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Traditional and ICT-Enhanced Chemistry Teaching in Nigerian Senior Secondary Schools: An Integrative Review with Implications for South-East Nigeria

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Abstract:

This study analyses traditional and ICT-integrated approaches to teaching chemistry in Nigerian secondary schools, focusing on South-East Nigeria. A structured integrative review was conducted to synthesise different types of recent evidence (e.g., experimental, quasi-experimental, survey, qualitative, review) published between 2023 and September 2026. The synthesis incorporates studies and related documents (e.g., policies) that discuss learning, understanding of chemical concepts and retention, engagement, and other related factors including teachers' readiness and integration of ICT in teaching, digital literacy and equity in the education system. Findings of the studies show that the use of digital resources in teaching chemistry, in conjunction with pedagogical strategies, promotes the understanding of chemical concepts and retention of students. Positive impacts of the use of computer simulation and virtual laboratory in teaching chemistry are reported in several studies. Moreover, several studies have documented challenges concerning the use of educational technologies in teaching and learning, such as the teaching staff's digital literacy and teacher education. The integration of digital technologies and strategies in the teaching of chemistry improves students' learning and retention of chemical concepts; however, digital technologies and strategies should be appropriately integrated along with pedagogical strategies and other teaching and learning methods in chemistry, including physical practical work. The use of digital technologies in teaching and learning chemistry should be guided by the principles of ICT in education. Based on the available evidence, there is a strong case for integrating various ICT in the teaching of chemistry in South-East Nigeria.

Keywords: use of ICT in chemistry teaching; virtual laboratories; simulation; digital pedagogy; SE Nigeria; secondary education; chemistry teaching and learning

1. Introduction

Chemistry is a major branch of science that has a positive impact on the understanding of various key areas of our society such as medicine, agriculture, industry, and the environment. It is important that teachers of senior secondary school chemistry enhance the conceptual understanding of their students by helping them relate various concepts of Chemistry to real life situations using various structures and tools to solve problems. Quality chemistry education should take into account students' diverse learning styles in order to meet the general expectation of the curriculum. In many parts of the world, including Nigeria, education has remained challenged due to several factors including large class sizes, teaching aids and textbook shortages, unreliable electricity and other forms of disruptive and unreliable school infrastructure. The question however remains, what are the possible approaches to enhancing chemistry learning and teaching in various institutions within the available constraining conditions?

There are several reasons why traditional chemistry teaching methods persist in Nigerian schools. For one, these methods are relatively inexpensive, and in the absence of adequate digital infrastructure, methods that do not rely on the internet and digital devices are easier to implement and adapt to the various situations that may arise due to unreliable electricity supply. Traditional teaching methods often incorporate explanation and examples, questions and practice. These may reduce the cognitive load of learners and are thus appropriate for beginner-level learners. Traditional teaching, however, becomes a problem when it incorporates lengthy examples and explanations that require learners to simply copy and memorise. Several studies have shown that in the teaching and learning of chemistry, traditional (especially teaching methods that involve long lectures), passive teaching methods are less effective than various interactive and cooperative teaching methods. In a related area, the same type of research has shown that various creative and alternative methods in teaching are more effective than traditional methods.

There are several features of ICT which are relevant when teaching an abstract subject like chemistry. For example, simulations can make previously invisible particle level processes visible. Virtual lab environments can enable users to carry out chemical experiments where the reagents cannot be replaced. Multimedia can be used to integrate various forms of expressions including chemical equations. Lastly, software can be designed to provide users with instantaneous feedback. Favourable outcomes to the use of ICT in teaching chemistry have been reported in several studies conducted in Nigeria (Fabeku and Enyeasi, 2024; Ugah, 2024; Ibrahim, Bolaji and Oyeyemi, 2025; Jack and Shidawa, 2025). However, there are challenges at the implementation level. For instance, Hamza et al. (2024) mentioned that available ICT resources in chemistry education in Kwara State are not adequately utilised. In Awka Education Zone, Nnoli and Muogbo (2025) reported positive attitudes of chemistry teachers towards the use of ICT in teaching chemistry, but expressed challenges with the use of ICT in teaching chemistry.

Wider evidence refutes techno-determinism. Findings on the integration of ICTs in post-primary education outline that, for ICTs to be effectively integrated and positively impact learning, there is a need for a coherent set of policies and reforms aimed at improving the capacity of teaching personnel (Msafiri, Kangwa & Cai, 2023; Msambwa, Kangwa & Lianyu, 2024). There are also studies focused on Chemistry Education where the integration of ICTs is found to assist in the visualisation of abstract concepts and improve student engagement. Again, the outcomes are dependent on the design of learning activities and the integration of ICTs (Palacios, Pascual & Moreno-Mediavilla, 2024; Ali, Talib & Jamal, 2023; Chen, Xue & Yang, 2024). Therefore, in conducting a comparative analysis of both types of chemistry teaching, it is crucial to be mindful of the ways in which technology has been integrated and the pedagogical approaches that informed its use.

It is also a structured approach because it outlines the various types of evidence and assures researcher diligence in separating primary evidence from the researcher's synthesis. It maintains focus on South East Nigeria but incorporates other regions of Nigeria in the absence of direct South East research evidence.

