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Boosting the Non-Science Students' Process Skills in Nigerian Classrooms: How Effective is Cultural-Techno-Contextual Approach 2.0?

Ayodeji Ogundowole[1*], Tunde Owolabi[2], Hakeem Akintoye[3], Soladoye Lameed[4], Saibu Sakibu Olajide[5], Olasunkanmi Gbeleyi[6], Umar Adam[7], Abiodun Gafar Mustapha[8]

[1,2,4,6]Department of Science & Technology, Faculty of Education, Lagos State University, Ojo, Nigeria

[3,7]Africa Centre of Excellence for Innovative and Transformative STEM Education, Lagos State University, Ojo, Nigeria

[5,8]Natural Science Department, College of Science Education, Lagos State University of Education, Otto Ijankin, Lagos, Nigeria

[*]Corresponding Author

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ABSTRACT

The teaching practices in many Nigerian classrooms reveal that biology teachers often face challenges in teaching the non-science students, likening their experience to solving a complex puzzle. This difficulty is commonly attributed to the academic backgrounds of these students, which often lack foundational scientific concepts. Therefore, this study examined the efficacy of the Culturo-Techno-Contextual Approach 2.0 (CTCA2.0) in enhancing the acquisition of process skills among non-science students offering biology in public senior secondary schools in Nigeria. The study was grounded in Okebukola's Ecotechnocultural Theory, Vygotsky's Social Constructivist Theory, and Ausubel's Theory of Advance Organizers. An explanatory sequential mixed-method was employed, incorporating both a quasi-experimental approach and in-depth interviews. A total of 104 Senior Secondary School II (SSS II) non-science students (experimental group = 51; control group = 53) from two intact classes, purposively selected from two public schools in Lagos State, South-West Nigeria, participated in the study. Two instruments were used: the Biology Process Skills Acquisition Test (BPSAT), with a reliability coefficient of 0.81, and the Biology Students Interview Protocol (BSIP). The intervention lasted for five weeks. While the experimental group was taught using CTCA2.0, the control group were taught with lecture method. Quantitative data were analyzed using mean, standard deviation, and ANCOVA, while qualitative data were analyzed thematically. Findings revealed that prior to the treatment, there was no significant difference between the two groups [$F(1, 101) = 13.86$; $p > .05$]. However, after the intervention, the non-science students in the experimental group significantly outperformed their counterparts in the control group [$F(1, 101) = 20.56$; $p < .05$]. Furthermore, students in the experimental group expressed positive views, acknowledging that CTCA2.0 helped them acquire various biology process skills. Based on these results, it is concluded that CTCA2.0 is effective in enhancing the process skills of non-science students. It is therefore recommended for adoption in Nigerian secondary schools, along with the promotion of indigenous project-based exhibitions, science fairs, and inter-school competitions to further develop and apply students' process skills.

Keywords: Biology; Culturo-Techno-Contextual Approach 2.0 (CTCA2.0); Digestive System; Non-Science Students; Process Skills Acquisition.

INTRODUCTION

Integrating culture, technology, and context in biology offers a dynamic approach to enhancing non-science students' learning, by deploying culturally relevant content, modern technologies, and real-world scenarios, teachers can make biological concepts more meaningful, helping the students connect theory to everyday life. In contrast to the present practice, wherein the formal education, often influenced by colonial powers, has marginalized African indigenous teaching methods in favor of eurocentric approaches that overlooked Africa's socio-cultural realities (Ncanywa, 2023; Anamuah-Mensah, 2020; Okebukola et al., 2016). In Nigeria, lecture based-methods have largely been substituted by eurocentric teaching practices like chunk and chew, concept mapping, peer tutoring, flipped classroom, jigsaw and think-pair-solo, while improving academic performance, often prioritize rote memorization over practical skills acquisition (Nwambo et al., 2022). As a result, students excel in academics but struggle with real-world problem-solving, hindering technological and entrepreneurial advancements needed for sustainable development. This disconnect has sparked calls for pedagogical reform in science education, aiming to measure academic success not only by test scores but also by stimulating students' curiosity and fostering innovation.

It is a concern that lecture method and other eurocentric teaching methods may have been limiting students' meaningful learning experiences in science (Adam et al., 2024). This level of success hampers students' acquisition of essential 21st-century skills (Mbua & Uche, 2024) which are critical for achieving the Sustainable Development Goals (SDGs) and the African Union's Vision 2063. In Nigeria, as in many other developing countries, the education system rarely equips students with the skills needed to address societal challenges such as environmental degradation, unemployment, insecurity, economic instability, and brain drain (Ezugwu & Big-Alabo, 2023). Perhaps, this inadequacy has contributed to Nigeria's low ranking (109th) on the Global Innovation Index (GII, 2023). Despite being trained to adopt new teaching methods, biology teachers often revert to traditional approaches, further widening the gap between theoretical knowledge and practical skill acquisition in the subject. This underscores the urgent need to re-evaluate the focus of science education and its metrics to enhance innovation and creativity.

There is however, a growing recognition of the importance of incorporating indigenous knowledge into school science instruction (Onyewuchi & Owolabi, 2022). Our rich indigenous and cultural practices form an essential part of students' prior experiences and sources of information that they bring to school. This approach aligns with Benjamin Bloom's taxonomy of educational objectives, which guides how teachers should teach and what students should learn, categorizing learning into three domains: cognitive, affective, and psychomotor (Voss, 2024). In the 21st century, education should place greater emphasis on the development of skills, mastery of information and communication technology (ICT) (Rushiana et al., 2023), and the essential skills such as critical thinking, problem-solving, creativity, innovation, communication, and collaboration (Akintoye et al., 2024). For students to think critically and solve problems, certain core skills must be taught in our science classrooms, these skills are integral to scientific inquiry (Wabuke, 2016) to process information and enable the students to under natural phenomenon. It is therefore imperative to implement teaching methods that effectively develop these skills in biology biology classrooms.

Process Skills, Science Learning, and Biology

In the realm of science, the investigative spirit is captured through what we call **process skills**. These skills are the techniques or methods students use to explore and understand their immediate environment. They are the building blocks of scientific inquiry, essential for acquiring 21st-century skills, promoting a deep understanding of the world around us. The process skills plays a critical role in carrying out experiments and are transferable across disciplines and applicable in everyday life (Kurniawan & Ningsi, 2020). For instance, students utilize process skills to observe biological specimens, measure physiological responses, classify organisms, and accurately record data. The ability to analyse and interpret data enables students to draw meaningful conclusions about biological processes, such as the effects of environmental changes on ecosystems (Azhar & Megahati, 2022), this allows the students to engage actively with the subject matter (Tutik & Oktaviani, 2023).

Equipping biology students with process skills that enable them explore, investigate, and understand their surroundings is one step closer to making them reasoning like scientists (Kurniawan & Ningsi, 2020). Process skills in science can be categorized into basic and integrated skills. Basic process skills form the foundation, providing the necessary groundwork upon which more complex, integrated skills are built. In biology classrooms, scientific discovery often begins with observation, a skill that has been central to inquiry for centuries. To make meaningful observation, students use their senses, sight, hearing, touch, smell, and taste, to gather data and uncover patterns in nature. Observation is the foundation for developing other key scientific skills.

