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Secondary School Students' Perceptions and Structural Bottlenecks of Digital Biology Pedagogy in Okene, Kogi State

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Highlights:

Examines digital Biology pedagogy in an under-studied Nigerian secondary context.

Links perception of digital teaching to Biology topics that are difficult to visualize.

Shows clearly that structural bottlenecks do not significantly weaken positive perceptions

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Abstract: This study evaluated students' perceptions of digital teaching and the challenges affecting its implementation in Biology education. A descriptive survey design was adopted using the Digital Technology Integration in Biology Education Questionnaire (DTIBEQ). Data was collected from a sample of 200 Biology students from 4 different schools, 50 students from each school through a questionnaire. Stratified random sampling technique was adopted in sampling the respondents across Okene. Self-developed questionnaire was used as instrument for data collection which was validated by experts. The reliability index of the instrument was done using Cronbach alpha statistics and found to be0.947. The data collected were analysed using mean and standard deviation to answer research questions and Pearson Chi-square statistical technique to test the hypotheses at 0.05 level of significance. Findings showed that most respondents perceived digital teaching as helpful in understanding complex biological concepts and increasing their interest in Biology. Respondents also identified lack of digital devices, poor electricity supply, inadequate teacher digital literacy, and poor internet connectivity as major barriers to effective implementation. The findings suggest a high level of student acceptance of digital teaching despite infrastructural limitations. The study recommends increased investment in digital infrastructure, teacher capacity building, and sustainable power solutions to enhance digital teaching in Biology education.

Keywords: Biological Concepts, Digital Teaching, Virtual Simulations, Biology Education.

Introduction

Biology is one of the core science subjects taught at the secondary school level, it is a science that, through its research, is called to convince people of the need to respect nature and observe its laws (Yakubjonova et al., 2024).This foundational knowledge helps students develop an understanding of basic biological processes. It also equips them with practical knowledge that can be applied in day-to-day life such as maintaining personal health, understanding environmental issues, and making informed decisions about nutrition and hygiene. The inclusion of Biology as a compulsory subject in many Nigerian secondary schools highlights its importance in building scientific literacy among students. In Biology, certain biological concepts such as Genetics, Cell division, Evolution are often considered complex and hard to understand by students. These concepts usually involve a series of stages occurring at a molecular level and are difficult to visualize through conventional teaching methods. This directly introduces the need for interactive digital visualization. Considering the significance of Biology in academic and societal development, there is a need to improve the methods of teaching. The traditional methods of teaching involve lecture-based on textbooks explanation and static diagrams. These methods convey basic information, but it is still inefficient

for teaching complex biological concepts that require visualization.

The increasing incorporation of digital technologies into education has created new opportunities for addressing these instructional challenges. Digital Biology pedagogy refers to the use of technology-enhanced instructional resources such as multimedia presentations, animations, simulations, virtual laboratories, educational videos, and online learning platforms to facilitate Biology teaching and learning. These tools provide visual and interactive representations of biological processes, enabling students to observe, manipulate, and explore concepts that are otherwise difficult to visualize through conventional classroom instruction. The growing adoption of digital technologies in education has been accelerated by recent advances in information and communication technology as well as the increased emphasis on technology-supported learning environments. Contemporary educational theories, particularly Mayer's Cognitive Theory of Multimedia Learning, suggest that students learn more effectively when information is presented through a combination of verbal and visual channels. The theory is based on the assumptions of dual channels for processing information, limited cognitive capacity, and active processing, making it particularly relevant to the use of multimedia resources in Biology education.

