nigeria.
[c, b, d] Department of Science Education, Akwa Ibom State University, Ikot Akpaden, Akwa Ibom State, Nigeria

*Corresponding email: sylvanjnr27@gmail.com

Received: March 14, 2026; Accepted: April 24, 2026; Published: April 30, 2026

ABSTRACT: This study investigated the effect of a computer-based visualization model on students' academic performance in the concept of the periodic table in Chemistry in secondary schools in Mkpat Enin Local Government Area. A quasi-experimental design was adopted for the study. The population consisted of 1,871 Senior Secondary School Two (SS2) students, while a sample of 97 students drawn from two co-educational secondary schools was used. The instrument for data collection was the Chemistry Achievement Test on the Periodic Table (CATPT), which had a reliability coefficient of 0.86 using the Kuder–Richardson Formula (K-20). Mean and standard deviation were used to answer the research questions, while Analysis of Covariance (ANCOVA) was used to test the hypotheses at the 0.05 level of significance. The findings showed that there was a significant difference in the performance of students taught using the computer-based visualization model and those taught using the expository instructional method ($F = 17.334$, $p < .05$), in favour of the computer-based visualization model. The results also indicated that there was no significant difference in the performance of male and female students exposed to the two instructional methods ($p > .05$). The study concluded that the use of computer-based visualization improves students' understanding and performance in the periodic table and provides an effective alternative to conventional teaching methods in Chemistry. It was recommended that Chemistry teachers should make use of computer-based visualization tools when teaching abstract concepts such as the periodic table in Chemistry.

Keywords: computer-based visualization model, expository instructional method, periodic table, performance, chemistry

INTRODUCTION

The global educational landscape is currently experiencing a dynamic breakthrough in terms of advancement in digital technologies. The teaching and learning process have undergone noticeable changes due to the integration of digital technologies into the classroom. The classrooms once heavily depended on traditional, teacher-centred approaches have now had a great shift to digital approaches. They system is now gradually shifting toward technology-supported methods that promote active participation and deeper understanding across subject areas. This transformation has become more pronounced with the advent of the Fourth Industrial Revolution (4IR). This has compelled educational systems in advance countries to re-evaluate instructional practices and prioritize digital literacy, and innovative pedagogical approaches among both teachers and learners [1]. Also, in most developed countries, the educational systems are placing greater emphasis on technology integration. This is not only to improve instructional delivery but also to enhance students' engagement and understanding of abstract concepts, particularly in subjects such as Chemistry [2].

In a developing country like Nigeria, the use of digital technology in schools is steadily gaining ground. Although still low, the integration is gradually taking the place of, or working alongside the traditional tools like chalkboards. With more students now having access to computers for Computer-

Based Test (CBT), smartphones, and other digital devices for their study needs. Schools are increasingly moving toward e-learning and computer-supported forms of instruction [3]. Notably, computer-based packages and models such as computer assisted instruction (CAI), artificial intelligence (AI) among others, have gained recognition for their capacity to address the abstract concepts, particularly in science subjects such as Chemistry that require high levels of visualization [4, 5, 6]. This evolving digital instructional environment provides a suitable foundation for examining how Chemistry is taught and learned, a discipline in which abstract representations and conceptual understanding play a central role.

Chemistry remains central to many areas of modern life, particularly in fields such as health, energy, and technological development. It helps explain how matter is structured, how it behaves, and how it changes during reactions [7]. Beyond its scientific relevance, it also supports efforts toward sustainability by providing knowledge that can be applied in developing safer materials, reducing waste, and promoting more efficient use of resources [8]. Within the school system, Chemistry is expected to help students build scientific awareness, think critically, and develop problem-solving abilities that are useful in today's technology-driven society [6]. Despite these expectations, many students still find the subject difficult to relate to, often describing it as abstract, which in turn affects their interest and overall achievement in the subject [7, 8].

One major difficulty in learning Chemistry is that many of its concepts are not directly visible. Ideas such as atomic structure, periodic trends, and electron arrangement exist at a level students cannot easily observe, which makes them harder to understand [6, 9, 10]. This becomes more challenging when these concepts are taught mainly through verbal explanations and textbook descriptions, which do not always help students build a clear understanding [11, 10]. The periodic table, widely regarded as the foundation of Chemistry, organizes all 118 known elements and their properties, making it essential for understanding the subject [12, 13]. Despite its importance, many students find it difficult to navigate and fully comprehend its underlying principles [11, 14]. This difficulty is largely due to the abstract relationships that govern periodic trends and electron configurations, which are not easily visualized. When these concepts are taught using traditional expository method that rely heavily on verbal explanations and static textbook representations, students often struggle to develop a clear and meaningful understanding [11, 10].