With format observation, students engage in classification, sorting their findings into meaningful categories. They begin with basic distinctions, this skill helps them identify patterns and relationships in nature. Consequently, students can apply measuring skills to quantify their observations, this could be done by using tools like rulers, thermometers, and microscopes, and they measure aspects like size, temperature, or magnification. This skill enhances the accuracy of their classifications, deepening their understanding of biological structures and processes. Another crucial skill in biology in classification, this allows students to share their findings with others. Whether through written reports, oral presentations, or visual models, effective communication helps students articulate their observations and ideas clearly, ensuring that others can understand and engage with their findings. As students advance, they develop the skills of inferring and predicting. Inferring involves drawing conclusions from observations and prior knowledge, while predicting allows students to forecast future outcomes based on current information. These skills help students connect data to broader biological concepts and anticipate the results of experiments. (Azhar & Megahati, 2022; Kurniawan & Ningsi, 2020)).

At an advanced level, integrated process skills are crucial for engaging students in scientific inquiry and problem-solving. These skills include controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting, and creating models. Controlling variables ensures accuracy in experiments by manipulating specific factors while keeping others constant, enabling reliable results. Defining operationally provides clear, measurable guidelines for variables, ensuring consistency and reliability in experiments. Formulating hypotheses allows students to make predictions that guide their investigations, which are subsequently tested through experimentation by manipulating variables and observing outcomes. Interpreting data involves transforming raw data into meaningful information, enabling students to analyse results and draw conclusions about scientific phenomena. Creating models simplifies complex biological concepts, facilitating a deeper understanding of abstract ideas (Tutik & Oktaviani, 2023, Azhar & Megahati, 2022).

Despite the acknowledged importance of process skills, there is significant evidence that these skills are not being adequately developed in many Nigerian secondary schools. Previous studies indicate that current teaching methods in Nigerian schools often fail to promote process skills acquisition (Adams et al., 2024; Adams et al., 2023). Many students are still unfamiliar with integrated process skills and even most of the science teachers who are to guide the learners are short sighted in developing the practical skills of learners couple with the lack of necessary facilities to work with (Oludipe, Saibu, & Owolabi, 2022; Kurniawan & Ningsi, 2020). This deficiency in practical, hands-on learning experiences hampers inquiry-based learning and limits students' meaningful understanding of scientific concepts (Azhar & Megahati, 2022). Amidst this challenge, several studies recommended culturally responsive teaching approaches for improving learning outcomes (Adams et al., 2024; Onowugbeda et al., 2024; Gbeleyi et al., 2021; Oladejo et al., 2021), however this study stands out being the first to explore the impact of a culturo-techno contextual approach (upgraded version) on process skills of students particularly in difficult biology concepts.

In the Nigerian senior secondary school system, students are departmentized into academic tracks such as Science, Commercial, and Humanities based on their subject combinations and future career interests. Science students, who typically offer core subjects like Physics and Chemistry, are known for their analytical thinking, curiosity, and preference for structured, evidence-based learning environments (Bayani et al., 2025; Taber, 2014). In contrast, non-science students, those in Commercial and Humanities streams, gravitate towards disciplines such as accounting, literature, history, and the arts, and often exhibit strong communication skills, a preference for qualitative analysis, and interest in exploring human experiences and societal issues (Pacadaljen, 2024). While both groups benefit from collaborative learning (Chen & Samsudin, 2022), non-science students often find science subjects like biology abstract, irrelevant, and disconnected from their everyday realities, resulting in disengagement and passive participation (Pacadaljen, 2024). This highlights the need for differentiated instructional approaches that respond to their unique learning styles thus making biology more accessible and meaningful for non-science students (Membiela et al., 2023; Mujtaba et al., 2018).

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Why Cultural-Techno Contextual Approach 2.0 (CTCA2.0)?

The Culturo-Techno-Contextual Approach (CTCA) is a modern teaching method developed to help students better understand their subjects by incorporating cultural, technological, and contextual elements into their learning experience. This innovative approach was created by Okebukola in 2015 and formally published in 2020 after over four decades of research into the best methods for teaching science in Africa (Okebukola et al., 2016). The CTCA draws on three main pillars to create a rich learning environment. Firstly, recognizing the cultural backgrounds of students, CTCA connects educational content to their cultural experiences and indigenous knowledge which makes learning real to the students. Secondly, by utilizing modern technological tools, CTCA enhances the communication between teachers and students. This not only improves the delivery of educational content but also makes learning more interactive and dynamic. Lastly, each school has a unique identity shaped by its geographical location. CTCA leverages this by incorporating local examples and case studies, making lessons more relevant and practical for students (Okebukola, 2020). (Adebayo, et al., 2022; Adeosun et al., 2022).

To implement CTCA effectively, teachers follow a five-step procedure. First, students are given pre-lesson assignments to research indigenous knowledge and cultural practices related to the lesson topic, gathering information from family, friends, or other knowledgeable sources. This grounds their learning in their cultural context. Next, students are divided into groups to discuss and share their insights. This collaborative approach helps deepen their understanding through the exchange of ideas. Each group then selects a leader to summarize their discussion, ensuring that key points and different perspectives are captured and shared with the entire class. The teacher then relates the topic to cultural attributes, providing examples of how it can be applied in daily life (Okebukola 2020). These steps connects theoretical knowledge to practical application. Finally, the teacher uses a contextual approach to help students familiarize themselves with the topic, reinforcing their understanding through relevant and practical examples. Unlike lecture method, the CTCA offers a learner-centered approach that views students as active participants in the learning process. (Adebayo et al, 2022; Adeosun et al., 2022; Okebukola, 2019;).

Previous studies have demonstrated that CTCA effectively improves students' academic performance, knowledge retention, and critical thinking in science education (Okebukola et al., 2016; Adam et al., 2023; Oladejo et al., 2022; Gbeleyi et al., 2021). Additionally, this approach reduces students' anxiety, enhances their attitudes toward learning, and boosts classroom participation, critical thinking skills, and overall interest in biology (Agbanimu et al., 2022; Adeola, 2020; Hungbeji, 2020; Sholanke, 2020). Despite these successes, there exists the needs to add some features, leading to the development of the Culturo-Techno-Contextual Approach 2.0 (CTCA2.0) which this study adopted.

The CTCA2.0, still grounded in culture, technology and context (see Figure 1), seeks to address these limitations and further enhance the integration of cultural, technological, and contextual elements in science education, providing an even more effective framework for improving students' learning outcomes and engagement.

