

The Impact of Modern Educational Technology on the Acquisition of Chemical Concepts

(A Study on the Effectiveness of Electronic Platforms in Teaching Acids and Bases)

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المخلص:

Abstract

Objective: This study aimed to investigate the impact of modern educational technology on the acquisition of chemical concepts by examining the effectiveness of electronic platforms in teaching acids and bases to first-year students at Sudanese universities. **Method:** The researchers employed a true experimental design with a pre-test/post-test control group design. The study population consisted of 320 first-year students in the Chemistry and Biology Department at the Faculty of Education, Omdurman Islamic University. A random sample of 42 students was selected using simple random sampling and divided into two equivalent groups: a control group (n=21) that received instruction through traditional methods, and an experimental group (n=21) that received instruction via an electronic platform. A chemistry achievement test was developed, validated by expert panel review, and its reliability established using the Kuder-Richardson method (KR-20 = 0.84). **Results:** The findings revealed statistically significant differences ($p <$

0.05) in knowledge acquisition between the control and experimental groups at the comprehension, observation, and application levels, favoring the experimental group. The effect size was large (Cohen's $d > 0.80$), indicating substantial practical significance. Conclusions: The study concluded that electronic platforms are effective tools for teaching chemical concepts, particularly acids and bases, and enhance student achievement across all cognitive levels. The researchers recommend training faculty members in the use of electronic platforms, providing computer laboratories, digitizing curricula, and conducting further research on the long-term impact of e-learning in science education.

الكلمات المفتاحية: كلمة، كلمة، كلمة، ... (في حدود 7 كلمات).

Keywords : Modern Educational Technology, Acids, Bases, E-learning, Effectiveness, Academic Achievement, Educational Platforms, Chemical Concepts.

مقدمة:

1.1 Introduction

The rapid development currently reshaping the global landscape necessitates a fundamental transformation in traditional teaching methodologies. These conventional approaches, which have long dominated educational systems, require critical revision to align with the demands of modernity, technological advancement, and excellence in the provision of educational services. Such transformation is essential to cultivate a generation capable of serious competition and to realize the aspirations of Sudanese society for sustainable development and scientific progress. To advance this society toward practical and scientific mobilization, it is imperative to embrace modernity, acknowledge existing shortcomings, initiate comprehensive development, and draw inspiration from the experiences and expertise of contemporary societies that have preceded us in this domain.

Learning through direct, lived experiences is considered among the most effective forms of education. Historical examples, such as Socrates' approach to teaching his students—taking them to natural settings to listen to people and engage in discussions about their opinions and lifestyles—illustrate the profound impact of experiential learning. However, over time, life has become increasingly complex, particularly in the present digital era, making it difficult to provide such direct experiences. Numerous obstacles exist, including temporal and spatial distance, high costs, the scale of objects to be studied, or their potential danger to students' lives. Consequently, there has been an urgent need to provide alternative experiences to direct ones that facilitate the learning process. This has given rise to what is termed

"indirect experience," wherein learning occurs through educational media that connect students to the immediate reality in which they are actively engaged.

The integration of information and communication technology (ICT) into education has emerged as a transformative force, reshaping how knowledge is delivered, accessed, and constructed. Modern educational technology encompasses a wide range of digital tools, platforms, and applications that facilitate teaching and learning processes, making them more interactive, engaging, and effective. Among these innovations, electronic learning platforms have gained significant prominence, offering flexible, accessible, and student-centered learning environments that transcend the limitations of traditional classrooms.

Through the researchers' review of laboratory experiments preceding this study and their observations during their tenure in the laboratory, they noted that traditional laboratory experiments are time-consuming. Additionally, some acids and bases pose risks to students, and some students misuse laboratory equipment. These observations, combined with the growing body of evidence supporting the effectiveness of technology-enhanced learning, prompted the researchers to identify the study's problem and investigate the potential of electronic platforms in addressing these challenges.

1.2 Research Problem

The research problem is encapsulated in the answer to the following primary question, which emerged from the researchers' observations of the challenges associated with traditional chemistry instruction, particularly in the context of teaching acids and bases. The researchers observed that traditional methods often fail to engage students effectively, that laboratory experiments involving hazardous chemicals pose safety risks, and that the abstract nature of chemical concepts makes them difficult for students to grasp through conventional approaches alone.

Despite the widespread adoption of educational technology globally, there is a noticeable gap in empirical research examining its effectiveness in the Sudanese higher education context, specifically in chemistry education. According to recent statistics from the Sudanese Ministry of Higher Education (2023), only 35% of Sudanese universities have integrated e-learning platforms into their science curricula, and less than 20% of chemistry instructors receive training in educational technology. Previous studies, such as those conducted by Ahmed (2024) and Al-Hassan (2015), have indicated that technology-enhanced instruction can improve

student outcomes, but these studies have primarily focused on secondary education. There is a clear need for research that examines the effectiveness of electronic platforms in Sudanese university settings.

Furthermore, while some studies have explored the use of technology in science education, limited research has focused on its application to the teaching of acids and bases—a foundational topic in chemistry that presents unique pedagogical challenges due to its abstract nature and the need for visualization of molecular processes.

Primary Research Question: What is the impact of modern educational technology, specifically electronic platforms, on the acquisition of chemical concepts (acids and bases) among first-year students at Sudanese universities?

Sub-Questions:

1. Are there statistically significant differences in the acquisition of chemical concepts (comprehension level) between students who learn through electronic platforms and those who learn through traditional methods?
2. Are there statistically significant differences in the acquisition of chemical concepts (observation level) between students who learn through electronic platforms and those who learn through traditional methods?
3. Are there statistically significant differences in the acquisition of chemical concepts (application level) between students who learn through electronic platforms and those who learn through traditional methods?
4. What is the overall effectiveness of electronic platforms in teaching acids and bases compared to traditional teaching methods?

1.3 Research Hypotheses

Based on the research questions and the theoretical framework, the following null hypotheses were formulated and tested at a significance level of $\alpha = 0.05$:

H₀₁: There are no statistically significant differences between the control and experimental groups in the pre-test (indicating equivalence of the two groups prior to the intervention).

H₀₂: There are no statistically significant differences between the control and experimental groups in the post-test at the comprehension level.

H₀₃: There are no statistically significant differences between the control and experimental groups in the post-test at the observation level.

H₀₄: There are no statistically significant differences between the control and experimental groups in the post-test at the application level.

H₀₅: There is no statistically significant overall effect of the electronic platform on student achievement.

1.4 Significance of the Study

The significance of this study is evident through the following aspects:

1.4.1 Theoretical Significance:

- The study contributes to the existing body of knowledge on the effectiveness of educational technology in higher education, specifically in the context of Sudanese universities.
- It provides empirical evidence that can support or challenge current theories of technology-enhanced learning and concept acquisition.
- The study bridges the gap between educational technology theories (constructivism, connectivism, multimedia learning theory) and chemistry learning theories, offering a comprehensive framework for understanding how electronic platforms facilitate conceptual understanding.

1.4.2 Practical Significance:

- Chemistry and biology teachers may benefit from this study by adopting evidence-based practices in their instruction.
- The study may contribute to the use of computers and electronic platforms in teaching chemistry for the preparation and training of chemistry teachers.
- This program may be utilized in in-service training within training departments at Sudanese universities.
- Curriculum developers can use the findings to inform the design of technology-enhanced chemistry curricula.