1.1 Problem Statement

Although the use of ICT in science education is encouraged and adopted in several countries, including Nigeria, its integration in science education in Nigerian secondary schools is sporadic. Insufficient ICT infrastructural facilities is not the major barrier. There are several other pedagogical and sociocultural barriers. For instance, a school may have ICT facilities, but the community may not have stable electricity to power such facilities. Also, a science teacher may have a science projector, but lacks the knowledge on how to project science content and facilitate learning through ICT. Also, a student may have access to ICT in school but has no such facilities in her/his home. Such sociocultural inequalities make it inappropriate to make generalisations that teaching science using ICT will lead to improvement in student achievement as compared to teaching science using the traditional pedagogy.

Another problem is lack of evidence. Most of the studies on ICT in chemistry education focus on the use of simulation and/or virtual laboratories. Other studies conduct survey research to assess students' readiness and/or perceptions about various ICT tools. Such studies employ different methodological approaches to assessment. Generally, assessment and comparative studies on the use of ICT in science and chemistry education suffer methodological challenges. Also, such studies make little or no effort to examine the conditions that may facilitate the transferability of their studies to other jurisdictions. Therefore, the aim of this study is to examine the recent evidence on the use of ICT in Nigeria and other related countries to determine the conditions that influence the use of ICT, as well as its impact on learning in science education.

1.2 Aim and Objectives

The aim of the study is to examine the traditional and ICT enhanced methods of teaching chemistry in Senior Secondary Schools in South-East Nigeria and to evaluate the conditions under which ICT enhances chemistry learning in the region.

1. Review recent studies on the role of traditional and enhanced ICT methods of teaching chemistry in terms of learning achievement and chemistry conceptual understanding and evaluation of learners' engagement and learning retention.
2. Identify and evaluate the formats and the types of ICT that, when incorporated in chemistry teaching, enhance learning.
3. Evaluate the Socio-economic and other conditions that limit the use of ICT in chemistry teaching.
4. Suggest strategies for the improvement of the curriculum and teaching of chemistry in Senior Secondary Schools in South-East Nigeria.

1.3 Research Questions

1. What are the consequences when chemistry is taught using traditional methods versus ICT methods?
2. In what ways do computer-based simulations and other computer-based aids in chemistry affect learning?
3. What are the barriers to the successful incorporation of ICT in the teaching of chemistry in secondary schools in South East Nigeria?

2. Literature Review and Analytical Framework

2.1 Traditional Chemistry Teaching: Strengths and Limitations

Different styles of teaching exist under the broad definition of traditional teaching. Some approaches to teaching can involve teaching strategies which reduce the cognitive load on students, thus enabling students to overcome a learning barrier. According to cognitive load theory, there are numerous chemistry problems which involve several component skills. Teachers therefore need to break down problems into simpler components and provide students with examples of the solution to each component. This would give students a framework to visualise the solution for a given problem. Within this context, teaching traditional chemistry can be considered an effective approach.

The focus will be on the ways instruction can be changed to reduce limitations on students' potential to predict, represented by various means, seek and discuss evidence and examples, and to apply chemical concepts in new situations. Passive teaching may not offer students the opportunity to construct sufficient connection between chemical concepts and representations. Agwu and Nmadu (2023) documented an improvement in students' behaviour and academic performance when cooperative learning was introduced. On the other hand, inquiry-based learning was found to be effective in achieving students' conceptual understanding, as documented by Ojo and Tijani (2025). The author's point is that the type of instructional design employed, as distinguished from the use of learning technologies, is the key determinant of quality learning in a teaching situation.

The findings of Ahmad et al. (2023), showed that in different contexts and locations in Africa, beyond Nigeria, conventional teaching and learning of chemistry is outdated and stifling; innovative, active teaching and learning approaches are vastly superior. Similarly, Karpudewan and Daman Huri (2023) demonstrated that integrated STEM-based approaches to laboratory work strengthened students' ability to apply chemical concepts to solve problems. Traditional teaching and learning of chemistry, as documented by these author's, demands a thorough rethink, and active teaching and learning, as well as digital integration, is the way forward.

2.2 ICT-Assisted Teaching of Chemistry

Various digital tools give teachers the ability to represent and demonstrate chemistry concepts in different ways. Ali, Talib and Jamal (2023) have identified interactive represented virtual chemistry structures, as well as digitised chemistry activities, as key aspects of integration of information communication technology (ICT) in chemistry education. Other aspects of ICT integration in chemistry teaching are the use of digital tools to facilitate virtual laboratory activities.

Virtual tools offer Nigerian teachers the opportunity to employ audio-visual aids to demonstrate various chemical concepts. Some of the chemicals concepts that are difficult to observe directly and/or require demonstration of processes or activities, can be represented using virtual tools. Some of the processes that are difficult to represent include ionic equilibrium, chemical and other equilibria, and kinetics. These and other processes can be demonstrated using virtual tools. Equally, some laboratory activities that require reagents and other chemicals that are costly, or hazardous to use, can be demonstrated using virtual tools.

Evidence on the use of various ICT tools for teaching chemistry in Nigeria is increasing. Computer simulation has been shown to improve students' achievement and retention. Use of virtual laboratory activities has also been shown to improve students' retention as compared to face-to-face chemistry laboratory activities.

While our results complement findings from other studies, some are ambiguous and may require additional explanation. Palacios, Pascual and Moreno-Mediavilla (2024) noted that simulations promote conceptual learning of chemical concepts and skills. However, they highlighted that the development and integration of simulations within instruction require thoughtful planning and may not be substitute for traditional instruction. Likewise, they noted that sustainability of simulations within instruction may require supporting professional development and integration of ICT within teaching and learning.