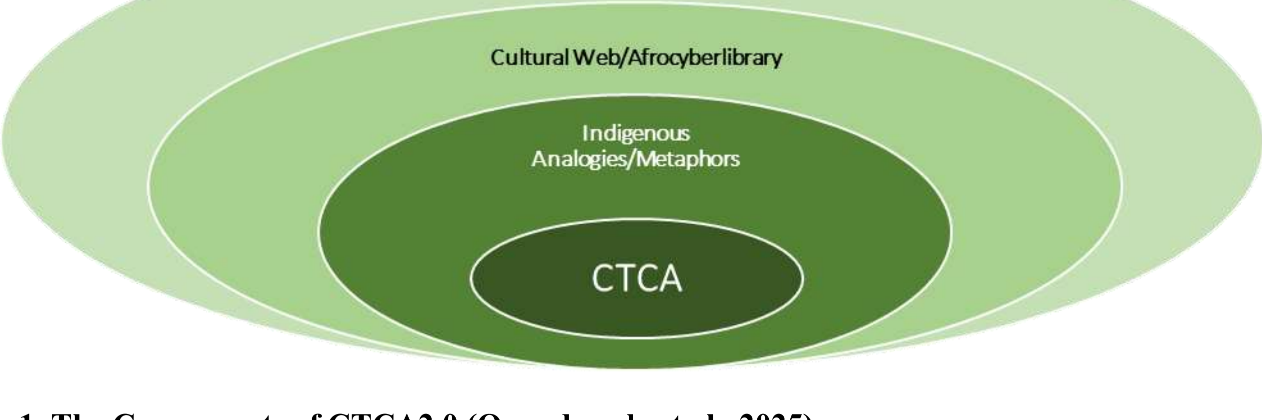

Figure 1. The Components of CTCA2.0 (Ogundowole et al., 2025)

The transformation of CTCA2.0 incorporates significant modifications to address the concerns of both students and teachers, thereby improving the overall effectiveness of the approach. One major limitation of CTCA, often highlighted by students and teachers, is the difficulty in accessing indigenous knowledge or cultural practices. Many students and teachers, especially those from urban areas, find these concepts unfamiliar, which deprives them of the full benefits of the CTCA approach. Another notable limitation of CTCA is its reliance on only two modes for delivering lesson summaries: WhatsApp and SMS. Considering a large class of about 150 students, the cost and logistical challenges of sending short messages can be substantial, necessitating the need for alternative methods. Additionally, the character limit in these summaries restricts the amount of information that can be conveyed, potentially hindering comprehensive understanding. Moreover, the CTCA requires formal method for assessing students' understanding of the concepts taught because without structured assessments, it is challenging for teachers to gauge students' comprehension or identify areas needing further attention. While the approach encourages student reflection and group sharing, the central role of the teacher in guiding lessons may limit deeper student engagement and opportunities for independent exploration.

The CTCA2.0 addresses these limitations by introducing significant changes. One advantage of this upgraded version is the use of analogies and metaphors where cultural practices and indigenous knowledge are not readily available, making the concepts more accessible. Furthermore, the CTCA2.0 avails students the opportunity to visit designated web resources and the Afrocyberlibrary to explore indigenous knowledge and cultural practices. This not only broadens their access to these resources but also enhances their learning experience. Additionally, CTCA2.0 now incorporates a six-step procedure (see Figure 2), as opposed to the five steps in CTCA. This new framework aims to enhance the inclusivity and effectiveness of the approach, ensuring that all students, regardless of their background or access to technology, can benefit from an engaging science education. The limitations of CTCA, when addressed, provides a more robust and inclusive educational framework that better meets the needs of both students and teachers.

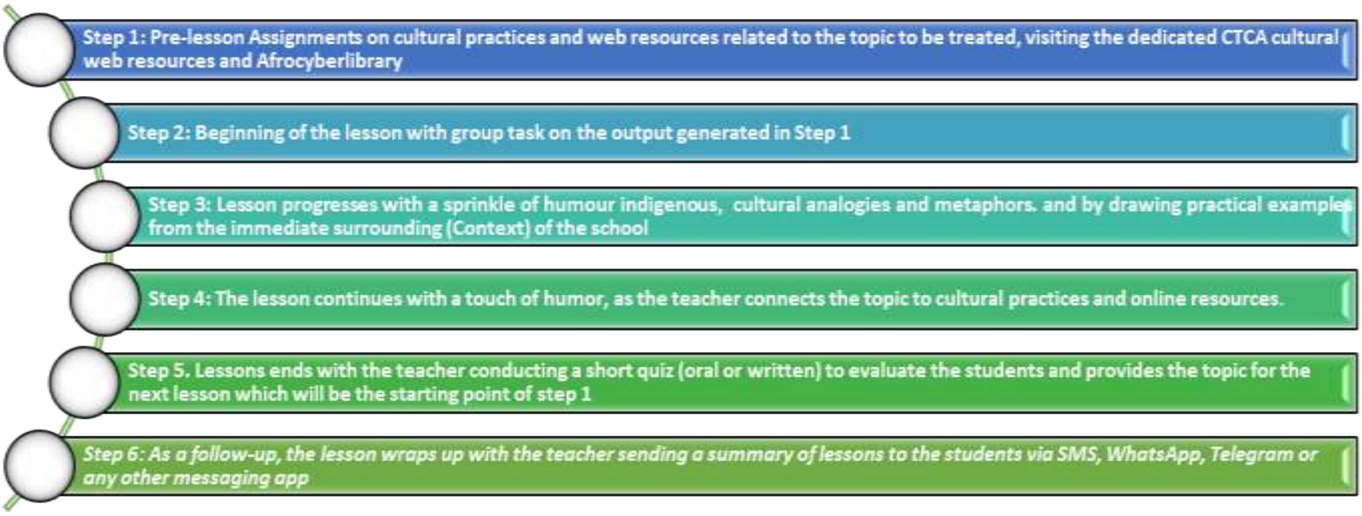

Figure 2. The CTCA2.0's Procedural Steps (Ogundowole et al., 2025)

Picture biology classrooms where science goes beyond memorizing facts, encouraging students to understand the world through the perspective of their own culture, supported by the latest technology and connected to their own environment. This reflects the essence of the CTCA2.0 framework in science education. The authors argue that;

"different cultural groups offer valuable perspectives in understanding the natural world, and that teachers can bridge the gap between students' existing knowledge and new scientific concepts by incorporating these cultural views. This can be achieved by using examples drawn from students' language and customs, which not only enhances understanding but also promotes skill development, helping students make connections between the classroom and their environment."

This study addresses current issues in science education by shifting the focus towards acquiring process skills in biology, rather than just concentrating on knowledge and attitude. Previous research on the CTCA framework has primarily evaluated its effectiveness in enhancing various factors such as performance, attitude, anxiety, retention, and critical thinking (Adam et al., 2024; Ademola et al., 2023; Oladejo et al., 2023; Samson et al., 2022; Gbeleyi et al., 2021; Okebukola et al., 2021). While these studies have shown the approach to be effective, they have not paid sufficient attention to the acquisition of core scientific skills. By extension, our study fills that gap by investigating indigenous analogies and metaphors in CTCA2.0 framework can redefine achievement metrics in biology. It emphasizes the importance of process skills acquisition, which is crucial for authentic learning in science education. This study stands out as the first to explore this combination, providing a fresh perspective on improving biology students' process skills. Gleaning on this, we hypothesized that CTCA2.0 could significantly enhance process skills of non-science students offering biology in senior secondary schools in Nigeria.