The expository teaching methods often relies a lot on fixed diagrams and teacher explanations. The method do not always help students understand difficult ideas, especially those that cannot be seen directly [15, 16, 17, 18, 19]. Furthermore, while method is commonly adopted by teachers, it does not fully engage students in the visualization necessary for deep understanding of abstract chemical concepts [20]. Reports from examination body such as the West African Examinations Council (WAEC), the Chief Examiners often highlight students' difficulties in topics requiring strong visualization skills, pointing to a persistent gap in conceptual understanding which the traditional expository method fail to bridge effectively. Hence, there is a growing need for instructional models and approaches that can translate these abstract chemical concepts into meaningful, concrete learning experiences, particularly through the use of computer-based and visualization-driven teaching approaches that align with contemporary digital learning environments.

Computer-based visualization model is teaching models that require the use of digital software and applications, such as interactive simulations, computer animations, or virtual periodic tables among others, to create dynamic and visual representations of chemical concepts, data, and processes, particularly the periodic table. According to Aliyu et al. [9] computer-based visualization model can be defined as an educational tool that leverages digital technology to create dynamic, interactive, and often three-dimensional representations of abstract scientific concepts. These tools help students form clear mental pictures of chemical structures and how they are arranged. This is important in Chemistry, where many ideas are not directly visible. With the help of these models, learners can see how molecules are built, how reactions happen, and how processes change over time, instead of relying only on fixed images in textbooks [6, 21]. In the classroom, computer-based visualization tools serve different purposes. They help students develop spatial skills needed to understand structures and also make abstract ideas easier to follow by presenting them in a more concrete and visual form [10, 22].

In support of this, the utilization of visualization tools such as periodic table Educalabs and MicroWorld. The tools are augmented reality application that specifically focused on improving students' understanding of chemical elements in the periodic table through enhanced visual representation [23]. Similarly, an exploration-based Spherical Video-based Virtual Reality (SVVR) approach has been reported to promote students' learning effectiveness in Chemistry by making abstract chemical concepts more accessible and easier to comprehend [24].

Numerous studies have reported the effectiveness of visualization models in Chemistry learning and science education more broadly [6, 25, 26]. However, most of these studies focused on general

Chemistry concepts such as chemical bonding and molecular structure, with less attention given to the periodic table as a distinct area of learning [9]. In addition, many of these studies were conducted outside the Nigerian context, which makes it difficult to directly apply their findings to secondary school classrooms in Nigeria [2, 19, 27].

The relevance of gender in Chemistry learning and possible differences in performance when technology-based instruction is used has received attention in recent studies. While some researchers have examined general academic performance and students' attitudes without focusing specifically on gender in computer-based learning environments [28, 29], others have looked directly at gender differences. For example, some studies have reported performance gaps between male and female students in Chemistry [30]. In contrast, other findings have shown no significant difference when students are taught using computer-based tools such as molecular modelling, animation, and infographics [6, 28, 31]. In addition, several studies have shown that both male and female students can benefit from these digital learning tools [8, 32, 33, 34, 35]. These mixed findings suggest that the issue of gender in technology-supported Chemistry learning is still not clearly understood and requires further investigation, especially in specific topic areas such as the periodic table [36].

Despite the growing use of digital tools in education, students' performance in topics such as the periodic table continues to raise concern, especially at the secondary school level. Reports from examination bodies such as the West African Examinations Council (WAEC) have consistently shown that students struggle with concepts that require strong visualization skills, including periodic trends and electron configurations [15, 16, 17, 18, 9]. Although previous studies have shown that visualization tools can improve learning in Chemistry [6, 25, 26], most of these studies have focused on other areas and have not given sufficient attention to the periodic table within the Nigerian context. In addition, findings on gender differences in technology-supported learning remain inconsistent [28, 29, 30]. Based on these gaps, this study examined the effect of a computer-based visualization model on students' academic performance in the concept of the periodic table in Chemistry. The study also investigated whether there are differences in performance between male and female students when exposed to this instructional approach, thereby extending existing research within a Nigerian secondary school setting.