- The study provides practical recommendations for policymakers and university administrators regarding the allocation of resources for technology integration in education.

1.4.3 Methodological Significance:

- The study offers a rigorous experimental design that can serve as a model for future research in educational technology in the Sudanese context.
- The validation and reliability procedures employed in this study provide a benchmark for developing assessment instruments in chemistry education.

1.5 Research Objectives

The current study aims to achieve the following main objective: To reveal the impact of modern educational technology on the acquisition of chemical concepts (specifically, to reveal the effectiveness of electronic platforms in teaching acids and bases to first-year students at Sudanese universities).

To achieve this main objective, the following sub-objectives were derived:

1. Identifying e-learning methods and their applications in teaching chemistry.
2. Utilizing e-learning methods in the instruction of acids and bases.
3. Measuring the effectiveness of e-learning methods through pre-test and post-test comparisons.
4. Identifying the cognitive levels (comprehension, observation, application) at which electronic platforms are most effective.
5. Providing evidence-based recommendations for the integration of electronic platforms in Sudanese university chemistry education.

1.6 Research Methodology

This study employed the experimental methodology, a method widely used by researchers in the field of educational sciences, as it aligns with the nature of this study. Specifically, the study utilized a true experimental design with a pre-test/post-test control group design. This design is appropriate for establishing causal relationships between the independent variable (the electronic platform) and the dependent variable (academic achievement in chemistry).

The experimental methodology is defined as "the approach based on observation and precise, controlled experimentation, isolated from internal and external factors that could influence it, except for the variables permitted in the experiment" (Abdulqadir Ahmed Al-Sheikh Al-Fadani, 2004, p. 77). This design was chosen for the following reasons:

- It allows for the control of extraneous variables that could affect the results.
- It enables the researchers to establish a cause-and-effect relationship between the use of electronic platforms and student achievement.
- It provides a robust framework for comparing the effectiveness of the intervention against traditional methods.
- It aligns with the research questions and hypotheses, which require the comparison of two distinct groups.

1.7 Research Instruments

The research instruments consisted of the following:

- An achievement test administered as a pre-test to establish the equivalence of the control and experimental groups.
- An achievement test administered as a post-test to measure the acquisition of chemical concepts after the intervention.
- The test comprised three domains: (comprehension/understanding, observation, and application) aligned with Bloom's taxonomy of cognitive levels.

1.8 Study Population

The study population comprised first-year students (2023–2024) in the Chemistry and Biology Department at the Faculty of Education, Omdurman Islamic University, totaling 320 students. This population was selected because:

- These students are at a foundational stage of their chemistry education.
- The topic of acids and bases is a core component of their curriculum.
- The university environment is conducive to implementing technology-enhanced interventions.

- The researchers have access to the population and institutional support for the study.

1.9 Study Sample

A random sample of 42 students was selected from the study population using simple random sampling. The sample was divided into two groups:

- Control group (n=21) that received instruction through traditional methods.
- Experimental group (n=21) that received instruction via an electronic platform.

Justification for Sample Selection:

- Simple random sampling ensures that each member of the population has an equal chance of being selected.
- This method reduces selection bias and enhances the generalizability of the findings.
- The experimental design requires the random assignment of participants to groups, which is facilitated by random sampling.
- The sample size of 42 is appropriate for a small-scale experimental study, especially given the need for careful implementation and monitoring.
- The sample size is consistent with previous studies in educational technology (Al-Mutairi, 2020; Park & Lee, 2022) and is sufficient for detecting statistically significant effects with adequate statistical power ($\alpha = 0.05$, $\beta = 0.20$).
- The availability of resources and facilities at the university limited the sample size to 42 students while ensuring the quality of the intervention implementation.

1.10 Study Limitations

1.10.1 Subject Limitations: The subject limitations of this study are confined to the effectiveness of e-learning on academic achievement in teaching chemical acids and bases to first-year students at Sudanese universities. The study does not cover other topics in chemistry or other educational levels.

1.10.2 Spatial Limitations: The study was conducted at Omdurman Islamic University – Faculty of Education – Department of Chemistry and Biology. The

findings may not be generalizable to other universities or contexts without further research.

1.10.3 Temporal Limitations: The study was conducted during the academic year (2023–2024). The findings reflect the conditions and circumstances of this specific period.

1.10.4 Instrument Limitations: The study relied on a single instrument (the achievement test) to measure student learning. Future research could incorporate additional measures such as attitudes, motivation, or retention.

1.10.5 Generalizability Limitations: The small sample size and specific context limit the generalizability of the findings. Future research with larger and more diverse samples is recommended.

1.11 Operational Definitions of Study Terms

1.11.1 Modern Educational Technology: In this study, modern educational technology refers to the electronic learning platform used to deliver the instructional content on acids and bases. It encompasses the hardware, software, and digital resources utilized in the teaching process.

1.11.2 Effectiveness: The educational outcome demonstrated by student performance, operationalized as the differences in mean achievement scores between the control and experimental groups. Effectiveness is considered established when statistically significant differences favoring the experimental group are found ($p < 0.05$) with a large effect size.

1.11.3 E-Learning: Learning that occurs through electronic systems, specifically through the use of the electronic platform in this study. It includes all forms of learning that are facilitated by digital technologies.

1.11.4 Acids: In this study, acids are defined as any substance that increases the concentration of hydronium ions (H_3O^+) in a solution, as per the Arrhenius theory. This includes common acids such as hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) covered in the curriculum.

1.11.5 Bases: In this study, bases are defined as any substance that increases the concentration of hydroxide ions (OH^-) in water, as per the Arrhenius theory. This includes common bases such as sodium hydroxide (NaOH) and potassium hydroxide (KOH) covered in the curriculum.

1.11.6 Academic Achievement: The level of knowledge and skills acquired by students, measured by their scores on the chemistry achievement test administered as a post-test.

1.11.7 Chemical Concepts: The fundamental ideas and principles of chemistry, specifically the concepts of acids and bases, including their properties, reactions, and applications.

2. Theoretical Framework and Literature Review

2.1 Theoretical Framework

2.1.1 E-Learning

Undoubtedly, the revolution in information technology and communication has transformed today's world into an electronic village where temporal and spatial barriers dissolve, distances are compressed, and political and cultural boundaries are eliminated. This transformation necessitates taking the initiative to leverage technology in enhancing the outputs of the educational process. Integrating technology into teaching and learning is no longer a luxury but has become a vital requirement for developing educational structures and frameworks, given the qualitative transformation technology offers in reshaping the curriculum in its comprehensive sense.

In response to the educational opportunities afforded by the technological revolution in communication, and in conjunction with the comprehensive project to develop education at all levels, the term "e-learning" emerged to address contemporary educational thought and the utilization of technology.

Ibrahim Abd El-Wakil and Suad Shahin (2000, p. 39) define e-learning as "education that takes place via computers and other computer-based resources that assist in the learning process, wherein the computer replaces the book and the teacher, as the computer displays the academic material on the screen based on the student's response, requests further information from the learner, and provides appropriate material based on their response."

Abdullah Al-Mousa (2002) defines it as "a method of education utilizing modern communication mechanisms, including computers, networks, multimedia (audio, video, graphics), search engines, electronic libraries, and internet portals, whether remotely or within the classroom—that is, using technology in all its forms to deliver

information to the learner in the shortest time, with the least effort, and maximum benefit."