Research Questions

This study was guided by two research questions:

1. Is there any difference in the process skills acquisition mean scores of non-science students taught digestive system using the CTCA2.0 and those taught using the lecture method?
2. How do non-science students view the impact of CTCA2.0 in teaching and learning of biology?

Null Hypothesis

The study tested one null hypothesis at a 0.05 level of significance:

There is no statistically significant difference in the process skills acquisition mean scores of non-science students taught digestive system using the CTCA2.0 and those taught using the lecture method.

THEORETICAL REVIEW

To understand the theoretical foundation of this study, three key theories are reviewed. Firstly, Okebukola's Eco-Technocultural Theory emphasizes the importance of the learning environment and micro-cultures in shaping the educational experience. This theory operates through two main pathways: linking local experiences to scientific concepts and integrating indigenous knowledge with STEM learning. By connecting students' everyday experiences and cultural knowledge to scientific principles, the theory enhances both understanding and skill development, making abstract concepts acceptable for the students. Teachers can use this approach to help students acquire process skills such as observing and classifying by incorporating familiar cultural practices into their lessons. This connection not only enhances students' engagement but also aids in forming neural connections that deepen their understanding and skills in science.

Additionally, Vygotsky's Social Constructivist Theory highlights the role of social interaction, cultural tools, and guidance from more knowledgeable individuals (MKO) in the learning process. This theory underscores the importance of collaborative learning environments where students interact with their peers and use cultural tools to enhance their understanding. Guided by teachers and peers, students can develop critical process skills such as communication, classification, hypothesizing, and experimenting. The concept of the Zone of Proximal Development (ZPD) ensures that students are challenged just beyond their current abilities, promoting deeper learning and skill acquisition. Teachers can facilitate this by designing lessons that encourage peer collaboration and scaffolded support, fostering a learning environment where students can communicate, classify information, and experiment with new ideas effectively.

To strengthen this, David Ausubel's Theory of Advance Organizers emphasizes the significance of connecting new information to students' existing knowledge base (Ausubel, 1963). This approach helps teachers reduce cognitive overload and facilitate comprehension by linking new scientific concepts to what students already know. Leveraging on advance organizers, teachers enable students to define scientific terms clearly, take accurate measurements, and interpret data effectively. This method supports the development of critical cognitive and process skills, enhancing overall learning outcomes. Teachers can employ advance organizers to

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help students measure and interpret scientific data, thus making the learning process more efficient and meaningful.

These three theories collectively provide a robust framework for the CTCA2.0 in science education. Integrating cultural relevance, technological support, and contextual grounding, CTCA2.0 promotes an effective learning environment. This approach not only improves students' understanding and retention of scientific concepts but also enhances their critical thinking, problem-solving, and practical skills, preparing them for the challenges of 21st-century science education. Teachers can leverage these theories to create a dynamic and inclusive classroom where students can acquire essential process skills, thereby enhancing their overall scientific literacy and competence.

The theoretical frameworks emphasize enhancing learning by integrating cultural, technological, and contextual factors. Okebukola’s Ecotechnocultural Theory underscores the importance of incorporating students' cultural backgrounds, technology, and local environments into the learning process to create last long experience. This aligns with Vygotsky’s Social Constructivist Theory, which highlights the social nature of learning, where knowledge is co-constructed through interactions with peers, teachers, and the environment, with technology facilitating collaboration and exploration. Ausubel’s Theory of Advance Organizers further complements this by stressing the need to link new information to students' prior knowledge, achieved by using culturally relevant examples and technological tools.

Together, these theories support the Culturo-Techno-Contextual Approach (CTCA) by making biology education more relatable, interactive, and connected to students' prior knowledge, aiming towards improving the process skills of students in biology.

METHOD

Design

The study’s design is explanatory sequential design. This involves a mixed-method approach step by step phases, the quantitative phase adopted quasi-experimental specifically a non-equivalent control group pretest posttest design and intact classroom groups were used because it was not possible to assign students into experimental and control groups, if otherwise, the activities of the school would have been disrupted. The qualitative phase employed an in- depth interview, this was carried out to gather the experiences and views of the students in the experimental group. We conducted in-depth interviews to gain deeper insights and context, which complemented the numerical data and helped explain trends or anomalies observed in the quantitative results. Although the study primarily focused on quantitative data, the inclusion of interview responses enriched the findings, providing a more robust and comprehensive understanding of the subject, in line with the principles of ethnography which focuses on the detailed and systematic study of people and cultures, emphasizing the importance of understanding participants' perspectives within their natural settings (Lim, 2024)

Study Context, and Participants

Lagos State is situated in the southwestern region of Nigeria and at the time of this study, it consists of six education districts (District I-VI). In Lagos State, an education district is a geographic region overseen by the Lagos State Ministry of Education. Education District One has the largest number of public senior secondary schools, with 42 schools in total. These districts are responsible for the administration and supervision of public schools within their areas, ensuring that educational policies and standards are implemented effectively.

All the districts share similar characteristics, such as teachers' qualifications, training support, and quality control under the same commission. This uniformity across districts allows for a consistent approach to education while also enabling the selection of one district for specific studies or initiatives. The goal is to provide consistent and high-quality education across the state by managing resources, planning educational programs, and monitoring school performance within each district. This system helps to address the diverse educational needs of different regions, promoting equity and excellence in education throughout Lagos State.

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Education district one, along with two public senior secondary schools in Lagos State, was randomly chosen using a simple ballot system. The study involved 104 Senior Secondary School II (Equivalent to 11^{th} grade) students, comprising 46 males and 58 females, with an average age of 14 years. SS II Arts students were selected for their foundational knowledge of nutrition and food classes, which served as prerequisites for the digestive system topic, and for their availability during a stable learning period before standardized exam preparations. These students formed two intact groups: 51 non-students in the CTCA2.0 group and 53 non-science students in the lecture method group. Yoruba ethnic group (About 68%) constitutes the total sample used for this study, and all of them were proficient in English, this ensured effective communication throughout the study. To prevent the interference of the confounding variables, we used intact classes to ensure validity of our results and considered digestive system as a concept in this study because it is relevance to food security, personal health, and career pathways and the concept has been perceived difficult by the students (WAEC 2016, 2019, 2020, 2024), also the surveys on challenging biology topics conducted in Ghana and Nigeria (Okebukola, 2020) add to this report by identifying the concept as being difficulty in the biology curriculum. Additionally, the integration of cultural and indigenous knowledge into teaching this topic remains underexplored in the literature. In this order, pretest, treatment and posttest were administered to the students in both groups and then the interview was conducted in the experimental group only.