RESEARCH METHODS

Materials and Tools

The study employed a quasi-experimental pretest–posttest non-equivalent control group design. This design was considered appropriate because intact classes were used, making the random assignment of individual students to experimental and control groups impracticable in a natural school setting. The design enabled the comparison of students' performance before and after the instructional treatment. The study was conducted in MKPAT Enin Local Government Area, located in the south-eastern part of Akwa Ibom State. The population of the study comprised 1,871 Senior Secondary School Two (SS2) students in sixteen (16) public senior secondary schools in the Local Government Area. The sample consisted of intact SS2 Chemistry classes selected from two public co-educational secondary schools in the study area. A total of 97 SS2 students from two intact classes constituted the sample for the study. A simple random sampling technique using the balloting method was employed to select the two schools from the list of public co-educational secondary schools in the area. In schools where more than one SS2 Chemistry stream existed, one intact class was selected through simple random sampling. One school was assigned to the experimental group, which received instruction on the concept of the periodic table using a computer-based visualization model CBVM, while the other school served as the control group and received instruction using the expository instructional method (EIM).

The Intervention

The computer-based visualization model was implemented using selected digital tools to support students' understanding of the periodic table. These included PhET simulations, Educalabs interactive periodic table, and MolView for visualizing atomic structures and element relationships. During instruction, students interacted with these tools through guided activities, demonstrations, and teacher-led explanations to explore periodic trends, electron configurations, and relationships among elements. The lessons were presented using computer-based visual displays to ensure that abstract concepts were clearly illustrated and easier for students to follow.

The instructional treatment lasted for a period of four weeks, during which both groups were taught the same content using their respective instructional methods. The intact classes comprised both male and female students, which enabled the examination of gender differences in students' academic performance. The instrument for data collection was the Chemistry Performance Test on the Periodic Table (CPTPT) developed by the researcher. The CPTPT was a 20-item multiple-choice test designed to measure students' academic performance in the concept of the periodic table. Each item consisted of four options labelled A–D, with one correct answer. Each correct response attracted one mark, resulting in a maximum obtainable score of 20. Efforts were made to control extraneous variables that could affect the outcome of the study. Both groups were taught using the same scheme of work and for the same duration. The same topics were covered, and similar learning conditions were maintained in both schools. In addition, the regular classroom teachers were used to avoid disruption of the normal school routine.

In addition, instructional lesson plans were developed for both the computer-based visualization model and the expository teaching method to ensure uniform content coverage during the instructional period. The instructional process was carried out in stages. First, a pretest was administered to both groups to determine their initial level of understanding of the periodic table. This was followed by the treatment phase, where the experimental group was taught using the computer-based visualization model, while the control group received instruction through the expository method. At the end of the treatment, a posttest was administered to both groups to assess students' performance. The Chemistry Performance Test on the Periodic Table and the instructional lesson plans were subjected to face and content validation by two experts: one expert in Chemistry Education and one expert in Measurement and Evaluation from the Department of Science Education, Faculty of Education, Akwa Ibom State University.

Method of Quantitative and Qualitative Analysis

The reliability of the CPTPT was established through a pilot test conducted on twenty (20) SS2 Chemistry students who were not part of the study sample but belonged to the same population. The data obtained were analysed using the Kuder–Richardson Formula 20 (KR-20), which was suitable for dichotomously scored items. A reliability coefficient of 0.86 was obtained and considered adequate for the study. Data analysis was carried out using mean and standard deviation to answer the research questions, while the formulated null hypotheses were tested using the Analysis of Covariance (ANCOVA) at the 0.05 level of significance to determine the effect of the computer-based visualization model and the influence of gender on students' performance in the Periodic Table.

RESULT AND DISCUSSION

Result of Quantitative Analysis

Research Question One: What difference exists in the mean performance scores of Chemistry students taught the periodic table using computer-based visualization model and expository instructional method?

TABLE 1: Mean and Standard Deviation of Students' Performance Scores on Pretest and Posttest Based on Instructional Methods

Instructional Method	N	PreCPTPT Mean	SD	PostCPTPT Mean	SD	Mean Gain
CBVM	50	35.54	10.20	75.52	14.11	40.00
EIM	47	35.62	12.07	60.17	21.82	24.55

The results in Table 1 show that students taught the periodic table using the Computer-Based Visualization Model (CBVM) recorded a pretest mean score of 35.54 (SD = 10.20), which increased to a posttest mean score of 75.52 (SD = 14.11), resulting in a mean gain of 40.00. Students taught using the Expository Instructional Method (EIM) had a pretest mean score of 35.62 (SD = 12.07) and a posttest mean score of 60.17 (SD = 21.82), producing a mean gain of 24.55. A comparison of the mean gains indicates that students in the CBVM group (40.00) achieved a higher gain than those in the EIM group (24.55). This suggests that although both instructional methods improved students' performance in the periodic table, the computer-based visualization model produced greater improvement in students' learning outcomes.