Although digital technologies offer considerable potential for enhancing Biology instruction, their effectiveness may depend on students' perceptions, experiences, and access to these resources. Students' views regarding the usefulness, accessibility, and ease of use of digital learning tools can influence their willingness to engage with technology-enhanced instruction. Furthermore, the implementation of Digital Biology Pedagogy may be constrained by structural and infrastructural challenges such as inadequate internet connectivity, limited access to digital devices, insufficient technical support, and inadequate power supply, particularly in developing educational contexts. Digital Biology pedagogy refers to the integration of digital technologies, multimedia resources, simulations, virtual laboratories, and online learning platforms into Biology instruction to enhance students' understanding, engagement, and learning outcomes. Digital teaching differs from traditional teaching, which is largely teacher-centered and text-based. Consequently, it may be limited in its ability to effectively visualize complex biological processes. In contrast, digital learning tools bridge this gap by offering dynamic visualizations that make abstract concepts more concrete and easier to understand. According to Haleem et al., (2022), technology-enhanced learning environments significantly improve comprehension and support more flexible and student-centered learning experiences. In Biology education, such digital tools are particularly valuable for explaining abstract concepts such as Cell division, Genetics, DNA replication,as well as other microscopic and dynamic biological processes that cannot be directly observed in the classroom.

An important feature of Digital Biology Pedagogy involves the use of technological tools such as multimedia presentations, animations, simulations, and online learning platforms to enhance instruction. These tools help to create interactive learning environments that go beyond traditional chalk-and-talk methods. Studies have shown that digital technologies

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increase student engagement, motivation, and participation in learning activities (Akram et al., 2021; Tusiime et al., 2022). A key component of Digital Teaching in Biology is the use of virtual simulations. These are computer-generated environments that allow learners to interact with biological processes in a controlled and immersive setting. Makransky and Petersen (2019) describe virtual simulations as interactive environments that enable learners to explore complex phenomena, thereby improving understanding and retention. Such simulations are particularly useful in explaining processes like genetics, where students can perform virtual crosses and see the results instantly.

Another important tool is multimedia presentations, which combine text, images, animations, audio, and video to present information in a more engaging and structured manner. Through multimedia resources, students can observe processes such as DNA replication, cell division, and ecological interactions through visual and interactive representations that enhance conceptual understanding and knowledge retention. This study is anchored on the Cognitive Theory of Multimedia Learning (CTML) developed by Richard Mayer (2009). The theory explains how learners process information presented through both verbal and visual channels and how multimedia resources can enhance understanding and retention. According to Mayer, individuals learn more effectively when information is presented using a combination of words and pictures rather than words alone. This position is supported by empirical evidence drawn from more than 60 experimental comparisons documented across Mayer's research programme.

The Cognitive Theory of Multimedia Learning is based on three major assumptions. First, the theory assumes that humans possess dual channels for processing information: a visual channel for processing images and a verbal channel for processing spoken or written words. Second, each channel has a limited capacity, meaning that learners can only process a certain amount of information at a time. Third, meaningful learning occurs when learners actively select, organize, and integrate information from both channels to construct knowledge. Building on these assumptions, Mayer argues that effective multimedia instruction should minimize extraneous cognitive load, manage essential processing, and promote generative processing. In teaching DNA replication, students are likely to benefit from learning the structures and functions of key enzymes before encountering the complete replication sequence.

Effective multimedia instruction should also manage essential processing by breaking down complex information into smaller, meaningful segments. In the context of DNA replication, students may first learn the names, structures, and individual functions of the enzymes involved before studying the complete replication process. This approach reduces the burden on students' working memory and allows them to integrate new information more effectively. Furthermore, generative processing is promoted when learners actively connect new concepts with prior knowledge, resulting in deeper understanding and improved retention of biological concepts. The Cognitive Theory of Multimedia Learning provides a suitable framework for the present study because it explains how digital teaching tools may enhance students' understanding of

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complex Biology concepts. It also supports the study's focus on students' perceptions of conceptual clarity, engagement, and the effectiveness of digital teaching in Biology education. Therefore, the theory offers a strong foundation for examining the integration of digital technologies into Biology instruction and understanding how such technologies influence students' learning experiences. Several empirical studies have examined the use of digital technologies in science education and their impact on students' learning outcomes. Akram et al. (2021) investigated the effectiveness of digital learning technologies in enhancing students' engagement and academic performance. The study found that the use of multimedia resources, animations, and interactive digital tools significantly increased students' motivation, participation, and understanding of scientific concepts. The researchers concluded that technology-supported instruction promotes active learning and improves students' academic achievement. Similarly, Tusiime et al. (2022) examined the influence of digital learning environments on students' engagement and learning experiences. Using survey data collected from secondary school students, the study revealed that digital technologies enhanced students' participation, motivation, and conceptual understanding. The findings further indicated that interactive learning resources provided opportunities for students to engage more actively in the learning process than traditional classroom approaches.