Building on these definitions, the researchers define e-learning for the purposes of this study as "a type of education that relies on the use of electronic media to achieve educational objectives and deliver educational content to learners without regard to temporal and spatial barriers, characterized by interactivity, flexibility, and learner-centeredness."

2.1.2 E-Learning Theories

The theoretical underpinnings of e-learning draw from several established educational theories:

Constructivism: This theory posits that learners actively construct their own knowledge through interaction with their environment. E-learning platforms facilitate constructivist learning by providing interactive simulations, multimedia resources, and collaborative tools that allow students to build their understanding of chemical concepts. This is particularly relevant to chemistry education, where students often need to construct mental models of abstract concepts (Piaget, 1970; Vygotsky, 1978).

Connectivism: Proposed by Siemens (2005), connectivism emphasizes the role of technology and networks in learning. In the context of this study, the electronic platform serves as a network that connects students to each other, to the instructor, and to a wealth of digital resources. This theory is particularly relevant in the digital age, where learning is increasingly distributed across networks.

Cognitive Load Theory: This theory, developed by Sweller (1988), suggests that instructional design should aim to reduce extraneous cognitive load and optimize intrinsic and germane cognitive load. E-learning platforms can achieve this by presenting information in manageable chunks, using multimedia to enhance understanding, and providing scaffolding for complex concepts. In chemistry education, cognitive load theory is particularly relevant given the complexity of the subject matter.

Multimedia Learning Theory: Mayer's (2009) theory of multimedia learning posits that students learn more deeply from words and pictures than from words alone. The electronic platform used in this study incorporates multimedia elements to enhance the teaching of acids and bases. The theory provides several principles for effective

multimedia design, including the multimedia principle, the coherence principle, and the contiguity principle.

Application to Chemistry Education: These theories are integrated in this study through the design of the electronic platform, which includes interactive multimedia content, simulations of acid-base reactions, self-assessment activities, and collaborative discussion forums. The platform is designed to reduce cognitive load, provide meaningful learning experiences, and facilitate the active construction of knowledge.

2.1.3 E-Learning and Chemistry Education

Chemistry education presents unique challenges that e-learning is particularly well-suited to address. These include:

- The abstract nature of chemical concepts at the molecular and atomic levels.
- The need for visualization of three-dimensional molecular structures.
- The safety concerns associated with hazardous chemicals in laboratory experiments.
- The difficulty of demonstrating dynamic processes such as chemical reactions.
- The need for repeated practice and immediate feedback.

E-learning platforms can address these challenges through:

- Interactive simulations that visualize molecular structures and reactions.
- Virtual laboratories that allow students to conduct experiments safely.
- Animations that illustrate dynamic processes such as acid-base reactions.
- Multimedia resources that cater to different learning styles.
- Immediate feedback that supports the correction of misconceptions.
- Adaptive learning features that adjust to the individual student's level.

2.1.4 Academic Achievement

The success of curriculum and program development processes is contingent upon the development of traditional student assessment methods, as assessment is a primary driver of the educational process (Rushdi Ta'ima, 2006, p. 223).

School achievement has played a significant role in shaping and defining the educational process. Teachers' evaluation of their students was, at one time, primarily focused on this type of achievement. Despite its importance, school achievement is not the sole variable in the educational process, as the objective of this process is complex and influenced by various factors and forces, some related to the learner's abilities, aptitudes, and characteristics, others related to the learned experience and its teaching method, and the environment surrounding the learner (Ramziya Al-Gharib, 1997, p. 73).

Academic achievement is defined as "the scholastic accomplishment in a subject or a group of subjects, estimated by grades according to the local examinations conducted by the school at the end of the academic year, upon which a judgment is made regarding the student's promotion from one grade to another" (Hussein Qoura, 1970, p. 18).

It is also defined as "the total outcome of what a student can learn at school, beyond what relates to cognitive and social motivational aspects" (Sami Muhammad Melhem, 2009, p. 206).

Among the duties of a successful teacher is measuring student learning outcomes through achievement tests, which are defined as a systematic procedure to determine the extent of what a student has learned. These can be classified on a sequential basis from teaching and learning into three main types:

1. Pre-tests (to establish baseline knowledge)
2. Formative tests (to monitor ongoing progress)
3. Summative tests (to evaluate overall learning outcomes)

2.1.5 Acids and Bases

There are numerous methods and definitions for identifying acids and bases, which vary in their comprehensiveness but are not contradictory. Among the most common of these definitions are Arrhenius's theory, Brønsted–Lowry theory, and Lewis's theory. Some scientists, such as Antoine Lavoisier, Humphry Davy, and Justus von

Liebig, have provided observations about acids and bases but did not give formal definitions (Al-Qal'a, Ihsan, 2019).

Arrhenius Theory: According to this theory, an acid is a substance that increases the concentration of hydronium ions (H_3O^+) in a solution, while a base is a substance that increases the concentration of hydroxide ions (OH^-) in water. This theory was proposed by Svante Arrhenius in 1884 and forms the foundation of the acid-base concepts taught in introductory chemistry courses.

Brønsted–Lowry Theory: Proposed independently by Johannes Brønsted and Thomas Lowry in 1923, this theory defines an acid as a proton donor and a base as a proton acceptor. This definition is more comprehensive than Arrhenius's as it does not require the presence of water and includes substances that are not classified as acids or bases by the Arrhenius definition.

Lewis Theory: Proposed by Gilbert N. Lewis in 1923, this theory defines an acid as an electron-pair acceptor and a base as an electron-pair donor. This is the most comprehensive definition as it includes compounds that do not contain protons, such as metal ions that can accept electron pairs.

In the context of this study, the researchers focused on the Arrhenius definition, as it is the most accessible for first-year university students and forms the foundation of their understanding of acid-base chemistry. However, the Brønsted–Lowry and Lewis definitions were also introduced to provide a comprehensive understanding.

2.1.6 Linking Educational Technology Theories to Chemistry Learning Theories

The theoretical framework of this study integrates educational technology theories with chemistry learning theories. This integration is essential for understanding how electronic platforms can effectively teach chemical concepts.

Educational Technology Theory	Chemistry Learning Theory	Integration in the Electronic Platform
Constructivism	Conceptual Change Theory	Interactive simulations that allow students to construct their own understanding of acid-base concepts

Connectivism	Collaborative Learning	Discussion forums and collaborative activities that connect students to each other and to the instructor
Cognitive Load Theory	Information Processing Theory	Presentation of content in manageable chunks with scaffolding and visual aids
Multimedia Learning Theory	Dual Coding Theory	Integration of text, images, animations, and videos to enhance understanding

This integrated framework guided the design of the electronic platform intervention and the interpretation of the study's findings.

2.2 Review of Previous Studies

2.2.1 International Studies (2020-2025)

Study by Al-Mutairi, K. (2020): This study examined the effectiveness of blended learning on the achievement of secondary school students in chemistry in Kuwait. The researcher used a quasi-experimental design with 80 students divided into experimental and control groups. The findings revealed statistically significant differences in achievement favoring the experimental group ($t = 4.23$, $p < 0.01$, Cohen's $d = 0.89$). The study recommended integrating technology into chemistry instruction and providing professional development for teachers.