Research Question Two: What difference exists in the mean performance scores of male and female Chemistry students taught periodic table using computer-based visualization model and expository instructional method?

Table 2 shows that under the Computer-Based Visualization Model (CBVM), male students improved from a pretest mean score of 36.14 (SD = 8.84) to a posttest mean score of 76.52 (SD = 13.40) with a mean gain of 40.38, while female students improved from 35.10 (SD = 11.22) to 74.79 (SD = 14.79) with a mean gain of 39.69. This indicates that both male and female students benefited substantially from the computer-based visualization model, with male students showing a slightly higher mean gain. Under the Expository Instructional Method (EIM), male students improved from 35.33 (SD = 8.44) to 59.87 (SD = 23.37) with a mean gain of 24.53, while female students improved from 35.75 (SD = 13.57) to 60.31 (SD = 21.44) with a mean gain of 24.56. Overall, both instructional methods enhanced students' performance irrespective of gender. However, the computer-based visualization model produced higher performance gains for both male and female students compared to the expository instructional method, while the difference between male and female students within each method appeared minimal.

TABLE 2: Mean and Standard Deviation of Students' Performance Scores on CPTPT by Gender and Instructional Method

Instructional Method	Gender	N	PreCPTPT Mean	SD	PostCPTPT Mean	SD	Mean Gain
CBVM	Male	21	36.14	8.84	76.52	13.40	40.38
	Female	29	35.10	11.22	74.79	14.79	39.69
EIM	Male	15	35.33	8.44	59.87	23.37	24.53
	Female	32	35.75	13.57	60.31	21.44	24.56

Hypothesis One: There is no significant difference in the mean performance scores of Chemistry students taught periodic table using computer-based visualization model and expository instructional method.

TABLE 3: Result of Analysis of Covariance (ANCOVA) on the difference in mean performance scores based on instructional method

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6330.571a	2	3165.286	9.590	.000
Intercept	30308.294	1	30308.294	91.823	.000
Pretest_CPTPT	622.349	1	622.349	1.885	.173
Instructional Method	5721.310	1	5721.310	17.334	.000*
Error	31026.769	94	330.072		
Total	486974.000	97			
Corrected Total	37357.340	96			

a. R Squared = .169 (Adjusted R Squared = .152)
*Significant at 0.05 level

The ANCOVA result in Table 3 shows that the effect of instructional method was statistically significant {$F(1,94)=17.334$, $p=.000 < .05$}. Since the probability value was less than 0.05, the null hypothesis was rejected. This indicates that a significant difference existed in the mean performance scores of students taught the periodic table using the computer-based visualization model and the expository instructional method. The difference favoured the computer-based visualization model, as students exposed to this method obtained a higher mean gain (40.00) compared with those taught using the expository instructional method (24.55).

Hypothesis Two: There is no significant difference in the mean performance scores of male and female Chemistry students taught periodic table using computer-based visualization and expository instructional method.

TABLE 4: Result of Analysis of Covariance (ANCOVA) on the difference in mean performance scores based on gender

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	729.488a	2	364.744	.936	.396
Intercept	30733.060	1	30733.060	78.872	.000
Pretest_CPTPT	600.537	1	600.537	1.541	.218
Gender	120.227	1	120.227	.309	.580
Error	36627.852	94	389.658		
Total	486974.000	97			
Corrected Total	37357.340	96			

a. R Squared = .020 (Adjusted R Squared = -.001)

The ANCOVA result in Table 4 shows that the effect of gender was not statistically significant {$F(1,94) = 0.309$, $p=0.580 > 0.05$}. Since the p-value exceeded 0.05, the null hypothesis was retained. This indicates that no significant difference existed in the performance scores of male and female students taught the periodic table using the computer-based visualization model and the expository instructional method when pretest scores were controlled.

The findings of this study revealed that students taught the concept of the periodic table using a computer-based visualization model demonstrated better academic performance than those taught using the expository instructional method. The result shows that technology-based visualization helps students understand abstract chemical concepts more clearly. This may be because the approach allows students to process information using both visual and verbal forms at the same time. When learners see and hear explanations together, it becomes easier to form clear mental images of abstract ideas. The periodic table contains patterns and relationships that are not easy to grasp through verbal explanation alone. With computer-based visualization, students are able to see these relationships more clearly. This reduces the mental effort required to imagine these ideas on their own, which is often a challenge when only verbal explanations are used. Features such as animations and interactive displays likely helped them understand periodic trends, atomic structure, and relationships among elements. This kind of engagement does not only make learning interesting; it also supports how students organise and connect new information with what they already know, leading to better understanding.

