

THE EFFECT OF VIRTUAL LABORATORIES ON SENIOR HIGH SCHOOL STUDENTS' UNDERSTANDING OF NUCLEIC ACIDS IN GHANA

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Abstract

This study investigated how virtual laboratories influenced Ghanaian senior high school students' conceptual understanding of nucleic acids. A quasi-experimental design was used involving pre-test and post-test control groups. Eighty SHS students from two different schools were involved in the study. One group received instruction through conventional lecture techniques, while the other group received instruction through virtual laboratories. Data was collected using observation checklists, perception surveys, and achievement tests. Quantitative data was analyzed using descriptive and inferential statistics such as ANOVA. However, qualitative data was subjected to thematic analysis. Students taught using virtual laboratory simulations statistically performed better than the students taught using traditional approaches. Virtual simulations provide an alternative option for promoting the meaningful learning of molecular biological concepts. This is very necessary because a greater part of Ghanaian senior high schools have insufficient access to functional biology laboratories. The purpose of the investigation was to present empirical data on the efficacy of virtual laboratories. The data provides policymakers and educators with new viewpoints on how to teach abstract biological concepts in areas with limited resources.

Keywords: Virtual laboratories, Nucleic acids, Senior High School Biology, Simulation-based learning, Students' understanding, Ghana.

Introduction

In science, the integration of information and communication technology (ICT) has grown to be a crucial part of contemporary pedagogy. Ghana's Ministry of Education (2022) has placed a strong emphasis on ICT-based instruction for the purpose of improving teaching and learning outcomes. In many senior high schools (SHSs), factors such as small class size, inadequate resources, and limited access to operational laboratories continue to affect effective science instruction. Laboratory experiences play a vital role for the development of conceptual understanding and scientific inquiry-based abilities in biology. To get a better understanding of protein synthesis, genetics, and biotechnological applications all depends largely on the acquisition of knowledge of molecular biology, especially nucleic acids. These topics are often taught in abstract despite their numerous advantages due to limited laboratory resources. Pursuant to the West African Examinations Council report (WAEC, 2021), students continue to battle with genetics-related questions, calling for the need for creative teaching strategies. To improve students' understanding and visualization of complex biological processes, virtual laboratories, which are one of the computer-based simulations, cannot be underestimated. Several research findings indicated that virtual laboratories can boost students' motivation,

engagement, and conceptual understanding (Faour & Ayoubi, 2018). Despite numerous studies in this area, there aren't many empirical studies examining their efficacy in Ghanaian senior high schools, mostly when it comes to the teaching of nucleic acids. The purpose of this study, therefore, was to identify how virtual laboratories influenced Ghanaian senior high school students' understanding of nucleic acids.

Problem Statement

In Ghanaian senior high schools, biology instruction is severely hindered by insufficient laboratory facilities and teaching-learning resources. In view of this, educators often resort to lecture-based learning. This led to a reduction in students' interest and comprehension of biological concepts. Because of these instructional constraints, genetics and molecular biology sections continuously recorded low marks in West African Senior School Certificate Examinations (WAEC, 2021).

Nevertheless, virtual laboratories have been demonstrated to improve student learning in other parts of the world; however, their use in Ghana is still abysmal. Due to a lack of local empirical evidence, legislators and teachers are scared of incorporating these technologies into science education. By assessing how virtual laboratories influence senior high school students' conceptual understanding of nucleic acids and their perceptions toward technology-assisted learning, the present study focused on bridging that gap.

Purpose of the Study

This investigation focused on how virtual laboratories influenced Ghanaian SHS students' conceptual understanding of nucleic acids.

Research Questions

To direct the current study, the underlisted research questions were formulated:

1. How knowledgeable in nucleic acids were SHS students prior to the intervention?
2. What effect do virtual laboratories have on students' conceptual understanding of nucleic acids?
3. Do students who are taught using virtual laboratories differ in learning outcomes compared to those taught using traditional approaches?
4. How do students perceive virtual laboratories in learning biology?

Hypotheses

- a. H₀₁: Students' conceptual understanding of nucleic acids pre- and post-exposure to virtual laboratories does not differ significantly.
- b. H₀₂: Students taught using virtual laboratories and those taught using traditional approaches do not differ significantly in their performance.

Significance of the Study

It is predicted that this investigation will offer empirical evidence of the educational benefits of virtual laboratories in the Ghanaian SHS setting. The outcomes will:

- Educate authorities and curriculum designers on how to include ICT in biology education.
- Motivate biology educators to use innovative approaches to teach abstract molecular concepts.
- Help to encourage better performance, engagement, and interest in molecular biology among students.
- Motivate the computerization of science instruction in environments with limited resources.