Other studies have identified the potential of digital environments within the context of chemistry education to break conceptual barriers and offer opportunities for learning through guided animations, simulations and digital resources. Stop motion animations have been found to assist the learning of junior secondary school students to engage with laboratory learning concepts. Other studies have shown that VisChem and related approaches have the potential to build students' molecular-level understanding of chemistry, and that the integration of computational chemistry and related activities may support learning of various concepts and ideas associated with chemistry.

Virtual and immersive environments also create differentiated effects on learning. Results from some studies have shown that while virtual laboratories have been effective in developing learners' chemical knowledge, directly interacting with the chemical substances improved learners' performance in planning and collecting evidences (Chen, Xue & Yang, 2024; Lathwesen & Eilks, 2024). Likewise, an immersive virtual chemistry classroom improved learners' understanding on the concept of bonding (Rahman et al., 2024). Another study showed learners' interest towards a digital chemistry escape room (Rahman et al., 2024). The same study also reported learners' positive attitude towards the digital game. Aslam et al. (2025) also studied learners' interest and attitude towards a different digital chemistry game.

Due to various reasons, such as learners' protection, financial cost, and availability, simulation-based learning is an excellent alternative for teaching chemistry. Examples of digital chemistry environments should not be seen as replacement to face-to-face chemistry laboratories; instead they should be examined based on their instructional functions, such as virtualising dangerous chemistry experiments, developing learners' understanding in chemical concept and providing chemical feedback to learners (Hou et al., 2023; Palacios, Pascual & Moreno-Mediavilla, 2024).

2.3 Teacher Readiness, Infrastructure and Equity

Amongst the implementation variables, teacher capacity is pivotal. Findings from Ogegbo (2023) indicated that the digital competence of 102 secondary school science teachers in Nigeria was at the level of B1 integrator. This means they were able to use digital technologies for teaching and learning. Nonetheless, there was scope to deepen their integration as well as digitise and create learning resources. Igboanugo (2024) conducted a study on the readiness of 410 chemistry teachers to integrate digital technologies and found no significant difference between men and women. Ogegbo (2024) reported that the majority of the participants in the study believed that ICT can facilitate teaching and learning of various science concepts. However, they expressed concerns about the absence of appropriate infrastructure and support to integrate ICT in teaching. Other research syntheses have also supported these findings. For example, Smestad et al. (2023) indicate that researchers often examine the digital competence of teachers by focusing on their perceptions and beliefs. As a result, researchers are encouraged to examine teachers' integrated digital competence in teaching practice.

There are access issues for teachers and other staff. Guobadia and Ekuobase (2024), based on their research in 2,107 students and 666 teachers in Nigeria, calculated an index of digital learning culture at 0.21, and showed that there were large regional variations. The research supported the view that students in Nigeria come into contact with digital learning resources in an equitable manner. At the same time, research by Nnoli and Muogbo (2025), conducted in the Awka Education zone, indicated teachers' and students' positive views on the role of ICT in enhancing the teaching and learning of Chemistry. Positive attitudes however need not indicate attainment of targeted learning outcomes.

Research from Nigeria provides insights on the inadequacies in the education system that go beyond the realm of ICT. Hamza et al. (2024), for example, highlighted the case of ICT resources in Chemistry Education that were largely remain untapped by the teachers. Similar situation of scarcity of ICT infrastructure was reported by Yoade and Ajayi (2025), and Benibo (2025) in the field of Basic Science Education. It was observed that integration of ICT in education improved teachers' confidence and readiness; however, teachers continued to have knowledge and skill gaps that should be addressed by professional development and aligned policy interventions.

Student achievement is also associated with the type of attitude towards science that teachers possess. It was documented that the attitude towards science of teachers in Ondo city influences student performance (Ikuejube, 2024). The study above confirmed the presence of a positive attitude towards science among chemistry teachers. However, there exists a lack of necessary pedagogical and content skills to utilise instructional technology among the teachers. Therefore, there is a need to create an enabling environment among science teachers in Nigeria to close the attitudinal gap towards innovation.

The same challenges are acknowledged by the Nigerian government. The Nigerian Federal Ministry of Education, through the Nigerian National Policy on Education (2023), acknowledges the need to increase digital content and educate teachers on the use of integrated digital resources and learning. UNESCO (2023), supporting the views of the Nigerian government, opines that to close the digital divide within education, the emphasis should be on sustainable integration of ICT in education, particularly in South Eastern Nigeria.

2.4 Theoretical and Conceptual Framework

Combining Constructivist Learning Theory and Cognitive Load Theory, along with associated principles of learning, allows the development of learning materials integrated with different types of educational multimedia. Constructivism focuses on the learning process of individuals and how they construct knowledge by interpreting and interacting with the environment and by assessing and evaluating information. It provides an explanation to the benefits of students constructing their own knowledge by manipulating variables and governing interactions in virtual environments, rather than watching a pre-recorded lecture. Although Cognitive Load Theory incorporates similar elements and principles of learning as that of Constructivism, it focuses on the limits of the human mind and the need to ensure that the learning materials do not overload the learner's working memory. Learning can also be overloaded by the combination of different types of media.

The theories and concepts of learning integrate different perspectives of teaching, including ICT-integrated teaching, and distance education. A simulation may create extraneous cognitive load for the learner if it contains inadequate and unclear controls. Based on this, ICT may not necessarily be the best option for all forms of teaching and learning. Each case needs to be assessed for its context, and the approach to teaching adapted. A contextual approach is the basis of the framework being employed in the review.