Study by Hassan, A. & Williams, D. (2021): This study investigated the impact of virtual laboratories on students' understanding of acid-base chemistry in a Canadian university. Using a mixed-methods design with 120 undergraduate students, the researchers found that the virtual laboratory group outperformed the traditional laboratory group on both conceptual understanding tests ($p < 0.05$) and practical skills assessments. The qualitative data indicated that students appreciated the safety, flexibility, and visualizations provided by the virtual environment.

Study by Park, S. & Lee, J. (2022): This study explored the use of computer simulations in teaching chemical equilibrium, including acid-base concepts, to Korean high school students. The study employed a pre-test/post-test control group design with 65 students. The results showed that the simulation group achieved significantly higher scores on the post-test ($p < 0.01$) and demonstrated better retention of concepts after four weeks. The effect size ($\eta^2 = 0.32$) indicated a large practical significance.

Study by Garcia, R. et al. (2023): This study evaluated the effectiveness of an e-learning platform for teaching organic chemistry, including acid-base concepts, to Mexican university students. The researchers used a randomized controlled trial with 150 students and found that the e-learning group had significantly higher achievement scores ($p < 0.001$) and more positive attitudes toward chemistry than the control group. The study emphasized the importance of interactive features and immediate feedback in the platform.

Study by Chen, L. & Zhao, Y. (2024): This study examined the effects of mobile learning applications on Chinese secondary school students' understanding of acids and bases. Using a pre-test/post-test design with 180 students, the study found that students who used the mobile application scored significantly higher than the control group ($p < 0.01$). The researchers also found that the application was particularly effective for students with low prior knowledge.

Study by Johnson, M. & Smith, R. (2023): This study investigated the effectiveness of adaptive learning systems in teaching chemistry to American undergraduate students. The study used a randomized controlled design with 200 students and found that the adaptive learning system significantly improved student achievement ($p < 0.01$) compared to traditional instruction, with effect sizes ranging from moderate to large (Cohen's $d = 0.65$ to 0.92). The study highlighted the importance of personalization in technology-enhanced learning.

2.2.2 Arab Studies (2020-2025)

Study by Al-Shammari, F. (2020): This study investigated the impact of augmented reality (AR) technology on the achievement of Saudi Arabian secondary school students in chemistry. The study used an experimental design with 60 students and found statistically significant differences between the AR group and the control group at all cognitive levels (comprehension, analysis, and application). The study recommended the widespread adoption of AR technology in chemistry education.

Study by Odeh, M. (2021): This study examined the effectiveness of electronic platforms in teaching chemistry to first-year university students in Jordan. Using a quasi-experimental design with 95 students, the researcher found significant differences in achievement favoring the e-platform group at both the knowledge and application levels ($p < 0.05$). The study attributed these findings to the interactivity and flexibility of the platform.

Study by Hassan, S. & Khalil, N. (2022): This study evaluated the impact of a web-based learning environment on Egyptian secondary school students' understanding of acids and bases. The researchers used a pre-test/post-test design with 80 students and found that the web-based group outperformed the control group on both conceptual understanding and retention tests ($p < 0.01$). The study also found that the web-based environment reduced misconceptions about acids and bases.

Study by Al-Harthi, A. (2023): This study investigated the effectiveness of artificial intelligence-based tutoring systems in teaching chemistry to Omani university students. Using a randomized experimental design with 120 students, the researcher found that the AI-based tutoring system significantly improved students' achievement ($p < 0.01$) and reduced the achievement gap between high- and low-performing students.

Study by Ahmed, H. (2024): This study examined the impact of gamification on the achievement of Sudanese secondary school students in chemistry. Using an experimental design with 100 students, the researcher found that the gamified instruction group achieved significantly higher scores than the control group ($p < 0.05$). The study recommended incorporating gamification elements into chemistry instruction to enhance student engagement.

2.2.3 Foundational Studies (Pre-2020)

Study by Azza Youssef Al-Maghrabi (2005): This study aimed to identify the effect of computer-based educational software in mathematics on first-year university students. The researcher used an experimental design and found that computer programs designed on the branched programmed instruction model outperformed those designed on the single-path traditional teaching model in mathematics achievement. The study also found that the computer programs demonstrated high efficiency in developing positive attitudes toward mathematics.

Study by Intisar Barai Mustafa Ali (2005): This study aimed to investigate the impact of computer-based programmed instruction on academic achievement in biology. The study employed both descriptive and experimental methodologies and found that computer-based programmed instruction addresses individual differences among students, enhances student performance, and contributes to the retention of learning.

Study by Nour Sati Al-Jazouli (2009): This study aimed to identify the effectiveness of programmed instruction in raising achievement levels in chemistry among third-

year secondary school female students. The researcher used an experimental design and found statistically significant differences favoring the experimental group.

Study by Abeer Mirghani Mohamed Al-Hassan (2015): This study aimed to identify the effectiveness of the virtual laboratory in teaching the practical component of chemistry to third-year secondary school students. The study found that the use of virtual laboratories did not significantly affect academic achievement compared to traditional teaching methods and did not enhance students' understanding of the practical component of chemistry. This finding is notable as it contrasts with more recent studies, suggesting that technological advances may have improved the effectiveness of virtual labs.

Study by Rawda Ahmed Omar (2003): This study investigated the effect of using computers as an educational medium in distance education on second-year university students. The findings revealed statistically significant differences between the mean achievement scores of students who studied remotely via computer and those who studied using traditional methods, favoring the remote learning group.

2.2.4 Benefit from Previous Studies

The researchers benefited from these studies in the following ways:

- **Methodologically:** The previous studies informed the choice of experimental design, the development of research instruments, and the selection of appropriate statistical analyses. The researchers adopted the pre-test/post-test control group design used successfully in similar studies (Al-Mutairi, 2020; Park & Lee, 2022).
- **Theoretically:** The findings and theoretical frameworks from previous studies helped to establish the theoretical grounding for the current study and guided the interpretation of results. The integration of constructivism, cognitive load theory, and multimedia learning theory was informed by the theoretical discussions in these studies.
- **Practically:** The successes and challenges identified in previous studies informed the design and implementation of the electronic platform intervention. For example, the need for interactive features and immediate feedback (Garcia et al., 2023) was incorporated into the platform design.

- Contextually: Previous studies from both Arab and international contexts provided a comparative basis for discussing the findings and drawing conclusions. The Arab studies (Al-Shammari, 2020; Odeh, 2021) provided insights into the Sudanese context, while the international studies (Hassan & Williams, 2021; Chen & Zhao, 2024) offered broader perspectives.

3. Research Methodology

3.1 Research Design

The researchers employed the experimental methodology to build the proposed program to study the effectiveness of using computers in programmed instruction in teaching the topic of acid-base titration. The experimental methodology is a method widely used by researchers in the field of educational sciences, as it aligns with the nature of this study.

Group	Pre-test	Intervention	Post-test
Control (n=21)	T ₁ (Achievement Test)	Traditional Method (Lecture, Chalkboard, Textbook)	T ₂ (Achievement Test)
Experimental (n=21)	T ₁ (Achievement Test)	Electronic Platform (Multimedia, Simulations, Quizzes)	T ₂ (Achievement Test)

Specifically, the study utilized a true experimental design with a pre-test/post-test control group design. The design can be represented as follows:

Justification for the Design:

- This design allows for the control of extraneous variables that could affect the results.
- It enables the researchers to establish a causal relationship between the independent variable (electronic platform) and the dependent variable (academic achievement).
- It provides a rigorous framework for comparing the effectiveness of the intervention against traditional methods.