This finding agrees with Ullah et al. [30], who developed an interactive virtual periodic table to improve students' understanding of atomic structure and elemental relationships. Their study found that students who used the tool performed better than those who relied on textbooks or conventional periodic tables. In the same way, the present study shows that visualization tools can simplify complex ideas in Chemistry and make them easier to understand. A similar result was reported by Aliyu et al. [4], who found that students exposed to three-dimensional visualization in chemical bonding showed better understanding than those taught using conventional methods. Unlike many of these earlier studies, the present study focused specifically on the periodic table within the Nigerian secondary school context, where students have consistently shown difficulty, thereby extending the use of visualization tools to a core but often challenging topic in Chemistry.

The study also found that gender had no significant influence on students' performance. Both male and female students benefited equally from the instructional methods used. This suggests that visualization-based learning provides a fair learning environment for all students. One possible reason for this is that the use of visual and interactive tools allows students to learn at their own pace, reducing differences that may arise from learning preferences or confidence levels. The finding supports Sunday et al. [28], who reported that although technology-based strategies improved students' performance, there was no difference between male and female students. Their study showed that such approaches support inclusive learning. This also suggests that technology-supported instruction can reduce learning barriers by presenting content in multiple forms, which aligns with how students naturally process information. In addition, Oladejo et al. [22], reported that computer simulation did not produce any significant difference between male and female students' performance in Chemistry. Their findings suggest that technology-based instruction offers equal support to learners. In this study, the visualization model likely allowed students to learn at their own pace, which helped reduce performance differences. Overall, the findings highlight the importance of using visualization tools in Chemistry teaching. These tools improve understanding, support active learning, and promote equal learning opportunities for students. From a practical point of view, this means that teachers can improve students' understanding of difficult topics by making use of simple digital tools that support visualization during instruction. However, it is important to note that the study was limited to a small number of schools, and the duration of the treatment was relatively short, which may affect how widely the findings can be applied.

CONCLUSION

This study established the effect of a computer-based visualization model on students' academic performance in the periodic table compared with the expository instructional method. The results showed that students taught with the visualization model performed better than those taught using the expository method. This confirms that the use of visualization-based instruction can significantly improve how students learn core Chemistry concepts that are usually difficult to understand. The study contributes to existing knowledge by showing that the use of computer-based visualization is particularly effective for teaching the periodic table, a topic that has remained challenging for many students. The study also found that gender had no significant influence on students' performance. Both male and female students benefited equally from the instructional approaches. This indicates that the methods used provided a fair learning opportunity for all students. It also suggests that technology-supported instruction can help reduce learning differences among students by providing multiple ways of understanding the same concept. Overall, the study highlights the importance of integrating computer-based visualization tools into the teaching of Chemistry, especially for abstract topics like the periodic table. The main contribution of this study lies in extending the use of visualization-based instruction to a specific and challenging concept within the Nigerian secondary school context. The findings have practical implications for classroom teaching, as they show that the use of simple digital tools can improve students' understanding and support more inclusive learning in Chemistry classrooms.

RECOMMENDATIONS

1. Chemistry teachers should make use of computer-based visualization tools when teaching abstract concepts such as the periodic table. These tools can help students see relationships among elements and better understand periodic trends, rather than relying only on lecture methods.
2. Students should be encouraged to engage actively with digital learning resources that present chemical concepts visually. Using simulations, visualization software, and interactive models can make complex topics easier to understand and improve their learning.
3. Educational policy makers should support the integration of technology-based instructional resources in secondary school science education.
4. Schools should be equipped with adequate digital infrastructure such as computers, projectors, and visualization software to facilitate effective teaching and learning of Chemistry.

LIMITATIONS

The study was conducted using a relatively small sample size drawn from only two secondary schools within Mkpat Enin Local Government Area. This limits the generalizability of the findings to other regions or educational contexts. In addition, the duration of the treatment was limited to four weeks, which may not be sufficient to capture long-term effects of the computer-based visualization model on students' academic performance. The study also focused on a single Chemistry concept the periodic table therefore, the findings may not fully represent the effectiveness of the model across other Chemistry topics. Furthermore, factors such as students' prior exposure to digital tools, availability of technological resources, and teachers' level of competence in using visualization tools were not controlled, which may have influenced the outcome of the study.

FUTURE RESEARCH DIRECTIONS

Future studies should consider using a larger sample size drawn from multiple schools across different regions to enhance the generalizability of findings. Researchers may also extend the duration of the instructional treatment to examine the long-term impact of computer-based visualization on students' academic achievement and retention. In addition, further research should explore the effectiveness of visualization-based instructional models across other Chemistry topics such as chemical bonding, thermodynamics, and organic chemistry.