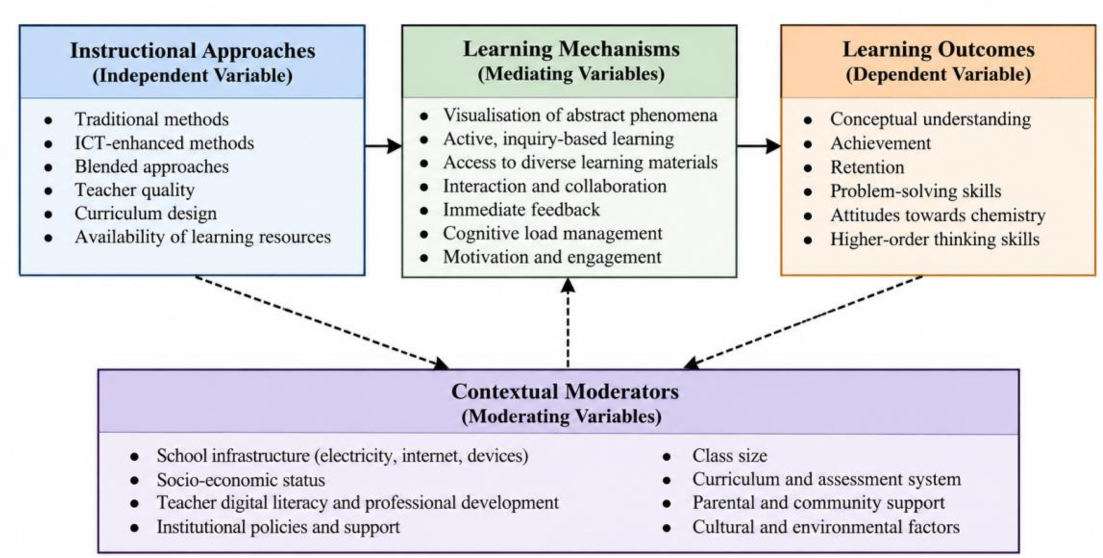

Figure 1. Analytical framework for comparing traditional and ICT-enhanced chemistry instruction.
Source: authors' conceptual synthesis.

3. Methodology

3.1 Research Design

As the evidence base comprises different research designs including, for instance, qualitative case studies, surveys, systematic reviews and policy documents, an integrative review design was adopted. Integrative reviews allow comparison of different types of evidence and are, therefore, appropriate for addressing questions requiring integration of different types of evidence. Since the main objective of this review is to assess evidence reported in different formats, the evidence was integrated through a structured narrative synthesis rather than a quantitative meta-analysis.

The unit of analysis was individual pieces of evidence. Results have been presented in a tabular and/or graphical form to the extent that they could be traced to a published or working document. Other information and materials were synthesised to support the results. Primary data were collected through literature search. No fieldwork was undertaken.

3.2 Search and Selection of Evidence

In order to capture the use of digital learning resources in the field of chemistry education in the different types of schools in Nigeria and adjacent areas, recently published (2023-2026) peer-reviewed articles were reviewed. Reference chaining was used to locate relevant articles. Other, often older, articles and reports were incorporated if they provided information on the mechanisms of learning.

Studies were included in the review if they: i) were about chemistry, the integration of ICT in the study of science or science teaching, or the readiness of teachers/students to use ICT and similar related issues in teaching chemistry, ii) reported primary data or were systemic/literature reviews, iii) reported sufficient information on research design to allow for interpretation of findings, iv) were published in English, and v) were published, printed and/or electronically accessible journals, or through other authorised records (e.g. Publisher, DOI, ERIC, Institutional Record, etc.). Of these, studies carried out in South-East Nigeria were given first consideration. Other studies carried out in Nigeria were considered if they provided better evidence on the use of the technology or highlighted other research findings. Evidence from other countries was considered if it provided implementation and/or mechanism related data.

Papers were excluded from the review if they were unpublished or difficult to access; provided little or no evidence to support their claims; reported the same or similar data as a paper already considered in the review; and/or reports results which are not supported by a clear and adequate research design. It was not possible to perform a quantitative synthesis (meta-analysis) because of the differences in the interventions and the measurement and definition of outcomes.

3.3 Data Extraction and Analytical Process

For each core source, the following details were extracted: location, research design, sample, instructional strategies or ICT, outcome measures, key findings, and connection to review questions. Evidence was categorised as one of the three following main aspects: learning outcomes, pedagogical approaches, and the combination of teacher readiness and ability to implement, along with available means and conditions. Evidence of learning was evaluated by experiments and quasi-experiments, while readiness and perception of teachers and other implementation actors was assessed with surveys and qualitative evidence. The system, -and the extent to which it reflect the conditions in other countries, was assessed by means of synthesis of evidence, especially in the field of education, and relevant documents.

Table 1. Evidence map of core studies used in the comparative synthesis

Study	Context	Design/sample	Key evidence	Analytical contribution
Agwu & Nmadu (2023)	Nigeria; secondary chemistry	Quasi-experimental; cooperative learning	Interactive pedagogy improved engagement and achievement relative to less interactive instruction.	Shows that active pedagogy itself can improve outcomes without ICT.
Ogegbo (2023)	Lagos, Nigeria	Survey; 102 science teachers	Most teachers were at B1/integrator digital competence; gaps remained in pedagogical integration and digital-content creation.	Teacher competence is a moderator of ICT effectiveness.
Fabeku & Enyeasi (2024)	Ife Central, Osun State	Quasi-experimental; 138 SSII students	Computer simulation produced the strongest achievement and retention results compared with video-media and conventional teaching.	Direct Nigerian evidence of simulation-related learning gains.
Guobadia & Ekuobase (2024)	Six geopolitical zones, Nigeria	Survey; 2,107 students + 666 teachers	National digital-learning culture index was low (0.21) with substantial community variation.	Strong evidence on inequality of access and digital-learning culture.