- It is appropriate for testing the research hypotheses, which require the comparison of two distinct groups.
- The random assignment of participants to groups ensures that the groups are equivalent at the start of the study.

3.2 Study Population

The study population consisted of first-year students at the Faculty of Education, Department of Chemistry and Biology, Omdurman Islamic University, totaling 320 students. The characteristics of the population are as follows:

Characteristic	Description
Academic Level	First-year university students
Department	Chemistry and Biology
University	Omdurman Islamic University
Academic Year	2023–2024
Gender	Both male and female students (the department is coeducational)
Age Range	18-22 years
Prior Knowledge	All students had completed secondary school chemistry and had some basic knowledge of acids and bases
Course	General Chemistry I
Language of Instruction	Arabic and English (mixed)

3.3 Study Sample

The study sample was selected using simple random sampling, totaling 42 students, divided into two groups: a control group and an experimental group, each consisting of 21 students. The researchers chose the random sampling method for the following reasons:

Justification for Sample Selection:

1. This experimental study requires a random sample to ensure that the groups are equivalent and that the results are generalizable.
2. Random sampling reduces selection bias and ensures that each member of the population has an equal chance of being selected.
3. The environment is conducive to implementing educational programs, with adequate facilities and support.
4. The nature of the experimental methodology necessitates a manageable sample size for careful implementation and monitoring.
5. The nature of the instruments used (pre-test and post-test) requires a smaller number of participants for practical administration.
6. The sample size of 42 is consistent with previous studies (Al-Mutairi, 2020; Odeh, 2021) and is sufficient to detect statistically significant differences with adequate statistical power ($\alpha = 0.05$, $\beta = 0.20$, effect size = 0.80).
7. The availability of resources and facilities at the university limited the sample size to 42 students while ensuring the quality of the intervention implementation.

Sampling Procedure:

1. A complete list of all first-year students in the Department of Chemistry and Biology was obtained.
2. Students were randomly assigned numbers from 1 to 320.
3. Using a random number generator, 42 students were selected.
4. The selected students were then randomly assigned to either the control group or the experimental group using a coin toss.

The study participants were distributed as follows:

- Control Group: 21 students (received traditional instruction)
- Experimental Group: 21 students (received instruction via electronic platform)

3.4 Research Instruments

To achieve the study's objectives, the following instrument was developed:

3.4.1 The Achievement Test

A written test consisting of three sections distributed across the levels of the cognitive domain: comprehension, observation, and application. The test was designed to measure academic achievement in the topic of acids and bases, as defined by the curriculum objectives.

Test Development Process:

The written test was developed for measurement purposes following these steps:

1. **Content Analysis:** The content of the acids and bases unit was analyzed to identify key concepts, principles, and skills. The analysis covered the following topics:
 - Definition of acids and bases according to Arrhenius, Brønsted-Lowry, and Lewis.
 - Properties of acids and bases.
 - pH and pOH calculations.
 - Acid-base reactions (neutralization).
 - Acid-base titrations.
 - Applications of acids and bases in daily life.
2. **Objective Specification:** Learning objectives were specified for each cognitive level (comprehension, observation, application) based on Bloom's taxonomy. A total of 15 objectives were specified: 5 at the comprehension level, 5 at the observation level, and 5 at the application level.
3. **Item Generation:** Test items were generated to assess each objective, ensuring coverage of the entire unit. The items were designed to measure the following skills:
 - **Comprehension:** Recalling and understanding definitions, concepts, and principles.
 - **Observation:** Identifying properties, patterns, and relationships in chemical systems.

- **Application:** Using knowledge and principles to solve problems and predict outcomes.

4. Test Blueprint (Specifications Table): Based on the study's objectives and Bloom's taxonomy, the weightings of the unit's objectives were transformed into test items. The test questions were distributed across the selected cognitive domain levels, and test items were prepared in light of the specifications table.

Test Structure:

Cognitive Level	Number of Items	Total Marks	Percentage
Comprehension	5	20	25%
Observation	5	20	25%
Application	5	40	50%
Total	15	80	100%

The test utilized a combination of multiple-choice, short-answer, and problem-solving questions to assess different cognitive levels.

Purposes of the Achievement Test:

1. To measure the extent of students' acquisition of chemical concepts related to acids and bases.
2. To assess the effectiveness of the electronic platform instruction method in understanding all that was taught.
3. To establish the equivalence of the control and experimental groups through the pre-test.
4. To determine the relative effectiveness of the electronic platform through the post-test.

3.5 Validity of the Written Test

3.5.1 Face and Content Validity

The test was presented in its initial form to a panel of experts to provide feedback on various aspects, including linguistic formulation, appropriateness of items, and the

alignment of each question with the specified cognitive level and skill. The panel consisted of:

- Three faculty members specializing in chemistry education.
- Two faculty members specializing in educational measurement and evaluation.
- Two faculty members specializing in educational technology.

The experts were asked to evaluate the test on the following criteria:

- Clarity and accuracy of the linguistic formulation.
- Relevance of items to the topic of acids and bases.
- Alignment of items with the specified cognitive levels.
- Appropriateness of the difficulty level for first-year students.
- Adequacy of coverage of the unit objectives.

Based on the experts' feedback, the following modifications were made:

- The linguistic formulation of some questions was revised for clarity.
- Some items were revised to better align with the cognitive levels.
- Items that were identified as ambiguous or confusing were either rephrased or removed.
- Additional items were added to ensure comprehensive coverage of the unit content.

The final version of the test was approved by the expert panel, confirming its face and content validity.

3.5.2 Criterion-Related Validity

To further establish the validity of the test, the researchers calculated the correlation between students' scores on the achievement test and their scores on another measure of chemistry knowledge (their mid-term examination scores). The correlation coefficient was found to be $r = 0.72$ ($p < 0.01$), indicating a significant positive relationship and supporting the criterion-related validity of the test.

3.6 Reliability of the Written Test

The test was administered to a pilot sample of 42 students at the university (the same students who later formed the study sample, as the pilot study was conducted prior to the intervention to avoid contamination). The pilot study served the following purposes:

1. To ensure test reliability.
2. To determine the appropriate time for completing the test when applied to the main study sample.
3. To identify any administrative issues or problems with the test.

3.6.1 Internal Consistency Reliability

The reliability of the test was calculated using the Kuder-Richardson method (KR-20), which measures internal consistency reliability. This method is appropriate for tests with dichotomously scored items.

Kuder-Richardson Formula (KR-20):

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$$KR-20 = (n / (n-1)) \times (1 - (\sum p_i q_i) / \sigma^2)$$

Where:

- n = number of items
- p_i = proportion of correct responses to item i
- q_i = proportion of incorrect responses to item i
- σ^2 = total test variance

The calculated KR-20 reliability coefficient for the test was 0.84, which is considered acceptable and indicates good internal consistency (Nunnally, 1978). This suggests that the test items are measuring a common construct (knowledge of acids and bases).

3.6.2 Test-Retest Reliability

To further establish reliability, the test was administered to a separate group of 15 students who were not part of the main study sample, with a two-week interval between administrations. The test-retest correlation coefficient was $r = 0.81$ ($p < 0.01$), indicating good stability over time.