Authors'contribution

- *Conceptualization: Edima Sylvanus Sunday;*
- *Data curation: Felicia Imeh Umanah;*
- *Formal Analysis: Edima Sylvanus Sunday;*
- *Funding acquisition: All authors;*
- *Investigation: George Johnson Ntegwung;*
- *Methodology: Edima Sylvanus Sunday;*
- *Project administration: Edima Sylvanus Sunday;*
- *Resources: Enobong Imoh Akpa;*
- *Software: Felicia Imeh Umanah;*
- *Supervision: Edima Sylvanus Sunday;*
- *Validation: George Johnson Ntegwung;*
- *Visualization: Edima Sylvanus Sunday;*
- *Writing – original draft: Edima Sylvanus Sunday;*
- *Writing – review & editing: Felicia Imeh Umanah & Enobong Imoh Akpan;*

All authors have read and agreed to the published version of the manuscript.

Ethics Statement

This research involved human subjects who had given informed consent to participate. All participants received treatment in accordance with their rights, dignity, and applicable research ethics principles.

Data availability statement

The data will be available upon request.

Funding
This research received no external funding. Additionally, specify "The APC was funded by all authors,"

Acknowledgments
We sincerely acknowledge the support of our respective institutions, colleagues, and the administration, teachers, and students of all the secondary schools used in the study during the course of this research. During the preparation of this manuscript, ChatGPT (OpenAI) and Bohrium AI were used minimally for searching related materials. The authors have carefully reviewed and revised all content and assume full responsibility for the final version of this publication.

Conflicts of Interest
The authors declare no conflicts of interest.

REFERENCES

[1] A. O. Akpan, F. I. Umanah, and A. U. Abasi, "Effects of virtual-field-trip and field-experience strategies on performance in air pollution among college of education students in Akwa Ibom State, Nigeria," *Federal University Gusau Faculty of Education Journal*, vol. 5, no. 3, pp. 110–117, 2025, doi: 10.64348/zije.202539.

[2] E. S. Sunday, A. A. Edet, and E. I. Akpan, "Effects of computer assisted instructions and computer animation on the teaching of chemistry in secondary schools," *International Journal of Modern Science and Research Technology*, vol. 3, no. 11, pp. 499–509, 2025, doi: 10.5281/zenodo.17935293

[3] A. Akubue, C. P. C. Prince, W. C. Okeke, and P. I. Ezeabasili, "Adapting the e-learning model of education in the digital age for Nigerian schools," *International Journal of Advances in Engineering and Management*, vol. 6, no. 10, pp. 47–55, 2024, doi: 10.35629/5252-0610158163

[4] S. S. Aldosari, B. Ghita, and D. Marocco, "A gesture based educational system that integrates simulation and molecular visualization to teach chemistry," *International Journal of Emerging Technologies in Learning (iJET)*, vol. 17, no. 4, pp. 194–211, 2022, doi: 10.3991/ijet.v17i04.26503

[5] F. Aliyu, A. Garba, and R. U. Faruk, "Students' visualization skills in chemical bonding through three dimensions: A study on secondary school chemistry students," *Journal of Natural Science and Integration*, vol. 6, no. 2, pp. 210–223, 2023, doi: 10.24014/jnsi.v6i2.27212.

[6] M. Alrige, H. Bitar, W. Al Suraihi, K. Bawazeer, and E. Al Hazmi, "MicroWorld: An augmented reality Arabian app to learn atomic space," *Technologies*, vol. 9, no. 3, pp. 34–42, 2021, doi: 10.3390/technologies9030053.

[7] S. B. Apata, J. T. Adeniyi, J. A. Ajiwoju, and K. K. Adeosun, "Digital transformation in teaching: The preparedness of in service teachers in Nigeria for the Fourth Industrial Revolution (4IR)," *British Journal of Contemporary Education*, vol. 5, no. 1, pp. 8–19, 2025, doi: 10.52589/BJCE-S8GBY9M3.

[8] I. Bobmanuel and T. Adolphus, "Effect of drama method of teaching chemistry on the interest of students in secondary schools in Rivers State," *International Journal of Science and Research Archive*, vol. 16, no. 1, pp. 92–101, 2025, doi: 10.30574/ijsra.2025.16.1.1946.

[9] C. E. Brown, D. Alrmuny, M. K. Williams, B. Whaley, and R. M. Hyslop, "Visualizing molecular structures and shapes: A comparison of virtual reality, computer simulation, and traditional modeling," *Chemistry Teacher International*, vol. 2, no. 2, pp. 1–10, 2020, doi: 10.1515/cti-2019-0009.