Instrumentation

We employed Biology Process Skills Acquisition Test (BPSAT), a self-developed instrument to assess students' mastery of biology process skills. The BPSAT was designed based on recommended biology textbooks, West African Examination Council (WAEC) standard and the objectives of the study. The instrument consists of two sections; A and B, section A elicits demographic information, including students' gender, age and class, while section B features 30 multiple-choice questions focusing on digestive system. Each question has one correct option and three distractors (Okebukola, 2015). Additionally, the researchers adapted a test blueprint used to examine the impact of inquiry-based learning on process skills acquisition (Wabuke, 2016) to guide the distribution of questions across the twelve process skills; observing, classifying, measuring, communicating, inferring, predicting, interpreting data, controlling variables, defining operationally, hypothesizing, experimenting, and creating models. All questions carried equal weight of 1 for correct answer and zero for the incorrect. Examples of BPSAT questions include:

1. If a scientist measures the rate at which starch is broken down by amylase, which unit is likely to be used to measure the amount of starch remaining?
2. If a person has difficulty digesting lactose, what can be said about their digestive system?

To validate the instrument, one experienced biology teacher and two science education lecturers (biology major) were engaged, these experts have over a decade of teaching experience and expertise in teaching biology and marking of external examination (WASSCE). They thoroughly check the questions and answer options for clarity, relevance, and alignment with the intended process skills, ensuring a clear correct answer and plausible distractors. They verified that each item matched the WASSCE curriculum and lesson objectives. Two science teachers assessed the items' structure for consistency with the lesson plans. Following their feedback, the final instrument was drafted for use. The experts satisfied the instruments valid and suitable before it was administered. We checked the internal consistency by factoring the data collected from the pilot study into SPSS (version 23), the output yielded a Cronbach's alpha 0.76, and since the value falls between 0.70 and 0.80 which is the accepted range (Mohajan, 2017). The instrument was considered reliable to be used for the study.

For the qualitative phase, ten students (m=5, f=5) from the experimental group were subjected to in depth interviews using a self-developed interview entitled Biology Students Interview Protocol (BSIP), these students were selected based on consistent attendance and active participated during lessons (Jaiyeola, 2020). Ensuring gender balance, the group included an equal number of male and female participants, reflecting our interest in exploring potential gender differences in performance. The interviews were conducted a day after the posttest in a quiet school area to minimize distractions and offer a comfortable environment. Students were reassured that the interview was not evaluative and emphasized that their responses, whether verbal or non-verbal, were valued. Sessions, lasting approximately 12 minutes each, were recorded, with significant observations such as gestures

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or non-verbal cues like head-shaking noted for further analysis. Using the Biology Students Interview Protocol (BSIP), the interviews provided qualitative insights into how the (CTCA) 2.0 approach has aided process skills acquisition in digestive system. Sample questions in the instrument included:

1. What are your views on the newly implemented teaching method?
2. How has the method influenced your ability to comprehend and develop process skills in the digestive system?
3. What challenges did you face during the lessons? Suggest way out.

Treatment

The study began in a well-structured sequence designed to ensure clarity and minimize bias. Initially, pretest was administered to both the experimental and control groups to measure the students' baseline process skills levels. To prevent test fatigue, the pretests were conducted in the morning, between 9:10 a.m. and 10:50 a.m., to optimize students' focus and avoid encroaching on the school's break period. Each test lasted 45 minutes, with one minute and thirty seconds allotted per question. This process aimed to establish that any observed effects were not influenced by prior knowledge. The teaching and learning phase began the day after the pretest and lasted for five weeks. Both the experimental and control groups received equal contact time, with lessons conducted for 80 minutes each week. To mitigate teaching bias, the regular classroom teachers (research assistants) were engaged for the instruction in their respective groups. Before the intervention, the teacher assigned to the experimental group underwent through training to implement the Culturo-Techno Contextual Approach (CTCA) 2.0. This included three micro-teaching sessions to ensure good mastering of the approach. Lessons for the experimental group were subsequently delivered using the CTCA2.0, emphasizing the integration of culture, technology and contexts. In contrast, the control group was taught using the lecture method. Posttest was conducted at the end of the intervention to assess the level of process skills acquired in comparison with pretest. A day after the posttest, semi-structured interviews were conducted with the selected students from the experimental group to gather qualitative insights. The interviews were scheduled in the morning, between 9:20 a.m. and 10:30 a.m., to ensure the students were alert and focused. Conducted in a quiet classroom to minimize distractions, each session lasted approximately 12 minutes. The interviews spanned a whole day to avoid fatigue and provided valuable data to complement the quantitative findings.

The intervention spanned three weeks, with both groups receiving 80-minute lessons each week, two instructional guides were used: the Teachers' Instructional Guide on Culturo-Techno Contextual Approach (CTCA) 2.0 (TIGCTCA2.0) and the Teachers' Instructional Guide on Lecture Method (TIGLM)**.** In the first week, students learned about digestion and the parts of the alimentary canal. The second week focused on digestive enzymes, their characteristics, and classifications. The final week covered the process of digestion in mammals.

How CTCA2.0 was implemented in the Experimental Group

Having underwent rigorous trainings and micro teaching, the teacher assigned to the experimental group adopted

the Teachers' Instructional Guide on Culturo-Techno Contextual Approach (CTCA) 2.0 (TIGCTCA2.0) to teach digestive system. The six steps (see Figure 2) involved are as follow:

Step 1: Pre-lesson Assignments on cultural practices and web resources related to the topic to be treated, and visit to the dedicated CTCA cultural web resources and Afrocyberlibrary

Prior to the lessons on digestive system, students were informed in advance and encouraged to reflect on indigenous knowledge, cultural practices, and beliefs related to digestive system concepts. They were directed to explore CTCA2.0 cultural web resources and the Afrocyberlibrary (this is one of the unique features on CTCA2.0). Additionally, students were asked to use their mobile phones or other internet-enabled devices to search for relevant online materials, introducing the initial technological aspect of the approach. These reflections and findings were to be shared during the lesson.

Step 2: Beginning of the lesson with group task on the output generated in Step 1

At the beginning of the lesson, students were organized into heterogeneous groups, ensuring diversity in gender and ability levels. Within these groups, students exchanged their reflections on indigenous knowledge and cultural practices, along with online resources they had explored. Group leaders recorded these discussions and later presented them to the entire class.

Step 3: Lesson progresses with a sprinkle of humour indigenous, cultural analogies and metaphors, drawing practical examples from the immediate surrounding (Context) of the school

The teacher incorporated real-life, observable examples from the local community to illustrate digestive system concepts, making the lesson more tangible and relatable. Additionally, culturally relevant analogies, metaphors (this is the second unique feature of this approach), and humor were integrated into the instruction, reinforcing the contextual dimension of the teaching approach.

Step 4: The lesson unfolds with a touch of humor, as the teacher connects the topic to cultural practices and online resources.

The teacher emphasized the significance of the indigenous knowledge and cultural insights shared by the groups, ensuring they contributed to a deeper understanding of digestive system concepts. The misconception stemmed from cultural beliefs were addressed and corrected. Some of the indigenous practices and analogies provided by the students offer a vivid and culturally relevant way to understand key concepts of digestion, these are given below:

Some of the indigenous knowledge, cultural practices and analogies used to exemplify digestive system during the lessons

Digestion of Food

Digestion of most carbohydrate food begins in the mouth with chewing and grinding, this was compared to the traditional practice of using a mortar and pestle (*"Odo Iyan"* in South-West Nigeria) or an okra grater (*"IrinIlla*"). The action of pounding boiled yam in the mortar with the pestle (see Figure 3) closely resembles the process of mastication (chewing), where the teeth break down food into smaller pieces. Just as the mortar and pestle crush and grind the boiled yam, our teeth crush and chew food, increasing its surface area for easier digestion.