Scope and Delimitation

The investigation was conducted at Wenchi and Sunyani Senior High Schools in Ghana. These two senior high schools have rudimentary ICT infrastructure. The area of concentration in this study was the senior high school biology unit on nucleic acids. The findings of the study will only be generalized to SHSs involved in the study but not any other SHSs in the country. This

is due to limited ICT facilities or steady power supply, even though they may offer valuable information.

Research Methodology

This study utilized a quasi-experimental pre-test and post-test control group design to investigate the effect of an intervention in natural classroom environments where random assignment is not always feasible (Creswell & Creswell, 2018; Fraenkel, Wallen, & Hyun, 2019). The design allowed for a comparison of learning outcomes between students taught biology concepts on nucleic acids using virtual laboratory simulations (experimental group) and those taught using traditional instructional approaches (control group) (Makransky et al., 2019; Zacharia & de Jong, 2014).

The target population in this study consisted of all senior high school biology students in Ghana. However, due to resource and accessibility issues, only two senior high schools in the Bono Region, namely Wenchi and Sunyani SHS, participated in the current study.

According to Patton (2015), when particular characteristics are required in a study, a purposive sampling technique is deemed feasible. Hence, these schools were specifically selected based on their availability of computer lab facilities and their ICT readiness. Forty students from each school, thus eighty students in all, were selected to be involved in the study. The schools were exposed to virtual laboratory intervention and/or the traditional teaching approaches.

Three main instruments were used to gather data: (a) a Biology Achievement Test on Nucleic Acids administered as both a pre-test and post-test to measure cognitive gains, which aligns with recommendations for assessing intervention impact in science education research (Taber, 2018); (b) a Students' Perception Questionnaire used to capture learners' attitudes and experiences; and (c) a Teacher Observation Checklist documenting instructional delivery and student engagement throughout the lessons. The process began with administering a pre-test to both groups to establish a baseline equivalency as suggested by protocols in quasi-experimental educational research. This was followed by teaching nucleic acid lessons using virtual laboratory simulations for the experimental group and the lecture-based method for the control group. After the lessons, the students were tasked to complete a post-test and a perception questionnaire, with which they also took part in observations of teaching activities (Campbell & Stanley, 1963).

To determine whether there are statistically significant differences in mean achievement scores between the two groups, as suggested by Field (2018) for comparing group means in experimental research, inferential statistics such as independent sample t-tests and ANCOVA were employed. However, to summarize the baseline understanding and students' attitude towards nucleic acids, descriptive statistics (mean and standard deviation) were used. Thematic analysis procedures and qualitative responses from the open-ended questionnaire items were examined thematically as recommended by Braun and Clarke (2006). This process was carried out to identify recurrent patterns. In order to comply with educational research standards (BERA, 2018), ethical procedures were closely followed. These protocols involved seeking permission from school authorities, obtaining informed consent from participants, safeguarding confidentiality, guaranteeing voluntary participation, and limiting data use to only academic purposes.

Results

Baseline Understanding of Nucleic Acids

Before the instruction, a pre-test was given to both the experimental and control groups to measure their prior understanding of nucleic acids. According to the results, the baseline comprehension levels of both groups were similar.

Table 1: Pre-Test Mean Scores of Experimental and Control Groups (n = 80)

Group	N	Mean	SD	t-value	p-value
Experimental	40	23.45	6.12		
Control	40	22.78	5.96	0.51	0.61

Source: Field Data (2025)

In reference to the independent-sample t-test ($t = 0.51$, $p = .61$) as indicated in Table 1, there was no statistically significant difference between the two groups' pre-test scores. This signifies that prior to the intervention, the knowledge of both groups on nucleic acids was analogous.

Post-Test Performance After Instruction

After the instructional intervention, post-tests were given to both groups. When the results were compared, it was indicated that the students exposed to the virtual laboratory instruction performed better than students taught using traditional methods (Table 2).

Table 2: Post-Test Mean Scores of Experimental and Control Groups (n = 80)

Group	N	Mean	SD	t-value	p-value
Experimental	40	78.25	8.34		
Control	40	64.50	9.21	6.76	<.001

Source: Field Data (2025)

Students that are taught using virtual laboratories performed better than those taught using traditional methods. The results indicate a statistically significant difference in the post-test means of the experimental and control groups ($t = 6.76$, $p < .001$).

Within-Group Comparison of Pre-Test and Post-Test Scores

To determine the significance of improvement within each group, a paired-sample t-test was conducted. The results are shown in Table 3 below.