[10] A. A. Edet, E. S. Sunday, A. U. Abasi, E. I. Akpan, E. I. Akai, and O. P. Ukafia, "Instructional Materials and Secondary School Students' Attitude and Performance in Mathematics in Mkpat Enin Local Government Area," *International Journal of Modern Science and Research Technology*, vol. 3, no. 11, pp. 486–496, 2025, doi: 10.5281/zenodo.17929186.

[11] T. T. Francis and S. J. Baba, "Effect of concept mapping teaching approach on students' academic performance in chemistry in senior secondary schools," *Indonesian Journal of Educational Research and Technology*, vol. 3, no. 1, pp. 35–44, 2022, doi: 10.17509/ijert.v3i1.46145.

[12] J. Elyasova, "The impact of molecular modeling and simulation technologies on students' conceptual understanding in chemistry education," *InterConf*, vol. 2024, no. 12, pp. 88–96, 2024, doi: 10.51582/interconf.19-20.08.2025.007.

[13] J. U. Etukapkan, F. I. Umanah, and A. O. Akpan, "Team-pair-solo, computer simulation, guided discovery teaching approaches and secondary school students' academic performance in cell structure in biology," *British Journal of Education*, vol. 13, no. 11, pp. 42–56, 2025, doi: 10.37745/bje.2013/vol13n114256.

[14] A. Iyamuremye, E. Nsabayezu, J. B. Nkurunziza, A. Nzavuga Izere, C. Karegeya, E. Gakuba, R. Ntihabose, J. P. Nahimana, and F. N. Niyonzima, "Exploring teachers' and students' perspectives toward the use of low-cost atomic model kits in teaching and learning electronic configuration and molecular structures," *Cogent Education*, vol. 12, no. 1, pp. 1–15, 2025, doi: 10.1080/2331186X.2025.2566893.
[15] I. Libata, H. Hassan, and R. Muhammed, "Evaluating the effectiveness of laboratory based instruction on female students' attitude and academic performance in chemistry in Kontagora, Niger State, Nigeria," *FUDMA Journal of Sciences*, vol. 9, AHBSI, pp. 233–242, 2025. [Online]. Available: https://fjs.fudutsinma.edu.ng/index.php/fjs/article/view/3402.
[16] R. E. Mayer, *Multimedia Learning*. Cambridge, U.K.: Cambridge University Press, 2001.
[17] F. Narod and V. Narrainsawmy, "Educators' reflections on the teaching and learning of the periodic table of elements at the upper secondary level: A case study," *Physical Sciences Reviews*, vol. 7, no. 4, pp. 45–58, 2022, doi: 10.1515/psr-2021-0182.
[18] E. Nsabayezu *et al*., "Investigating contemporary teaching approaches and technological integration in organic chemistry instruction in selected Rwandan secondary schools," *Education and Information Technologies*, vol. 29, no. 2, pp. 2143–2162, 2024, doi: 10.1007/s10639-024-13075-2.
[19] E. Nsabayezu, A. Iyamuremye, J. Mukiza, A. Mbonyiryivuze, E. Gakuba, F. N. Niyongabo, and T. Nsengimana, "Impact of computer-based simulations on students' learning of organic chemistry in the selected secondary schools of Gicumbi District in Rwanda," *Education and Information Technologies*, vol. 28, no. 3, pp. 3537–3555, 2023, doi: 10.1007/s10639-022-11344-6.
[20] G. J. Ntegwung, "Vocational skills acquisition and entrepreneurship development among building technology students in Akwa Ibom State technical colleges," *AKSU International Journal of Research in Education (AKSUIJRE)*, vol. 1, no. 2, pp. 197–205, 2025.
[21] G. J. Ntegwung and N. A. Njoku, "Repackaging technical vocational education and training (TVET) for sustainable national development," *African Journal of Educational Archives*, vol. 8, no. 1, pp. 136–146, 2022.
[22] B. N. Nweze and C. N. Ogwu, "Effect of computer aided instruction on chemistry students' achievement in organic chemical nomenclature in Enugu Education Zone of Enugu State, Nigeria," *British Journal of Education*, vol. 10, no. 1, pp. 45–58, 2022.
[23] A. I. Oladejo, N. C. Nwaboku, P. A. Okebukola, and I. A. Ademola, "Gender difference in students' performance in chemistry – can computer simulation bridge the gap?" *Research in Science & Technological Education*, vol. 41, no. 3, pp. 1031–1050, 2023, doi: 10.1080/02635143.2021.1981280.
[24] Q. F. Yang, H. Lin, G. J. Hwang, P. Y. Su, and J. H. Zhao, "An exploration-based SVVR approach to promote students' chemistry learning effectiveness," *Interactive Learning Environments*, vol. 32, no. 5, pp. 2003–2027, 2024, doi: 10.1080/10494820.2022.2135106.
[25] M. Rusek, M. Tóthová, V. Chytrý, and J. Říčan, "Students' ability to work with the periodic table: The use of three-tier tasks," *Journal of Chemical Education*, vol. 101, no. 11, pp. 4590–4602, 2024, doi: 10.1021/acs.jchemed.4c00485.
[26] E. S. Sunday and A. A. Edet, "Renewable resources in teaching Chemistry practical and students' learning outcome in secondary schools," *Asia-Africa Journal of Education Research*, vol. 4, no. 1, pp. 119–127, 2024. [Online]. Available: https://journals.iapaar.com/index.php/aajer.
[27] E. S. Sunday, A. A. Atabang, and M. C. Ekon, "Leveraging AI-powered learning tools in developing critical thinking skills among Nigerian undergraduates to combat insecurity," *International Journal of Modern Science and Research Technology*, vol. 3, no. 11, pp. 534–543, 2025, doi: 10.5281/zenodo.17959324/
[28] E. S. Sunday, F. I. Umanah, and S. E. Udofia, "Enhancing students' academic achievement in chemical reactions through computer-based molecular modelling and hackathon teaching strategies," *International Journal of Research and Innovation in Social Science*, vol. IX, no. IIIS, pp. 1815–1824, 2025, doi: 10.47772/IJRISS.2025.903SEDU0139.
[29] P. Thote and S. Gowri, "Outcome based learning: An analysis of impact on academic achievement among school students," *International Journal of Research – GRANTHAALAYAH*, vol. 8, no. 11, pp. 115–123, 2020, doi: 10.29121/granthaalayah.v8.i11.2020.2222.
[30] S. Ullah, B. Mehmood, M. Raees, N. Ali, and I. ur Rehman, "Virtual periodic table for dynamic visualization of atomic structure and hierarchical-based interaction: A system to enhance student's learning," *Journal of Chemical Education*, vol. 102, no. 5, pp. 1829–1838, 2025, doi: 10.1021/acs.jchemed.4c00825.