Adedoyin et al. (2020) investigated the challenges associated with the rapid transition to online learning during the COVID-19 pandemic. Their findings revealed that many teachers lacked adequate digital competencies and pedagogical skills required for effective online instruction. Students also experienced difficulties with self-regulated learning and adapting to technology-mediated education. The study emphasized the need for continuous professional development and institutional support to enhance the effectiveness of digital learning. Haleem et al. (2022) examined the role of digital technologies in modern education and reported that technology-enhanced learning environments significantly improved students' comprehension and learning flexibility. The study further found that digital teaching promotes student-centered learning and supports the visualization of complex concepts. However, the researchers identified inadequate infrastructure, insufficient teacher competence, and limited institutional support as major challenges affecting effective implementation.

The reviewed studies generally indicate that digital teaching enhances students' engagement, motivation, conceptual understanding, and academic performance. They also demonstrate that virtual simulations and multimedia resources are effective tools for teaching complex scientific concepts. Nevertheless, challenges such as inadequate digital infrastructure, insufficient teacher training, and limited institutional support continue to hinder the successful implementation of digital teaching, particularly in developing countries. These findings provide a basis for investigating secondary school students' perceptions and the structural bottlenecks affecting digital Biology pedagogy in Okene, Kogi State. Understanding students' perceptions of digital Biology pedagogy and identifying the barriers that affect its

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effective implementation are therefore essential for improving teaching and learning outcomes. While previous studies have highlighted the potential benefits of digital technologies in science education, there remains a need to examine how secondary school students perceive these instructional approaches and the challenges they encounter in their use. This study was therefore conducted to investigate secondary school students' perceptions of digital Biology pedagogy and the structural bottlenecks affecting its implementation.

Although digital technologies have been identified as promising tools for enhancing the teaching of complex Biology concepts, their successful implementation depends largely on students' acceptance and access to these technologies. In many Nigerian secondary schools, challenges such as poor electricity supply, inadequate digital infrastructure, and limited access to technological devices may hinder effective integration. Consequently, there is a need to examine students' perceptions of digital Biology Pedagogy and the structural barriers affecting its implementation to help curriculum planners in implementing digital learning policies. The primary objective of this study is to evaluate secondary school students' perceptions and systemic challenges regarding digital technology integration in Biology education.

Research hypotheses

1. There is no significant relationship between students' access to digital tools and their perception of digital Biology pedagogy.
2. There is no significant relationship between students' utilization of digital tools and their perception of digital Biology pedagogy.
3. There is no significant relationship between structural bottlenecks and students' perception of digital Biology pedagogy.

Methodology

Research Design

This study employed a descriptive survey research design. This design is appropriate as it allows for the collection of data from a specific group of people to describe the characteristics, behaviors, opinions, or the current status of a population without manipulating the variables under study. According to Creswell and Creswell (2018), descriptive research is used to provide a quantitative or numeric description of trends, attitudes, or opinions of a population by studying a sample of that population.

Population of study

The population of the study consisted of Biology students from four secondary schools in Okene, Kogi State. A sample of 200 Biology students served as respondents for the study, with 50 students selected from each school.

Sampling and Sampling technique

A stratified random sampling technique was adopted in selecting respondents from the four secondary schools in Okene, Kogi State.