Study	Context	Design/sample	Key evidence	Analytical contribution
Igboanugo (2024)	Nigeria	Survey; 410 chemistry teachers	Preparedness to integrate digital technology did not differ significantly by gender.	Capacity building should target competence and access, not gender assumptions.
Ogegbo (2024)	Lagos, Nigeria	Qualitative case study; 6 science teachers	Positive perceptions coexisted with low classroom use because of poor resources, electricity, support and TPACK-related constraints.	Explains implementation gap between attitude and practice.
Ugah (2024)	Nigeria; senior secondary chemistry	Empirical study; 209 students	ChemLab simulation significantly influenced intention to engage in chemistry practical experiments.	Supports engagement pathway.
Palacios et al. (2024)	International; secondary chemistry	Systematic review	Simulations improved comprehension and scientific competence when embedded in sound instructional design; guided inquiry was particularly effective.	Clarifies that pedagogy mediates technology effects.
Jack & Shidawa (2025)	Jalingo, Taraba State	Quasi-experimental; 106 students	Virtual-laboratory group retained chemistry learning significantly better than the physical-laboratory comparison group.	Supports virtual-lab use as complementary practical preparation.
Ibrahim et al. (2025)	Kwara State	Quasi-experimental; senior secondary students	PhET-supported group showed stronger post-test performance than the conventional control group.	Supports interactive simulation for conceptual learning.
Nnoli & Muogbo (2025)	Awka Education Zone, Anambra State	Survey; 20 teachers + 130 students	Respondents perceived ICT as improving chemistry teaching/learning quality and increasing interest.	Direct South-East evidence on acceptance and perceived value.
Na'Allah (2026)	Nigeria	Survey; 86 chemistry teachers	Teachers reported highly positive perceptions but only moderate digital competence; connectivity, devices, electricity and training were major barriers.	Recent evidence on continuing implementation constraints.
Ahmad et al. (2023)	International; high-school chemistry	Systematic review and meta-analysis; 35 pedagogical approaches	Innovative pedagogies generally improved learning relative to traditional control conditions, with variation by instructional method.	Establishes that pedagogy itself is a major determinant of chemistry achievement.

Study	Context	Design/sample	Key evidence	Analytical contribution
Wohlfart et al. (2023)	Germany; secondary chemistry	Qualitative interviews; 10 chemistry teachers	Teachers valued subject-specific digital tools but identified time, workload, infrastructure, support and resistance to change as barriers.	Shows that teacher acceptance requires enabling school conditions.
Hamza et al. (2024)	Kwara State, Nigeria	Descriptive survey; 250 chemistry teachers	Available ICT resources were rarely utilised; utilisation differed by teacher characteristics.	Provides chemistry-specific Nigerian evidence on the implementation gap.
Chen, Xue & Yang (2024)	China; junior high chemistry	Comparative laboratory study	Virtual laboratory supported knowledge performance; hands-on laboratory retained strengths for planning and evidence collection.	Supports a blended rather than substitution model of laboratory learning.
Hu, Zhu & Bi (2024)	China; middle-school chemistry	Computer-simulation intervention	Simulation improved students' translation among chemical representations, especially macro-submicro links.	Explains how digital visualisation can support representational competence.
Yan et al. (2024)	Junior secondary chemistry	Exploratory study; Grade 9 students	Stop-motion animation supported conceptual understanding of gas-collection processes.	Illustrates targeted digital visualisation for misconceptions.
Lathwesen & Eilks (2024)	Germany; high-school chemistry	Digital escape-room intervention; 91 students	Students learned green-chemistry content and reported positive motivation and attitudes.	Shows the potential of digital game-based learning when curriculum aligned.
Ikuejube (2024)	Ondo State, Nigeria	Survey/correlational; 30 teachers and 200 students	Chemistry teachers' scientific attitudes were significantly related to students' achievement.	Highlights teacher dispositions as part of the instructional ecology.
Yoade & Ajayi (2025)	Ondo State, Nigeria; Basic Science	Descriptive survey; 72 teachers	Technological tools showed limited availability and very low utilisation.	Corroborates infrastructural and utilisation constraints in Nigerian schools.
Christopoulos et al. (2026)	International; secondary chemistry	Systematic review; immersive VR/AR studies	Immersive technologies improved conceptual understanding and engagement but faced cost, infrastructure and digital-literacy barriers.	Provides current evidence on immersive chemistry laboratories and implementation limits.

4. Findings

4.1 Comparative Evidence on Achievement, Understanding and Retention

Evidence from Nigeria's education sector shows that the effects of major interventions are attributed to findings from evaluations of research and development projects, and quasi-experimental designs. For example, Fabeku and Enyeasi (2024) used a quasi-experimental design to evaluate the impact of a workshop on computer-simulated (virtual) instruction and video-media instruction, relative to conventional instruction. Participants in the computer-simulated group outperformed the other two groups on immediate post-test. Further, the computer-simulated group outperformed the conventional group on the retention post-test. These findings add to the evidence base for the use of interactive digital media and representation to enhance teaching and learning.