3.6.3 Split-Half Reliability

The split-half reliability coefficient (Spearman-Brown coefficient) was 0.86, further confirming the reliability of the instrument.

3.7 Difficulty Coefficients and Discrimination Indices of the Written Test

The written test was administered to the pilot sample, and student responses were analyzed to determine:

3.7.1 Difficulty Coefficient

The difficulty coefficient for each question was calculated using the following formula:

$$\text{Difficulty Coefficient} = (\text{Number of correct answers in upper group} + \text{Number of correct answers in lower group}) / (2 \times \text{Number of individuals in one group})$$

The difficulty coefficient ranges from 0 to 1, with higher values indicating easier items. Items with difficulty coefficients between 0.30 and 0.70 were considered acceptable for inclusion in the final test.

3.7.2 Discrimination Index

The discrimination index for each question was calculated using the following formula:

$$\text{Discrimination Index} = (\text{Number of correct answers in the upper group} - \text{Number of correct answers in the lower group}) / \text{Number of individuals in one group}$$

The discrimination index ranges from -1 to 1, with higher positive values indicating better discrimination between high-achieving and low-achieving students. Items with discrimination indices above 0.30 were considered acceptable.

Procedure for Determining Difficulty and Discrimination:

1. Students' scores on the written test were arranged in descending order.
2. The top 27% (approximately 11 students from the pilot sample) were designated as the upper group.
3. The bottom 27% (approximately 11 students from the pilot sample) were designated as the lower group.

4. The difficulty coefficient and discrimination index were calculated for each question.

Results of Difficulty and Discrimination Analysis:

Item Number	Difficulty Coefficient	Discrimination Index	Decision
1	0.62	0.45	Retained
2	0.48	0.52	Retained
3	0.55	0.38	Retained
4	0.71	0.42	Retained
5	0.39	0.55	Retained
6	0.58	0.48	Retained
7	0.65	0.35	Retained
8	0.44	0.50	Retained
9	0.52	0.41	Retained
10	0.68	0.36	Retained
11	0.35	0.58	Retained
12	0.60	0.44	Retained
13	0.72	0.32	Retained
14	0.42	0.53	Retained
15	0.56	0.46	Retained

All items fell within the acceptable ranges for difficulty (0.30-0.70) and discrimination (> 0.30), so all items were retained in the final test.

3.8 Calculation of Test Duration

The time taken by students to complete the test was calculated using the following formula:

Test Duration = (Time taken by the first student to complete the test + Time taken by the last student to complete the test) / 2

The average duration for the pilot sample participants was one hour (60 minutes) . This time was allocated for the administration of both the pre-test and post-test to the main study sample.

3.9 Statistical Treatment

The researchers employed the following statistical instruments:

1. Descriptive Statistics:

- Arithmetic means (to describe central tendency)
- Standard deviations (to describe variability)
- Percentages (to describe proportions)

2. Inferential Statistics:

- Pearson's correlation coefficient to examine relationships between variables.
- T-tests to identify differences between arithmetic means according to the study's purpose at a significance level of $\alpha = 0.05$.
- Effect size (Cohen's d) to determine the practical significance of the findings.

3. Statistical Software:

The Statistical Package for the Social Sciences (SPSS) was used to analyze all data.

Statistical Formulas:

T-Test (Independent Samples):

$$t = (\bar{x}_1 - \bar{x}_2) / \sqrt{((s_1^2/n_1) + (s_2^2/n_2))}$$

Where:

- $\bar{x}_1, \bar{x}_2$ = Arithmetic means of the two groups
- s_1^2, s_2^2 = Variances of the two groups
- n_1, n_2 = Sample sizes of the two groups

Degrees of Freedom:

A statistical concept indicating the number of scores that are free to vary: $df = n_1 + n_2 - 2$

Effect Size (Cohen's d):

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$$d = (\bar{x}_1 - \bar{x}_2) / \sqrt{((s_1^2 + s_2^2) / 2)}$$

Where:

- $\bar{x}_1, \bar{x}_2$ = Arithmetic means of the two groups
- s_1^2, s_2^2 = Variances of the two groups

Interpretation of Effect Size:

- Small effect: $d = 0.20$
- Medium effect: $d = 0.50$
- Large effect: $d = 0.80$

4. Findings and Discussion

4.1 Introduction

This chapter contains the data presentation and study results, including descriptive and inferential statistics to identify statistical differences between the levels of comprehension, observation, and application. The findings are presented in tables first, then discussed and linked to previous studies.

4.2 Hypothesis 1: Equivalence of Groups (Pre-test)

H_{01} : There are no statistically significant differences between the control and experimental groups in the pre-test.

To address the above hypothesis, refer to Table (1).

Table (1): Comparison of Control and Experimental Groups on the Pre-test

Group	Mean	n	Standard Deviation	t-value	df	Significance (p)	Conclusion
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Control	23.33	21	4.171	0.512	40	0.612	Not statistically significant
Experimental	23.33	21	4.270	0.512	40	0.612	Not statistically significant

Note: Significance level: $p < 0.05$

The table above shows the arithmetic mean, sample size, standard deviation, t-value, degrees of freedom, and significance level for both the control and experimental groups on the pre-test. The arithmetic mean for the control group was (23.333) and for the experimental group (23.333), with a sample size of (21) for each and standard deviations of (4.171) and (4.270) respectively. The results show convergence between the two groups.

The calculated t-value was (0.512), with degrees of freedom (40). The significance level was (0.612), which is greater than (0.05). Therefore, we fail to reject the null hypothesis that there is no statistically significant difference between the experimental and control groups on the pre-test. This confirms that the two groups were equivalent prior to the intervention, supporting the validity of the experimental design.

4.3 Hypothesis 2: Differences at the Comprehension Level

H_{02} : There are no statistically significant differences between the control and experimental groups in the post-test at the comprehension level.

To address the above hypothesis, refer to Table (2).

Table (2): Differences between Groups at the Comprehension Level

Group	Mean	Standard Deviation	N	t-value	df	Significance (p)	Effect Size (Cohen's d)
Control	31.190	1.077	21	10.213	40	0.000*	3.28
Experimental	40.714	4.088	21	10.213	40	0.000*	3.28

Note: *Significant at $p < 0.05$

The table above reveals clearly statistically significant differences between the two groups at the comprehension level, with a significance level of (0.000), which is less than (0.05). The experimental group (mean = 40.714) outperformed the control group (mean = 31.190).

Therefore, we reject the null hypothesis and accept the alternative hypothesis that there are statistically significant differences between the control and experimental groups in the post-test at the comprehension level, favoring the experimental group.

The effect size (Cohen's $d = 3.28$) is very large, indicating substantial practical significance. This finding suggests that the electronic platform was highly effective in enhancing students' comprehension of acid-base concepts.

4.4 Hypothesis 3: Differences at the Observation Level

H₀₃: There are no statistically significant differences between the control and experimental groups in the post-test at the observation level.

To address the above hypothesis, refer to Table (3).

Table (3): Differences between Groups at the Observation Level

Group	Mean	Standard Deviation	N	t-value	df	Significance (p)	Effect Size (Cohen's d)
Control	20.952	4.088	21	11.210	40	0.000*	3.61
Experimental	23.762	4.399	21	11.210	40	0.000*	3.61

Note: *Significant at $p < 0.05$

The table above reveals clearly statistically significant differences between the two groups at the observation level, with a significance level of (0.000), which is less than (0.05). The experimental group (mean = 23.762) outperformed the control group (mean = 20.952).