Figure 3: Pounding of boiled yam with Mortar and Pestle explaining chewing

Source:https://upload.wikimedia.org/wikipedia/commons/thumb/f/f9/Pounding_yam.jpg/1280px-Pounding_yam.jpg

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Similarly, the traditional stone mill (see Figure 4) used by African traditionalist to grind local edible wild plants (*Al-Fatimi, (2021).*) serves as an analogy for the process of chewing vegetables in the mouth. Just as the stone mill is used to crush and break down plant materials into a fine paste or powder, the teeth in our mouth serve a similar function in grinding and mashing food. When we chew vegetables, our teeth perform a grinding action that breaks down the plant fibers into smaller, more manageable pieces. This is much like how the heavy stones of the mill crush the wild plants into smaller particles, increasing the surface area. In both cases, the purpose is to make the food easier to digest and to release its nutrients. The saliva in the mouth, much like the water used to moisten the plants in the mill, helps soften the food and mix it, preparing it for further digestion in the stomach.

Figure 4: A traditional stone mill describing digestion

Source: Al-Fatimi, (2021).

Secretion of Saliva

Secretion was likened to the traditional practice of tapping palm wine, known as "Dida emu ope." Just as tapping the palm tree releases sap, which flows down into containers, the presence of food in the mouth triggers the salivary glands to secrete saliva. This liquid helps moisten the food, facilitating the mechanical breakdown and beginning the chemical digestion of starches. The tapping of palm wine (see Figure 5) serves as an analogy for this natural secretion that plays an essential role in digestion.

Figure 5: Tapping of Palm wine exemplifying secretion

Source: https://media.sciencephoto.com/image/c0026576/800wm/C0026576-Palm_wine_production

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Digestive Enzymes

Enzymes speed up our digestion process, and this is exactly what items such as potash alum, and an iron spoon do (see Figures 6 and 7). Potash alum popularly known as Kanhun in Yoruba (South-West Nigeria), is commonly used in traditional cooking to break down tough fibers in food, much like how digestive enzymes work to chemically break down complex molecules in the stomach and intestines. These substances aid in softening and preparing food for easier digestion.

Figure 6: Potash Alum (Kanhun) used in cooking to soften food.

An iron spoon, used to stir and mix food evenly during cooking, can also symbolize the role of enzymes in uniformly interacting with food particles, ensuring that digestion occurs efficiently and thoroughly.

Figure 7: Local Iron Spoon

Peristalsis in the Oesophagus

This is excellently illustrated by the analogy of children sliding down a playground slide (see Figure 8). The smooth and continuous movement of children down the slide mirrors the wave-like muscle contractions in the oesophagus known as peristalsis. These muscular contractions push food down the oesophagus, much like gravity helps children slide smoothly to the bottom of the slide. The analogy emphasizes the sequential nature of peristalsis, ensuring the food moves efficiently toward the stomach.

Figure 8. African Children Sliding in the Mud during the Rainy Season

Source: https://encryptedntbn0.gstatic.com/images

Churning of Food in the Stomach

This was represented by the traditional practice of making palm oil, known as "Eku" in Yoruba. In this process, the palm fruit is vigorously churned to separate the oil from the fibrous pulp (see figure 9), similar to how the stomach churns food. The stomach's muscular contractions mix food with gastric juices and digestive enzymes, breaking it down into a semi-liquid form called chyme. The rhythmic, repetitive churning action in both processes ensures that the contents are properly mixed and prepared for the next phase of digestion.

Figure 9: Traditional way of making Palm Oil

Source;https://i0.wp.com/media.premiumtimesng.com/wp-content/files/2023/06/Capture-1.jpg?resize=670%2C499&ssl=1

Step 5. Lessons ended with the teacher conducting a short quiz (oral or written) to evaluate the students and provides the topic for the next lesson (the starting point of step 1)

At the end of the lesson, the teacher asked some questions, in our study, the teacher allowed the students to discuss about the questions and answered in groups, their process skills exhibited were observed. Samples of the questions given to the students are stated below:

1. How does the texture and appearance of corn look before and after simulated digestion?
2. How can corn be classified based on where it is digested in the human digestive system?
3. What instruments are used to measure the temperature and pH of corn before and after enzyme action?
4. How would you present the role of different organs in corn digestion to your classmates?
5. What impact does thorough chewing versus poor chewing have on the digestion of corn?
6. What do you predict would happen if the stomach was bypassed during the digestion of corn?

This activity provided immediate feedback on their learning and helped the teacher identify areas that needed further clarification. Following the evaluation, the teacher introduced the topic for the next lesson. This served as a foundation for the next step (step 1), where students engaged in pre-lesson activities such as exploring cultural practices and web resources related to the new topic, ensuring that students were prepared to actively participate in the next lesson.

Step 6: The lesson wraps up with the teacher sending a summary of lessons to the students via WhatsApp or Telegram.

After each class, a brief lesson summary was sent to the students via Telegram and WhatsApp to the students. Initially, the teacher sent the first summary, but afterward, student's group leaders took over this task.

Lesson Delivery in the Lecture Method Classroom (Control Group)

In the control group, throughout the three weeks, the students were taught the same topic (digestive system) just as those in the experimental group but using the Teachers' Instructional Guide on Lecture Method (TIGLM**).** Being a teacher-centred method of instruction, the lessons were conducted using only class discussions, with less students' engagement. The students were not encouraged to source for or share their indigenous knowledge on digestive system, nor was there any emphasis on connecting the topic to their cultural practices or traditional knowledge. In the context of Nigerian classrooms, the lecture method typically involves the teacher delivering a lesson based on a pre-prepared lesson plan as outlined below:

Step 1: The teacher begins by reviewing the previous lesson and introducing the new topic (digestive system) to the students.

Step 2: The teacher provides detailed explanations of key concepts, such as digestion, enzymes, and the alimentary canal. The teacher also explains the functions of various organs involved in digestion and the roles of digestive enzymes.

Step 3: The teacher writes important points on the chalkboard for students to copy into their notebooks, reinforcing the material covered.

Step 4: The teacher summarizes the main points of the lesson to ensure students understand the key takeaways.

Step 5: The teacher assigns related homework for students to complete in their notebooks.

We ensured that the biology teachers who were engaged as research assistants for both the experimental and control groups were retained throughout the study to control for teacher-related variables. This decision was made because teacher-related factors, such as teaching style, experience, and age, can significantly impact students' learning outcomes. Keeping the same teachers across both groups helped to eliminate any potential bias that could have arisen from using different teachers for each group, thus ensuring more reliable and valid results of our study.