Also, Jack and Shidawa (2025) used a laboratory-based design to evaluate the impact of virtual versus traditional laboratory instruction. They found that exposure to virtual laboratory instruction enhanced students' retention of the subject matter relative to the traditional laboratory instruction. Based on these results, virtual laboratories do not replace traditional laboratory instruction. Rather, virtual laboratories extend opportunities for cognitive practice and reconstruction of the subject matter.

Similar findings are seen in international secondary-level research. Stronger knowledge outcomes were reported by Fabeku and Enyeasi (2024) with the support of a virtual lab, while better performance in instructed lab inquiry was reported by Hu, Zhu and Bi (2024). Use of simulation in chemistry education has been found to nurture learners' ability to translate between different representations of chemical species (Hu, Zhu & Bi, 2024). Also, use of digital technology to facilitate chemistry education has been found to help learn to address misconceptions related to chemical phenomenon (Magnone & Yezierski, 2024). Therefore, both digital and physical technology in chemistry education promote learners' understanding of chemistry to some extent.

As reported by Obembe (2024), learners outperformed their pre-test performance post-exposure to a PhET simulation. The evidence also illustrates that certain non-digital active learning strategies help improve learners' achievement in chemistry. Benefits have been reported when the JAMA (i.e. juice as acid-base indicator) experiment was used to teach acid-base indicators (Ojo & Tijani, 2025). From the evidence base, digital technologies and active learning strategies facilitate chemistry education to some extent. Therefore, active learning may play a major role in enriching and improving students' learning in chemistry.

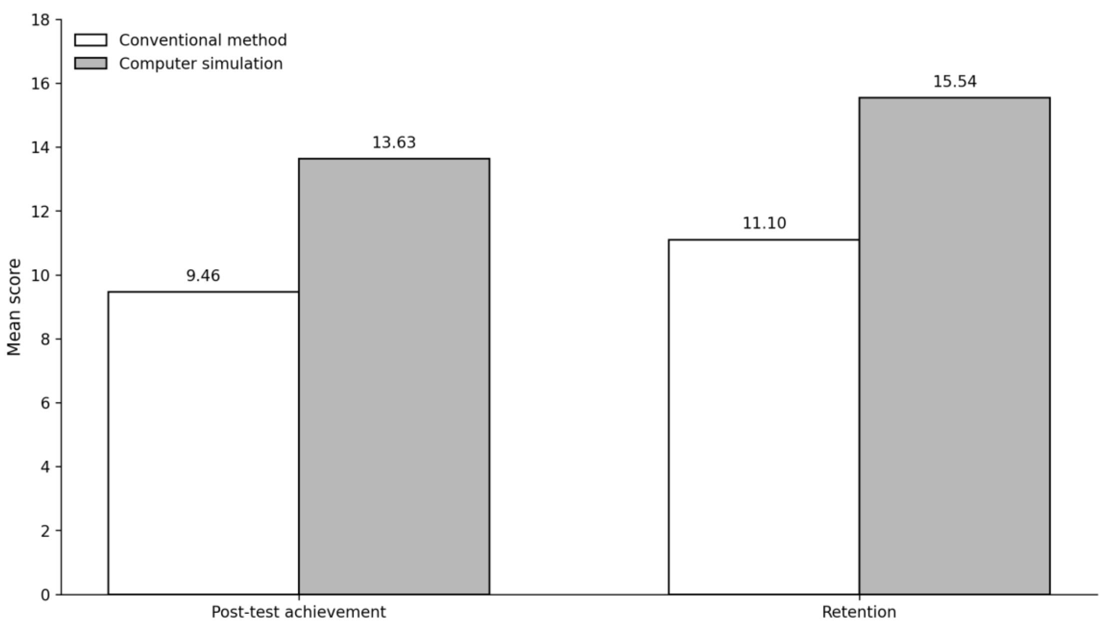

Figure 2. Mean-score comparison for computer simulation and conventional instruction.
Source: authors' visualisation based on data reported by Fabeku and Enyeasi (2024).

4.2 Engagement and Participation

Engagement is commonly cited as a benefit of digital teaching methods. However, engaging students should not be the goal of teaching. Instead, it should be seen as a means to an end. Ugah (2024) mentioned that use of the

ChemLab simulation impacted students' engagement in practical chemistry class. It is likely that the simulation helped students to get over their psychological impedance when they do not understand or are afraid to perform a laboratory activity. Similar results can be obtained using other interactive or visually engaging methods.

Other digital activities such as games and virtualfield trips can also be engaging. Lathwesen and Eilks (2024) showed that a digital chemistry escape room increased learners' interest in the subject. Rahman et al. (2024) showed that an engaging virtual chemistry classroom helped learners in understanding and interactively engaging with the concepts of chemical bonding. Engaging activities are not new to pedagogy. What is new is the value addition such activities create in furthering the learners' understanding, reasoning and applying their knowledge.

While technology is engaging, it may not always foster the desired learning outcomes. Therefore, a judicious and educable use of technology is required. Palacios, Pascual and Moreno-Mediavilla (2024) recommend that educators use digital games judiciously and integrate other pedagogies in teaching to bring about the desired learning outcomes.