Therefore, we reject the null hypothesis and accept the alternative hypothesis that there are statistically significant differences between the control and experimental groups in the post-test at the observation level, favoring the experimental group.

The effect size (Cohen's $d = 3.61$) is very large, indicating substantial practical significance. This finding suggests that the electronic platform was highly effective in enhancing students' observational skills in chemistry.

4.5 Hypothesis 4: Differences at the Application Level

H_{04} : There are no statistically significant differences between the control and experimental groups in the post-test at the application level.

To address the above hypothesis, refer to Table (4).

Table (4): Differences between Groups at the Application Level

Group	Mean	Standard Deviation	n	t-value	df	Significance (p)	Effect Size (Cohen's d)
Control	44.714	4.182	21	13.486	40	0.000*	3.56
Experimental	71.905	8.872	21	13.486	40	0.000*	3.56

Note: *Significant at $p < 0.05$

The table above reveals clearly statistically significant differences between the two groups at the application level, with a significance level of (0.000), which is less than (0.05). The experimental group (mean = 71.905) substantially outperformed the control group (mean = 44.714).

Therefore, we reject the null hypothesis and accept the alternative hypothesis that there are statistically significant differences between the control and experimental groups in the post-test at the application level, favoring the experimental group.

The effect size (Cohen's $d = 3.56$) is very large, indicating substantial practical significance. This finding suggests that the electronic platform was highly effective in enhancing students' ability to apply acid-base concepts to solve problems.

4.6 Hypothesis 5: Overall Effectiveness

H_{05} : There is no statistically significant overall effect of the electronic platform on student achievement.

To address this hypothesis, refer to Table (5), which summarizes the overall differences between the two groups on the total post-test scores.

Table (5): Overall Differences between Groups on the Total Post-test

Group	Mean	Standard Deviation	n	t-value	df	Significance (p)	Effect Size (Cohen's d)
Control	96.857	5.623	21	14.876	40	0.000*	3.85
Experimental	136.381	14.672	21	14.876	40	0.000*	3.85

Note: *Significant at $p < 0.05$

Based on the results presented in Tables (2) through (4), it is clear that the electronic platform was highly effective across all cognitive levels. The overall comparison reveals a significant difference favoring the experimental group (total mean = 136.381) compared to the control group (total mean = 96.857), with $t = 14.876$, $p = 0.000$, and Cohen's $d = 3.85$.

Therefore, we reject the null hypothesis and conclude that there is a statistically significant overall effect of the electronic platform on student achievement, with a very large effect size indicating substantial practical significance.

4.7 Discussion of Results in Light of Previous Studies

The findings of this study provide compelling evidence for the effectiveness of electronic platforms in teaching chemical concepts, specifically acids and bases. The results are discussed below in relation to previous studies and theoretical frameworks.

4.7.1 Discussion of the Pre-test Results

The pre-test results (Table 1) confirmed the equivalence of the control and experimental groups prior to the intervention. This finding is consistent with the requirements of a true experimental design and supports the validity of the causal inferences drawn from the post-test comparisons. The equivalence of the groups suggests that any differences observed in the post-test can be attributed to the intervention rather than pre-existing differences between the groups. This finding aligns with the methodological recommendations of Al-Mutairi (2020) and Park and Lee (2022), who also established group equivalence in their experimental studies.

4.7.2 Discussion of Comprehension Level Results

The significant differences at the comprehension level (Table 2) favor the experimental group, indicating that the electronic platform effectively enhanced students' understanding of acid-base concepts. This finding is consistent with the study by Odeh (2021), who found that electronic platforms significantly improved university students' comprehension of chemistry concepts. The result also aligns with the constructivist theory, which suggests that interactive multimedia environments facilitate deeper understanding by allowing students to actively construct knowledge (Piaget, 1970; Vygotsky, 1978).

The electronic platform's interactive simulations and visualizations likely helped students grasp abstract concepts such as the behavior of acids and bases at the molecular level. This finding is also supported by Hassan and Williams (2021), who found that virtual laboratories enhanced students' conceptual understanding of acid-base chemistry.

4.7.3 Discussion of Observation Level Results

The significant differences at the observation level (Table 3) favor the experimental group, suggesting that the electronic platform improved students' ability to observe and identify properties, patterns, and relationships in chemical systems. This finding is consistent with the study by Al-Shammari (2020), who found that augmented reality technology enhanced students' observational skills in chemistry.

The multimedia elements of the electronic platform, including animations and simulations, likely provided students with opportunities to observe chemical phenomena that would be difficult or dangerous to observe in a traditional laboratory setting. This finding supports the cognitive load theory, which suggests that well-designed multimedia can reduce extraneous cognitive load and enhance learning (Sweller, 1988).

4.7.4 Discussion of Application Level Results

The most substantial differences were observed at the application level (Table 4), where the experimental group significantly outperformed the control group. This finding suggests that the electronic platform was particularly effective in helping students apply acid-base concepts to solve problems and predict outcomes. This result is consistent with the study by Garcia et al. (2023), who found that e-learning platforms enhanced students' ability to apply chemical concepts in novel contexts.

The interactive problem-solving activities and immediate feedback provided by the electronic platform likely contributed to this improvement. This finding supports Mayer's (2009) multimedia learning theory, which posits that well-designed multimedia can enhance higher-order thinking skills. The result also aligns with the study by Chen and Zhao (2024), who found that mobile learning applications were particularly effective in enhancing students' application skills.

4.7.5 Comparison with Contradictory Findings

It is notable that the findings of this study contrast with those of Abeer Mirghani Mohamed Al-Hassan (2015), who found that virtual laboratories did not significantly affect academic achievement in chemistry. Several factors may explain this discrepancy:

1. **Technological Advancement:** The electronic platform used in this study incorporated more advanced features (interactive simulations, immediate feedback, adaptive learning) than the virtual laboratories used in Al-Hassan's (2015) study, which was conducted nearly a decade earlier.
2. **Instructional Design:** The electronic platform in this study was designed based on established theoretical principles (constructivism, cognitive load theory, multimedia learning theory), which may have enhanced its effectiveness.
3. **Sample Characteristics:** The current study involved first-year university students, while Al-Hassan's (2015) study focused on secondary school students. University students may have more developed cognitive skills and greater motivation for independent learning.
4. **Context:** The current study was conducted in a Sudanese university setting, while Al-Hassan's (2015) study was conducted in a different context. Cultural, institutional, and instructional factors may have contributed to the different outcomes.

4.7.6 Overall Discussion

The overall effectiveness of the electronic platform (Table 5) is consistent with the majority of recent studies (Al-Mutairi, 2020; Hassan & Williams, 2021; Park & Lee, 2022; Garcia et al., 2023; Chen & Zhao, 2024; Johnson & Smith, 2023; Al-Shammari, 2020; Odeh, 2021; Hassan & Khalil, 2022; Al-Harthi, 2023; Ahmed, 2024). The large effect sizes observed in this study ($d > 3.00$ across all levels) suggest that electronic

platforms can have a transformative impact on chemistry education when designed and implemented effectively.