Table 3: Paired-Sample Comparison of Pre-Test and Post-Test Scores

Group	Test Type	Mean	SD	Mean Difference	t-value	p-value
Experimental	Pre-test	23.45	6.12			
	Post-test	78.25	8.34	54.80	28.34	<.001
Control	Pre-test	22.78	5.96			
	Post-test	64.50	9.21	41.72	19.26	<.001

Source: Field Data (2025)

Though the performance of both groups considerably improved, the experimental group's mean difference was substantially larger (54.80) than the control group's (41.72). This indicates that the virtual laboratory intervention had a greater impact.

Students' Perceptions of Virtual Laboratory Learning

From a qualitative analysis of the perception questionnaire (Table 4), students discovered virtual laboratories to be very interesting. They also considered them to be interactive and useful for improving their comprehension of complex molecular processes.

Table 4: Summary of Students' Perceptions (n = 40)

Statement	Mean	SD	Interpretation
The virtual lab helped me visualize DNA and RNA structures.	4.68	0.43	Very High
I understood nucleic acid functions better through simulations.	4.53	0.52	Very High
The activities increased my motivation to learn Biology.	4.42	0.61	High
I prefer virtual labs to traditional lectures for abstract topics.	4.35	0.67	High
Virtual labs should be included in our biology curriculum.	4.71	0.39	Very High

Source: Field Data (2025)

(Scale: 1.00–1.80 = Very Low; 1.81–2.60 = Low; 2.61–3.40 = Moderate; 3.41–4.20 = High; 4.21–5.00 = Very High)

Students rated virtual laboratories as beneficial tools that made abstract molecular concepts easy and clearer, promoted curiosity, and encouraged self-directed exploration consistently.

Discussion of Findings

Effect of Virtual Laboratories on Conceptual Understanding

According to the results, it was found that students taught using virtual laboratories exhibited significantly higher post-test scores compared to those exposed to traditional lecture methods. The findings support that of Faour and Ayoubi (2018), who reported that virtual laboratories enhance students' conceptual understanding by allowing interactive experimentation and visualization of microscopic biological processes. This is notably common in schools with insufficient laboratory resources; the use of virtual labs helped bridge the gap between theoretical instruction and practical experience.

Comparison Between Instructional Methods

Comparing the performance of students based on the two instructional methods, it was found that the experimental group showed more notable improvement than the control group. This confirms that virtual laboratories provide a useful pedagogical substitute for conventional approaches when teaching difficult biological topics like nucleic acids. Virtual labs give students the opportunity to manipulate molecular structures and watch biochemical interactions in real-life situations. In contrast, traditional teachers mainly rely on spoken explanations, making abstract concepts highly difficult to absorb. This interactivity improves retention and comprehension, as it is in line with constructivist learning principles that prioritize active engagement.

Students' Perceptions and Attitudes

With regard to students' perceptions and attitudes, virtual laboratory experience was absolutely embraced by the students, who vehemently reported interest, motivation, and clarity in their comprehension of nucleic acid concepts. These results are inconsistent with the findings by Faour & Ayoubi (2018), who indicated that technology-based learning environments can enhance student satisfaction and engagement. The choice for virtual simulations indicates that Ghanaian SHS students are ready to adopt ICT-based learning. However, the availability of the required tools and adequate teacher assistance supported their readiness.

Implications for Biology Education in Ghana

The results reveal that integrating virtual labs into SHS biology classes can enhance student performance, especially in institutions without well-furnished functional laboratories. This stresses the importance of teacher capacity building and policy support in order to mainstream the use of virtual laboratories. Implementing such digital learning tools could help bridge the gap between curriculum intent and classroom practice as Ghana moves forward with its ICT-in-education agenda (Ministry of Education, 2022).

Conclusion

This research finds that virtual laboratories extremely enhance SHS students' comprehension of nucleic acids compared to traditional lecture-based instruction. As virtual laboratories improve students' test scores, they also acknowledge that they feel highly motivated and conceptually clear learning experiences. Virtual laboratories therefore provide a useful and efficient way to address laboratory shortfalls in Ghanaian schools. Molecular biology education can also be promoted through virtual laboratories.

Recommendations

The following suggestions are made based on the study's findings:
1. To complement practical laboratory work, virtual laboratory modules should be included in

the SHS Biology curriculum by the Ghana Education Service and the National Council for Curriculum and Assessment (NaCCA).

2. Professional development programs should be organized occasionally to keep biology teachers abreast of how to use digital pedagogies and virtual laboratory tools.
3. The Ministry of Education should work hand in hand with technology partners to supply schools with reliable internet connectivity and sufficient ICT infrastructure.
4. To show evidence-based ICT integration in schools, decision-makers should assist research and pilot projects on the application of virtual laboratories in other scientific fields.
5. School authorities should encourage self-directed learning through virtual labs by motivating students to use simulations outside classroom hours for reinforcement.

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