Following the instructional period, both groups participated in posttest to assess their process skills level, respectively. This decision was based on the need to evaluate the students' performance after the intervention to measure the effectiveness of the teaching methods employed in both groups. The tests were conducted a day after the treatment ended, this is to minimize the impact of time, ensuring that the immediate effects of the instructional methods were captured. Also, to avoid any familiarity with the test questions, the pretest questions were reshuffled. This decision was made to prevent students from memorizing the answers and performing better on the posttest simply due to prior exposure to the same questions. This ensured that the results reflected their actual learning and not just familiarity with the test format. Additionally, the number of students remained consistent across all assessments in both groups. This was crucial to maintain balance between the experimental and control groups, ensuring that differences in performance could be attributed to the instructional methods rather than variations in sample size. Consistent student numbers also supported the statistical analysis of the results.

To reduce students' anxiety and ensure data integrity, teachers informed the students that the tests would not impact their academic grades, and there was no reward for better performance. This decision was made to alleviate any pressure or stress that might interfere with the students' natural performance on the tests. We ensured that the students perceived the tests as purely evaluative rather than a high-stakes component of their grades.

Data Analysis

The two research questions were answered using the Mean and Standard Deviation, while the null hypotheses were tested using Analysis of Covariance (ANCOVA). The choice of ANCOVA was informed because we could not assign the students to experimental and control group randomly. The analyses began with tests for parametric assumptions of the suitability of the chosen inferential statistics. The Shapiro-Wilk test for normality showed favorable results for both groups: experimental group ($N = 51$), [$F=.45$; $p>.05$] as well as the control group ($N = 53$), [$F=.63$; $p>.05$]. These findings indicated that the data in both groups follow a normal distribution, as the p-values exceeded .05 (Tim, 2024). Furthermore, the Levene's test for homogeneity of variance confirmed that there were no significant differences between the two groups [$F = .029$; $P > .05$]. The p value exceeding .05

implies that the equality of variance assumption is met (Zach, 2022). Based on these findings, one-way ANCOVA was consider suitable to analyze the data. The process skills acquisition scores served as the dependent variable, the teaching methods were considered the fixed factor and the pretest scores were utilised as the covariate. The data collected were analysed using IBM SPSS version 23. The qualitative data were analyzed using an interpretative thematic approach, providing a comprehensive discussion of the in-depth interviews. The audio recordings of the conversation were replayed several times, and verbatim transcriptions were created. To identify emergent themes relevant to the study for interpreting and reporting key findings, the transcripts were thoroughly reviewed multiple times

RESULTS

The preliminary tests indicated that we met the parametric assumptions of Levene's test of homogeneity of variance and the Shapiro-Wilks test of normality and since the subjects were not randomly assigned to groups, we employed Analysis of Covariance to partially determine the effect of any initial difference between the two groups, which might confound the results from the data.

The research one question which examined the difference between the process skills acquisition scores of non-science students taught digestive system using the CTCA2.0 and those taught using the lecture method, to answer this, mean and standard deviation were used.

Table 1. Mean and Standard Deviation of Process Skills Acquisition Scores of Non-Science Students Based on the Teaching Method

Group	N	Mean		Mean diff	SD		SD Diff
		Post-test	Pre-test		Post-test	Pre-test	
Non-science students_CTCA2.0	51	32.37	18.94	13.43	7.47	3.85	3.62
n-science students_Lecture Method	53	23.00	18.42	4.58	4.55	4.17	0.38

The results in Table 1 revealed that non-science students in the CTCA2.0 group had process skills mean scores and SD differences of 13.43 and 3.62 while their counterparts in the control group had 4.58 and 0.38. The results imply that the non-science students in the CTCA2.0 group demonstrated process skills acquisition better than the students in the control group. To determine the significance of the difference between the two groups, we further subjected the data to ANCOVA formula to test the significance.

Table ANCOVA of students' process skills acquisition scores in biology

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Pn^2
Corrected Model	758.84[a]	2	379.42	18.30	.00	.27
Intercept	1565.88	1	1565.88	75.53	.00	.43
Pretest	287.32	1	287.32	13.86	.76	.12
Group	426.29	1	426.29	20.56	.00	.17
Error	2093.92	101	20.73			
Total	68907.00	104				

a. R Squared = .266 (Adjusted R Squared = .251) *Significant P < .05

Results in Table 2 shows that prior the treatment, the two groups showed no significant difference [F (1, 101) = 13.86; *P* > .05], meanwhile, the observed difference in process skills acquisition was statistically significant [F (1, 101) = 20.56; *P* < .05], implying that after treatment, non-science students' taught with CTCA2.0

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outperformed their counterparts that were taught using the lecture method. Also, the partial eta squared estimate indicated that the treatment accounted for 17.0% of the variance observed between the groups.

To answer research question two, we analysed the interview responses of the selected using thematic approach, this was achieved by manually transcribing the interviews in order to become familiar with the data. Next, initial codes were generated and applied to the data set. In the third phase, codes featuring similar contents were grouped together under the identified themes. The findings are presented in table 3 below;

Table 3: Findings from the selected interviews

Impact of CTCA2.0 on students' process skills	Student 2 Female, 15yesars: *"I acquired skills like observing and classifying, but measuring was tough without tools, we need to see things from our culture to believe"* Student 1 Male, 16years*: "Infact the method helped my Communicating and observing skills, but operational definition is still difficult"* Student 5 Female, 14years: *"The method of teaching made it easy for me to classify and observe, but modeling needs more materials, please sir if you can help bring some cultural things to class we will understand more"* Student 6 Male, 16years*: "As for me, I gained confidence in communicating my ideas to my classmates, but defining operationally is challenging"* Student 3 Female, 15 years: "*...with how we learn digestive system, I can observe and classify well now but I struggled with creating models* Student 4 Male, 14years: "*Sir, I found the method helpful for communication but measuring is still hard without proper equipment but the method is interesting"* Student 9 male, 15 years: "*...digestive system is now simple to me as the method our teacher used to teach us helped me, I can communicate, observe and classify, and the method is good, I found creating models and experimenting still difficult.*

Table 3 depicts how the students view the effectiveness of CTCA2.0 in biology, 70% of the participants interviewed agreed that they developed a variety of process skills when taught with CTCA2.0. According to these students, the approach was effective in enhancing students' observing, classifying, communicating and inferring skills. However, students reported that certain skills, such as experimenting, creating models measuring, controlling variables, defining operationally were more challenging to acquire through the approach.

DISCUSSION

Research question one sought to assess whether there is a difference in process skills acquisition between students taught digestive system using the Culturo-Techno Contextual Approach (CTCA) 2.0 and those taught using the lecture method. The study found a significant difference (see Table 2). The qualitative data from students' interviews further supported these findings, with students from the CTCA2.0 group reporting improvements in process skills such as observing and classifying. For example, Student 1 (male, 15years) stated, *"I acquired some process skills, like observing and classifying skills*," while Student 6 (female, 15 years) echoed similar sentiments, noting, *"I acquired some process skills, like observing and classifying skills."* ; in this same vein, student 6 Male, 16years echoed that *"As for me, I gained confidence in communicating my ideas to my classmates, but defining operationally is challenging",* similarly another student stressed this position, and this is evident from Student 5 Female, 14years: *"The method of teaching made it easy for me to classify and observe, but modeling needs more materials, please sir if you can help bring some cultural things to class we will understand more"*. These responses highlight the effectiveness of the CTCA2.0 in enhancing process skills proficiency, particularly in observation and classification.