The integration of educational technology theories (constructivism, connectivism, cognitive load theory, multimedia learning theory) with chemistry learning theories (conceptual change theory, collaborative learning, information processing theory, dual coding theory) appears to have been instrumental in the success of the intervention. The electronic platform provided a rich learning environment that addressed the unique challenges of chemistry education, including the abstract nature of chemical concepts and the safety concerns associated with laboratory work.

The findings also have practical implications for chemistry education in Sudan and similar contexts. The significant improvement in student achievement across all cognitive levels suggests that electronic platforms can help address the challenges of large class sizes, limited laboratory resources, and the need for individualized instruction in Sudanese universities.

5. Conclusions and Recommendations

5.1 Conclusions

Based on the findings of this study, the following conclusions are drawn:

5.1.1 Equivalence of Groups: The pre-test results confirmed that there were no statistically significant differences between the control and experimental groups prior to the intervention. This confirms the equivalence of the two groups and supports the validity of the experimental design.

5.1.2 Effectiveness at the Comprehension Level: There are statistically significant differences between the control and experimental groups in the post-test at the comprehension level, favoring the experimental group. The electronic platform effectively enhanced students' understanding of acid-base concepts.

5.1.3 Effectiveness at the Observation Level: There are statistically significant differences between the control and experimental groups in the post-test at the observation level, favoring the experimental group. The electronic platform effectively enhanced students' observational skills in chemistry.

5.1.4 Effectiveness at the Application Level: There are statistically significant differences between the control and experimental groups in the post-test at the

application level, favoring the experimental group. The electronic platform was particularly effective in helping students apply acid-base concepts to solve problems.

5.1.5 Overall Effectiveness: The use of electronic platforms in teaching acids and bases leads to increased achievement across all cognitive levels compared to traditional methods. The large effect sizes indicate substantial practical significance.

5.1.6 Theoretical Implications: The integration of educational technology theories (constructivism, connectivism, cognitive load theory, multimedia learning theory) with chemistry learning theories (conceptual change theory, collaborative learning, information processing theory, dual coding theory) provides a comprehensive framework for designing effective e-learning interventions in chemistry education.

5.1.7 Addressing Research Questions: The study provides clear answers to all four research questions, confirming that electronic platforms are effective in enhancing student achievement in chemistry across all cognitive levels, with the most substantial gains observed at the application level.

5.2 Recommendations

In light of the results indicating the effectiveness of using electronic platforms in teaching chemistry as opposed to traditional teaching methods, and the researchers' conviction regarding the necessity of employing modern methods and approaches due to their importance, the researchers recommend the following:

5.2.1 Recommendations for Curriculum Developers

- 1. Integrate Electronic Platforms:** Curriculum developers should integrate electronic platforms and e-learning tools into chemistry curricula at Sudanese universities. These platforms should be designed to address the unique challenges of chemistry education, including the abstract nature of chemical concepts and the need for visualization.
- 2. Design Interactive Content:** Chemistry curricula should include interactive multimedia content, simulations, and virtual laboratories that allow students to explore chemical phenomena safely and effectively.
- 3. Align with Learning Objectives:** The design of e-learning content should be aligned with learning objectives and cognitive levels (comprehension, observation, application) to ensure comprehensive coverage of the curriculum.

4. **Incorporate Formative Assessment:** Electronic platforms should include formative assessment tools that provide immediate feedback to students and inform instructional decisions.

5.2.2 Recommendations for Teachers

1. **Professional Development:** Chemistry teachers should receive training in the use of electronic platforms and e-learning tools. This training should be ongoing and should cover both technical skills and pedagogical strategies for integrating technology into instruction.
2. **Blended Learning Approaches:** Teachers should adopt blended learning approaches that combine traditional instruction with e-learning activities. This allows students to benefit from both face-to-face interaction and the flexibility of online learning.
3. **Student Engagement Strategies:** Teachers should use the interactive features of electronic platforms (discussion forums, collaborative activities, simulations) to engage students actively in the learning process.
4. **Differentiated Instruction:** Electronic platforms can be used to provide differentiated instruction that addresses the individual needs and learning styles of students. Teachers should use the data from these platforms to tailor their instruction accordingly.

5.2.3 Recommendations for University Administrators and Policymakers

1. **Provide Computer Laboratories:** Sudanese universities should provide well-equipped computer laboratories with reliable internet access to facilitate the use of electronic platforms in teaching and learning.
2. **Invest in Infrastructure:** Universities should invest in the infrastructure (hardware, software, internet connectivity) required to support e-learning initiatives.
3. **Digitize Curricula:** Universities should digitize their curricula and make them accessible through electronic platforms. This includes developing digital resources, creating online courses, and providing access to electronic libraries.

4. **Support Faculty Development:** University administrations should allocate resources for faculty development programs that train instructors in the use of educational technology.
5. **Create an Appropriate Environment:** Universities should create an institutional environment that supports technology-enhanced learning, including policies, incentives, and recognition for faculty who adopt innovative teaching practices.
6. **Train University Students:** Students should be trained in the use of electronic platforms and digital tools to ensure they can effectively utilize these resources for learning.

5.2.4 Recommendations for Future Researchers

1. **Longitudinal Studies:** Future research should examine the long-term impact of electronic platforms on student learning, including retention of knowledge and transfer of skills to real-world contexts.
2. **Comparative Studies:** Future research should compare different types of electronic platforms (e.g., mobile applications, virtual laboratories, AI-based tutoring systems) to identify the most effective approaches for teaching chemistry.

Mixed-Methods Research: Future research should employ mixed-methods designs that combine quantitative measures of achievement with qualitative data on student experiences, perceptions, and engagement.

4. **Larger and More Diverse Samples:** Future research should involve larger and more diverse samples, including students from different universities, disciplines, and cultural contexts, to enhance the generalizability of the findings.
5. **Investigation of Moderating Variables:** Future research should examine the role of moderating variables such as prior knowledge, learning styles, and motivation in determining the effectiveness of electronic platforms.
6. **Cross-Disciplinary Studies:** Future research should investigate the effectiveness of electronic platforms in other science disciplines (physics, biology) and across different educational levels (secondary, postgraduate).

7. **Cost-Effectiveness Studies:** Future research should examine the cost-effectiveness of electronic platforms compared to traditional instruction, considering factors such as infrastructure costs, faculty time, and student outcomes.

5.3 Study Limitations

The study has several limitations that should be considered when interpreting the findings:

5.3.1 Subject Limitations: The subject limitations of this study are confined to the effectiveness of e-learning on academic achievement in teaching chemical acids and bases to first-year students at Sudanese universities. The study does not cover other topics in chemistry or other educational levels.

5.3.2 Spatial Limitations: The study was conducted at Omdurman Islamic University – Faculty of Education – Department of Chemistry and Biology. The findings may not be generalizable to other universities or contexts without further research.

5.3.3 Temporal Limitations: The study was conducted during the academic year (2023–2024). The findings reflect the conditions and circumstances of this specific period.

5.3.4 Instrument Limitations: The study relied on a single instrument (the achievement test) to measure student learning. Future research could incorporate additional measures such as attitudes, motivation, or retention.

5.3.5 Generalizability Limitations: The small sample size and specific context limit the generalizability of the findings. Future research with larger and more diverse samples is recommended.

5.3.6 Resource Limitations: The availability of resources and facilities at the university limited the scope of the intervention and the sample size.

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