Instrument for Data Collection

The study used a researcher-designed structured questionnaire called the *Digital Teaching in Biology Education Questionnaire (DTIBEQ)* to collect data on students' experiences with digital tools. It had 4 sections, section A- which collected demographic data on the student, section B

– which measured exposure to digital tools and utilization, section C – which measured perceived usefulness and effectiveness of digital tools and section D – which measured the structural bottlenecks to digital Biology Pedagogy. It used a 5 scale - likert scale for measurement.

Validity and Reliability of the Instrument

The questionnaire was reviewed by experts in Biology Education and Educational Research to ensure that it adequately measured the variables of the study. Their observations and suggestions were used to improve the clarity, relevance, and appropriateness of the questionnaire items. The reliability of the instrument was determined using Cronbach's Alpha. The questionnaire consisted of sixteen Likert-scale items measuring students' access to and utilization of digital tools, perceived usefulness and effectiveness of digital Biology pedagogy, and structural bottlenecks affecting implementation. The analysis yielded an overall Cronbach's Alpha coefficient of 0.947, indicating that the instrument had a very high level of internal consistency.

Method of Data Analysis

The data collected were analysed using mean and standard deviation to answer the research questions. Pearson Chi-square statistics were used to test the hypotheses at the 0.05 level of significance. For hypothesis testing, respondents' composite scores for access to digital tools, utilization of digital tools, structural bottlenecks, and perception of digital Biology pedagogy were computed. The composite scores were categorized into high and low levels using the criterion mean of 3.00. Scores above the criterion mean were classified as high or positive, while scores below the criterion mean were classified as low or negative.The results were presented in tables to show respondents' responses, mean ratings, standard deviations, and the relationships among the variables.

Results

Research Question 1: What is the level of students' access to and utilization of digital tools for Biology learning?

Table 1: Mean and Standard Deviation of Students' Access to and Utilization of Digital Tools for Biology Learning

S/N	Access and utilization of digital tools	Mean	SD	Remark
1	I have access to a digital device such as a computer, tablet or smartphone for learning Biology	**3.85**	0.93	Accepted
2	I frequently use digital devices to support my Biology learning	**3.85**	0.93	Accepted
3	I often access online educational resources to learn complex Biology concepts	**3.87**	0.94	Accepted
4	My Biology assignments sometimes require the use of digital technologies	**3.89**	0.92	Accepted
5	Digital technologies are available for Biology learning in my school	**3.85**	0.94	Accepted

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		3.86		

Interpretation

Data presented in Table 1 showed that students had a high level of access to and utilization of digital tools for Biology learning. All items recorded mean scores ranging from 3.85 to 3.89, indicating a high level of agreement among respondents. The grand mean of 3.86 further confirms that students generally had access to digital technologies and utilized them in learning Biology.

Research Question 2: What are students' perceptions of the usefulness and effectiveness of digital Biology pedagogy?

Table 2: Mean and Standard Deviation of Students' Perceptions of the Usefulness and Effectiveness of Digital Biology Pedagogy

S/N	Perceived usefulness and effectiveness	Mean	SD	Remark
1	The use of digital learning resources makes abstract Biology concepts easier to comprehend	**4.05**	0.67	Accepted
2	Digital instructional materials help me visualize Biology concepts that usually involve series of steps	**4.08**	0.68	Accepted
3	I need less assistance from my teacher to understand challenging Biology concepts when digital resources	**4.03**	0.69	Accepted
4	I achieve better results in Biology assessments when digital tools are used during instruction	**4.06**	0.68	Accepted
5	Digital teaching provides learning experiences that improve my mastery of Biology concepts	**4.07**	0.68	Accepted
		4.06		

Interpretation

Data presented in Table 2 revealed that students had a high perception of the usefulness and effectiveness of digital Biology pedagogy. The mean ratings ranged from 4.03 to 4.08, indicating that students believed digital teaching enhanced understanding, visualization, academic performance, and mastery of Biology concepts. The grand mean of 4.06 indicates a high positive perception of digital Biology pedagogy among the respondents.

Research Question 3: What structural bottlenecks affect the implementation of digital Biology pedagogy?