4.3 Teacher Preparedness and Digital Pedagogy

The evidence indicates that teacher preparedness is a critical factor in the moderation of the effectiveness of ICT integration in schools. Regarding the digital competence of Nigerian Science teachers, Ogegbo (2023), found they had attained an intermediate level, but lacked skills on how to use technology in the Science classroom in an advanced manner. To exemplify, using a digital tool to deliver a lecture does not qualify a teacher as skilled in digital pedagogy. Effective digital pedagogy obliges teachers to understand students' Science misconceptions, make appropriate instructions to address students' interaction in the Science classroom and use their judgement to decide whether the technology has enhanced students' Science understanding.

The observation reported in the studies is in consonance with other research findings in the review sample of the Nigerian education. Hamza et al. (2024) reported on the low integration of ICT by some chemistry teachers at the Senior Secondary School level in Kwara State. Likewise, low integration of ICT by Basic Science teachers at the Primary level in Ondo State was reported by Yoade and Ajayi (2025).

With respect to the readiness level of rural secondary school teachers to incorporate AI in teaching, the results showed a relatively high level of adaptability to integrate AI in teaching. It is important to note that being adaptable to new technologies doesn't eliminate the need for adequate training, access, and supportive infrastructure. These findings indicate that integrating new technologies in training, and supporting the instructor with the required infrastructure, should be done in combination.

The results of the study of Igboanugo (2024) further revealed that among 410 chemistry teachers, the level of preparedness to integrate AI in teaching was similar for both males and females. This shows that simplifying preparedness with respect to integration of new technologies based on teacher's gender and other demographic variables, should be avoided. Positive attitudes toward integration of new technologies in teaching were reported by Na'Allah (2026) but had moderate level of competence to integrate the technologies in teaching. Ogegbo (2024) in his qualitative study reported that the attitude and competence gap is caused by inadequate integrative support, lack of required ICT infrastructure and Teaching-Learning-Resources, and inadequate TPCK of teachers.

4.4 Infrastructure, Access and Equity

Adequate infrastructure is lacking. A lesson designed to integrate technology (IIT) in chemistry depends on a stable electricity supply and functioning equipment. The lack of any of these may make the lesson ineffective. Digital activities in chemistry are planned to support practical activities and/or clarify students' conceptual understandings. Therefore, any disruption to the digital activities in chemistry increases cognitive load on students and may fragment the lesson.

In their literature review, Christopoulos, Mystakidis and Perikos (2026), point to high costs of education technology, deficient ICT infrastructure and varying levels of educators' technology skills as barriers to the implementation of instructional use of AR and VR in secondary level chemistry education. Na'Allah (2026), equally points out that lack of stable power and ICT infrastructure in Nigeria complicate education technology-related initiatives and adversely impact educators' professional development. For sustainability of education Technology in teaching chemistry, Guobadia and Ekuobase (2024), recommend local efforts as high-income countries do. These include installations of renewable energy sources, improvement in ICT infrastructure, and educators' professional development.

In view of inequities in access to the Internet and ICT in Nigeria, UNESCO (2023) recommends school-level strategies, and initiatives to lessen the adverse effect of lacking Internet in students' homes. ICT integrated teachings of chemistry may further widen inequities if educators' assume students have sufficient means and resources at home.

South-East Nigeria should not use the lack of optimal ICT infrastructure in schools to postpone using ICTs in learning. There are numerous solutions that can be integrated with available ICT to enhance teaching and learning. Use of equipment with offline simulations,shared equipment, projectors, local servers, and other solutions can be more effective than relying on broadband connectivity.

4.5 Overall Comparative Synthesis

Table 2. Comparative synthesis of traditional and ICT-enhanced chemistry teaching

Dimension	Traditional teaching	ICT-enhanced teaching	Evidence-based interpretation
Concept explanation	Strong for structured sequencing, worked examples and teacher clarification.	Strong where dynamic visualisation helps represent particles, molecular interactions and abstract processes.	Use conventional explanation to orient learners, then ICT to visualise and test ideas.
Achievement	Can be effective when active and well scaffolded; passive lecture is less consistently effective.	Recent Nigerian quasi-experiments generally report higher post-test performance under simulation-based conditions.	Evidence favours ICT-supported active learning, not technology in isolation.
Retention	Depends on retrieval practice, application and revisiting content.	Virtual laboratories and simulations can support repeated practice and improved retention.	Combine digital rehearsal with teacher questioning and later retrieval.
Engagement	Highly dependent on teacher interaction and task design.	Often higher because of interactivity, novelty and visible cause-effect relationships.	Engagement should be converted into prediction, explanation and problem solving.
Practical learning	Authentic manipulation and laboratory routines remain strengths of physical work.	Useful for pre-lab preparation, repeated procedures, inaccessible or risky experiments.	Use virtual and physical laboratories complementarily where possible.
Cost and infrastructure	Low digital dependence; feasible in resource-constrained classrooms.	Requires devices, power, maintenance and technical support.	Adopt low-bandwidth/offline tools and staged infrastructure investment.
Teacher capacity	Relies on subject knowledge, explanation and classroom management.	Adds need for digital pedagogical competence and technical confidence.	Professional development should integrate chemistry pedagogy with tool use.

Dimension	Traditional teaching	ICT-enhanced teaching	Evidence-based interpretation
Equity	Can be delivered with minimal technology but may still reflect laboratory/resource inequality.	Can either widen or narrow inequality depending on school and home access.	Prioritise school-based access and avoid mandatory home connectivity assumptions.