[31] E. I. Akpan, F. I. Umanah, and S. E. Udofia, “Comparative effects of learning cycle models and students’ academic achievement in chemistry in Uyo, Akwa Ibom State,” *GAS Journal of Education and Literature (GASJEL)*, vol. 2, no. 11, 2025, doi: 10.5281/zenodo.17615814.
[32] F. I. Umanah and A. A. Atabang, "Effect of animated and static infographic instructional materials on students’ academic performance in isomerism in chemistry," *International Journal of Research and Innovation in Social Science*, vol. IX, no. IIIS, pp. 1515–1524, 2025, doi: 10.47772/IJRISS.2025.903SEDU0118.
[33] F. I. Umanah and E. S. Sunday, "Crosswords puzzle, flashcards teaching strategies and senior secondary school students’ academic performance in chemistry," *International Journal of Educational Benchmark*, vol. 22, no. 2, pp. 1–12, 2022. https://www.academia.edu/download/105170685/IJEB_22_1a_1.pdf
[34] F. I. Umanah and E. S. Sunday, "Effects of teacher-made model and student made model instructional materials on senior secondary students’ academic performance in unsaturated hydrocarbons in chemistry," *International Journal of Research and Innovation in Social Science*, vol. IX, no. IIIS, pp. 4414–4421, 2025, doi: 10.47772/IJRISS.2025.903SEDU0315..
[35] F. I. Umanah and E. S. Sunday, "Effects of teacher-made model and student made model instructional materials on senior secondary students’ academic performance in unsaturated hydrocarbons in chemistry," *International Journal of Research and Innovation in Social Science*, vol. IX, no. IIIS, pp. 4414–4421, 2025, doi: 10.47772/IJRISS.2025.903SEDU0315.
[36] E. U. Umoetuk, E. S. Sunday, A. A. Edet, A. M. Elijah, and I. E. Williams, "Computer simulation and expository teaching strategies on students’ academic achievement in Basic Science and Technology in junior secondary schools," *GAS Journal of Education and Literature (GASJEL)*, vol. 2, no. 3, pp. 28–34, 2025, doi: 10.5281/zenodo.16694239.