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Table 3: Mean and Standard Deviation of Structural Bottlenecks Affecting the Implementation of Digital Biology Pedagogy

S/N	Structural bottlenecks	Mean	SD	Remark
1	Lack of digital devices limit the use of digital teaching in Biology	4.58	0.52	Accepted
2	Poor internet connectivity affects the use of digital learning resources	4.60	0.52	Accepted
3	Biology teachers require additional training to effectively use digital technologies for instruction	4.57	0.54	Accepted
4	My school lacks adequate digital infrastructure for Biology teaching	4.59	0.52	Accepted
5	The cost of internet access affects students' participation in digital learning.	4.58	0.52	Accepted
		4.59		

Interpretation

Data presented in Table 3 showed that respondents perceived a very high level of structural bottlenecks affecting the implementation of digital Biology pedagogy. All items recorded mean ratings ranging from 4.57 to 4.60, indicating strong agreement that inadequate digital devices, poor electricity supply, poor internet connectivity, inadequate teacher training, insufficient digital infrastructure, and high internet costs constitute major barriers to digital Biology instruction. The grand mean of 4.59 confirms that these challenges are significant obstacles to the effective integration of digital technologies in Biology education.

Testing of Hypotheses

Hypothesis One

H_{01}: There is no significant relationship between students' access to digital tools and their perception of digital Biology pedagogy.

Table 4: Chi-square Analysis of Students' Access to Digital Tools and Their Perception of Digital Biology Pedagogy

Access to digital tools	Negative perception	Positive perception	Total
High access	4	152	156
Low access	39	5	44

Total	43	157	200

Test statistic	**Value**	**Df**	**Asymp.Sig. (2-sided)**
Pearson Chi-square	145.592	1	<.001
Number of valid cases	200		

Decision: Since p < .001 is less than 0.05, the null hypothesis is rejected.

Interpretation: There is a significant relationship between students' access to digital tools and their perception of digital Biology pedagogy. Students with high access to digital tools were more likely to have a positive perception of digital Biology pedagogy.

Hypothesis Two

H_{02}: There is no significant relationship between students' utilization of digital tools and their perception of digital Biology pedagogy.

Table 5: Chi-square Analysis of Students' Utilization of Digital Tools and Their Perception of Digital Biology Pedagogy

Utilization of digital tools	**Negative perception**	**Positive perception**	**Total**
High utilization	5	154	159
Low utilization	38	3	41
Total	43	157	200

Test statistic	**Value**	**Df**	**Asymp.Sig. (2-sided)**
Pearson Chi-square	149.572	1	<.001
Number of valid cases	200		

Decision: Since p < .001 is less than 0.05, the null hypothesis is rejected.

Interpretation: There is a significant relationship between students' utilization of digital tools and their perception of digital Biology pedagogy. Students who frequently utilized digital tools were more likely to report positive perceptions of digital Biology pedagogy.

Hypothesis Three

H_{03}: There is no significant relationship between structural bottlenecks and students' perception of digital Biology pedagogy.

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Table 6: Chi-square Analysis of Structural Bottlenecks and Students' Perception of Digital Biology Pedagogy

Structural bottlenecks	Negative perception	Positive perception	Total
High bottlenecks	33	140	173
Low bottlenecks	10	17	27
Total	43	157	**200**

Test statistic	Value	Df	Asymp. Sig. (2-sided)
Pearson Chi-square	3.464	1	0.063
Number of Valid cases	200		

Decision: Since p = .063 is greater than 0.05, the null hypothesis is not rejected.

Interpretation: There is no significant relationship between structural bottlenecks and students' perception of digital Biology pedagogy. Although many students reported structural bottlenecks such as inadequate digital devices, poor electricity supply, poor internet connectivity, insufficient teacher training, and inadequate digital infrastructure, these bottlenecks were not significantly associated with their perception of digital Biology pedagogy in this study.