5. Discussion

Simulations and virtual laboratories have the potential to improve Chemistry education in Nigeria and should be adopted (Fabeku and Enyeasi, 2024; Jack and Shidawa, 2025; Ibrahim, Bolaji and Oyeyemi, 2025). Improvement of Chemistry education should be the focal point of activities, and the use of ICT in education should be strategic. Improvement in Chemistry Education has been attained in several Nigerian schools through various low cost, simple strategies (Ojo and Tijani, 2025).

One of the key lessons from effective ICT integration in education is that improvement associated with ICT in education should be attributed to the strategies and activities adopted and not to the ICT in isolation (Agwu and Nmadu, 2023).

Constructivism provides a framework for understanding a key element of good ICT integration. Symbol manipulation and testing of hypotheses are fundamental to learning chemistry and other science disciplines. However, a cautionary note is provided by Cognitive Load Theory. It is possible for learning to be disrupted if a computer simulation contains extraneous details which exceed the learner's working memory. In such cases, a teacher is justified in facilitating learners in engaging with the digital content in a way that achieves the desired learning objective.

There is evidence in the review that suggests the belief that sufficient computers in the classroom is the major barrier to technology integration is misplaced. Other barriers, like the competence of teaching personnel, remain. While devices integrated into teaching and learning are desirable, it is more valuable to have a smaller number of integrated learning resources coupled with professional development of teaching personnel and teaching resources. There is value in training personnel. Some researchers point to positive perceptions of both teachers and students, e.g. in Awka, as being more indicative of the general state of the education system rather than direct outcomes of teaching and learning.

There are hints on what sequencing of reforms should entail for South-East Nigeria. A rapid swap to full modern-style schooling is not required. Rather, mechanisms should be put in place to transform didactic instruction step by step to a more constructive and interactive approach (and where appropriate, to integrate the use of ICT in Chemistry). This should be cost effective. A school need not invest in multimedia resources for every single chemistry lesson. Prioritising the production of digital content for lessons on atomic and molecular levels, stoichiometry and chemical equilibrium, for example, would be an improvement over the current teaching of chemistry.

Reforms should also focus on access and equity. The development of ICT infrastructure may create wider equity gaps if online content remains inaccessible to a large part of the school population. For school-based reforms, off-site ICT infrastructure should be utilised to ensure equity.

There are multiple virtual environments that can be as dangerous and unsolvable as the real world. Therefore, for the majority of the cases, students should first work through simulated environments and only do the related practical work if the resources are available. At the end, students should reflect on and analyse the results digitally.

6. Policy and Practice Suggestions for South-East Nigeria

Amongst all suggestions, the most important is for educational systems to adopt a 'pedagogy-first' attitude to the integration of digital technology. This means that ministries of education and school administrators ought to first define the chemistry of teaching and learning of a specific topic, and then search for and/or develop appropriate digital technology to address the chemistry.

Preparation of teachers to integrate ICT in the classroom and educational administration is of high priority. In addition to being computer-literate, the teachers should be equipped with knowledge and skills on how to effectively integrate Information and Communication Technology (ICT) in classroom teaching. Educational administrators also need similar skills and knowledge.

Improving educational infrastructure is best served by prioritizing reliable electricity for power and uninterrupted access to digital teaching and learning materials. Teaching and learning digital materials should be accessible in the absence of electricity. Equity should be ensured by prioritizing in-person teaching. Off-site teaching should be supplemented by ICTs and educational resources including digital educational and training simulators. Education authorities should base their choice of ICTs on evidence of their impact on improving the main educational outcomes.

7. Limitations and Opportunities for Future Research

Differences in the characteristics of available evidence make generalisation challenging. Geographical differences and heterogeneity in the evidence meant that studies from other areas of Nigeria were used to corroborate learning effects and extend the findings. Although studies from various areas of Nigeria were analytically useful, it does not eliminate the need to conduct studies in the region of interest. Several studies, using various interventions, were identified. As a result, a single overall effect size could not be determined.

Studies should primarily focus on the states in the Southeastern region of Nigeria and utilise adequate design clusters to accomplish reasonable statistically powered studies. Effect sizes and equivalence tests should be reported. To what extent do teachers influence the effects of ICT as compared to other factors? What are the effects of ICT on student learning in the long term? How do integrated ICTs compare to traditional ICTs and vice versa? The cost-effectiveness of integrated ICTs should be evaluated.

8. Conclusion

Findings from several studies indicate the potential of integrated ICTs in Chemistry education in Nigerian Senior Secondary Schools. Virtual Chemistry laboratories and other ICTs improve students' achievement in Chemistry and enhance students' representation in Chemistry. Other studies have shown that the application of ICTs for Chemistry education has the potential to promote students' achievement. However, several factors should be considered when utilising ICTs. Among these factors are the experience of the teacher and the stability of the ICTs and the related infrastructure.

Considering South-East Nigeria, I suggest an integrated approach. Teaching chemistry in South-East Nigeria can be improved by a judicious integration of digital tools. However, teachers need to be trained, and the education infrastructure needs to be strengthened. If these are done, ICTs have the potential to not only increase the number of chemistry teachers, but also improve the quality of chemistry teaching in South-East Nigeria. Otherwise, new ICTs can potentially widen the digital divide in education.

9. Statement of Ethical Consideration and Data Availability

9.1 Ethical Consideration

This study combines data and information published in peer-reviewed and/or governmental journals and reports. It does not contain primary data or information, and it does not include intervention or research initiatives. Therefore, it did not require the consent of research participants and/or approval of an ethical review board.

9.2 Data Availability

This study does not include new data or information, and the supporting data and information in this study are published and easily accessible. The illustrations and tables in this article are original.

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