Discussion

The findings of this study indicate that secondary school students in Okene, Kogi State, had a high level of access to and utilization of digital tools for Biology learning, with a grand mean of 3.86. This suggests that digital devices and online resources were reasonably available to many students and were already being incorporated into their Biology learning activities. This finding is consistent with studies which indicate that technology-enhanced learning environments can support flexible and student-centered learning experiences. Students also expressed a high positive perception of the usefulness and effectiveness of digital Biology pedagogy, with a grand mean of 4.06. Respondents indicated that digital resources made abstract Biology concepts easier to understand, supported the visualization of multi-step processes, and improved their mastery of Biology concepts. This finding is consistent with the Cognitive Theory of Multimedia Learning developed by Richard Mayer, which explains that students learn more effectively when information is presented through both verbal and visual channels.

Students reported a very high level of structural bottlenecks affecting digital Biology pedagogy, with a grand mean of 4.59. Lack of digital devices, poor electricity supply, poor internet connectivity, inadequate teacher training, insufficient school infrastructure, and the cost of internet access were all identified as

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major barriers. This suggests that although students are receptive to digital Biology pedagogy, schools may face substantial challenges in implementing it consistently and effectively. The hypothesis testing further showed that access to digital tools and utilization of digital tools were significantly associated with students' perception of digital Biology pedagogy. Students with higher access to digital tools and those who utilized such tools more frequently were more likely to report positive perceptions of digital Biology pedagogy. This implies that regular exposure to and use of digital learning resources may contribute to students' positive attitudes toward digital Biology instruction.

However, structural bottlenecks were not significantly associated with students' perception of digital Biology pedagogy. Although respondents rated these bottlenecks as very high, their presence did not significantly affect whether students held positive or negative perceptions of digital Biology pedagogy. This may suggest that students recognize the usefulness of digital teaching even when the necessary infrastructure is inadequate. Overall, the findings suggest that student readiness and acceptance of digital Biology pedagogy are relatively high. However, infrastructural and systemic constraints remain major barriers to the consistent and effective implementation of digital Biology pedagogy in secondary schools in Okene, Kogi State.

Conclusion

This study examined secondary school students' perceptions of digital Biology pedagogy and the structural bottlenecks affecting its implementation in Okene, Kogi State. The findings showed that students had a high level of access to and utilization of digital tools for Biology learning. Students also had a high positive perception of the usefulness and effectiveness of digital Biology pedagogy in understanding complex Biology concepts. The study further revealed that students perceived a very high level of structural bottlenecks, particularly inadequate digital devices, poor electricity supply, poor internet connectivity, insufficient teacher training, inadequate digital infrastructure, and the high cost of internet access. Access to and utilization of digital tools were significantly associated with students' perceptions of digital Biology pedagogy, whereas structural bottlenecks were not significantly associated with students' perceptions. The findings suggest that students are generally receptive to digital Biology pedagogy. However, infrastructural and systemic limitations remain major barriers to its consistent and effective implementation in secondary schools.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. School authorities and government education boards should provide adequate digital devices, such as computers and tablets, as well as ICT infrastructure in secondary schools to support the effective use of digital Biology pedagogy.
2. Sustainable power solutions, including solar power installations, should be provided in schools to address poor electricity supply and support uninterrupted digital teaching.

3. Education stakeholders and internet service providers should explore subsidized internet access schemes for schools and students to reduce the cost of internet access and improve participation in digital learning.
4. Regular training programmes should be organized for Biology teachers to strengthen their capacity to use digital technologies effectively for instruction.
5. Curriculum planners should incorporate digital Biology pedagogy, including virtual simulations, animations, multimedia presentations, and online learning resources, into Biology instruction.
6. School administrators and policymakers should prioritize improvements in digital infrastructure, electricity supply, internet connectivity, and teacher training to ensure the consistent implementation of digital Biology pedagogy.

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Data Availability

The data collected will be made available by the author upon any reasonable request, and subject to institutional and ethical requirements.

Declaration / Conflict of Interest

The author declares that there is no form of conflict of interest.

Disclosure of AI Use

Generative AI was used for language refinements, and the researcher is responsible for every aspect of the research.

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