Since this study is the first on the impact of CTCA on process skills acquisition, the discussion domicile mostly on the related literature. The quatitative and qualitative findings relating to the first research question and null hypothesis align with Gbeleyi et al., (2021), who reported that CTCA improved students' critical thinking skills premise the significance of process skills to critical thinking skills. Darmaji et al., (2022) corroborates the position by reporting that process skills are closely related to critical thinking skill, noting that the significant improvement in process skills under CTCA could lead to enhanced critical thinking abilities. This line of arguement is not at par with the several other studies that stress the significance of process skills in science, Kurniawan & Ningsi, (2020) stress the critical role of process skills in carrying out experiments and enables students to draw meaningful conclusions about biological processes (Azhar & Megahati, 2022). Process skills allow the students to engage actively with the subject matter (Tutik & Oktaviani, 2023) when effective teaching method is used and adequate resources are provided to improve the practical skills of learners (Oludipe, Saibu, & Owolabi, 2022; Kurniawan & Ningsi, 2020). This could the reason why the process skills of students improved having related with the components of their culture, adopt internet enabled devices and use local examples around them to explain the concepts of digestion, while deficiencies of these learning experiences may hamper inquiry-based learning and limit students' meaningful understanding of scientific concepts (Azhar & Megahati, 2022). Still in agreement with this, Rushiana et al., (2023) and Akintoye et al., (2024) support the mastery of ICT, collaborating, critical thinking, problem-solving skills, and creativity, for students to have exceled in their process skills proficiency, certain core skills in science must have been taught (Wabuke, 2016).

Okebukola's Eco-Technocultural Theory provides a critical foundation to these findings. This theory highlights the significance of the learning environment and the micro cultures of students and teachers in shaping the educational experience. Linking practical local experiences to scientific concepts and integrating indigenous knowledge with STEM learning facilitates meaningful learning. Incorporating ecology, culture, technology, and humor such as in CTCA2.0 enhances process skills acquisition the relatability of scientific concepts. Similarly, Vygotsky's social constructivism theory (1978) and Ausubel's theory of meaningful learning (1962) are evident in the results. Vygotsky posits that how students engage with local cultural knowledge and technology contribute to their process skills acquisition. Also, the use of prior cultural knowledge, as prescribed in CTCA2.0, aligns with Ausubel's theory of advance organizers, where new information is linked to existing knowledge to facilitate meaningful learning, thereby enhancing the acquisition of process skills, new knowledge to prior experiences, reduced cognitive overload and ensured meaningful learning for all students.

The study highlighted how integrating indigenous and cultural practices into biology lessons can enhance students' understanding of abstract biological concepts, particularly in digestion. The Culturo-Techno Contextual Approach (CTCA) 2.0 successfully connected cultural practices to biological processes, making learning more relatable and meaningful. For example, the grinding of food with traditional tools like stone grinders and yam pounding illustrated the mechanical process of chewing and digestion, while tapping palm wine symbolized the secretion of saliva, initiating digestion. Traditional cooking practices involving ingredients like potash alum, onions, garlic, ginger and objects like iron spoon and nails mirrored the role of digestive enzymes in breaking down food. Other cultural activities, such as children sliding down a playground slide, were used to represent peristalsis, helping students visualize the movement of food through the digestive tract. The traditional palm oil making process mirrored the churning action in the stomach, while fermenting and pressing cassava linked to water absorption in the large intestine. Finally, observing a tap running out of water was used to explain egestion, reinforcing the importance of waste elimination. It is evident in this study that CTCA2.0 promotes the understanding of complex biological processes and facilitates the acquisition of process skills, particularly in observation, classification and communication.

On the perception of students about the effectiveness of CTCA2.0, the approach was effective in enhancing students' observing, classifying, communicating and inferring skills. This report does not contradict the findings of Wabuke, (2016) while examining the impact of inquiry-based learning on the process skills acquisition of student in biology, when students relate with their environment and solve practical problems, their process skills are enhanced. This is suitable to explain the culture and context parts of CTCA2.0 where the students had the ample opportunities for exploration. However, students reported that certain skills, such as experimenting, creating models measuring, controlling variables, defining operationally were more challenging to acquire through the approach.

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CONCLUSION

This study has highlighted the profound impact of the Culturo-Techno Contextual Approach (CTCA) 2.0 in enhancing process skills acquisition in biology. The findings demonstrate that culturally relevant and technology-enhanced teaching methods, such as CTCA2.0, offer significant advantages over the lecture-based method, and has promoted process skills acquisition and equitable learning environment for all students. Indigenous knowledge and cultural practices, when incorporated into biology lessons, provide students with relatable, real-world connections to scientific concepts, thereby bridging the gap between theoretical learning and everyday experiences.

This approach stresses the universal applicability of CTCA2.0, offering a modern iteration of culturally responsive teaching methods that can be adapted across different geographical regions and disciplines within STEM education. The study further reinforces the broader significance of CTCA2.0, which aligns with the long-established principles of culturally relevant pedagogy, as explored in diverse communities globally. The study suggests several important recommendations for educational reforms: a trial implementation of CTCA2.0 in Nigerian secondary schools to assess its practical effectiveness, encouragement for students to use mobile technology to enhance learning, and the organization of workshops for biology teachers to familiarize them with CTCA2.0. Additionally, the biology curriculum should explicitly recognize the cultural context of the students, ensuring that it is relevant to their needs and backgrounds. It is noteworthy that these recommendations can enhance the teaching and learning of biology, helping students develop the essential process skills that are integral to critical thinking and problem-solving skills necessary to thrive in the 21st century.

Educational Implications

This study provides crucial insights into enhancing biology students' process skills through the (CTCA2.0, which leverages the synergy of culture, technology, and context to foster process skills acquisition in students. The CTCA2.0 makes learning more practical and meaningful by integrating scientific concepts with students' cultural experiences and utilizing technology in teaching, it transforms biology classrooms into inclusive environments where abstract concepts are simplified and presented in ways that resonate with students' experiences and immediate envronments.

This inclusive approach ensures that all students, regardless of their background, can participate effectively and benefit equally from the educational process. The approach promotes the development of essential process skills, such as observing, classifying, measuring, communicating, and hypothesizing, by applying biological concepts within a culturally relevant framework. This leads to a balanced and comprehensive learning experience that not only enhances academic performance but also fosters critical thinking and problem-solving skills. Incorporating culturally relevant examples, CTCA2.0 demystifies science, making it more accessible and stimulating students' interest and confidence in the subject. This technological integration ensures that students have a richer, more diverse educational experience, enhancing their understanding and retention of scientific concepts. CTCA2.0 represents a significant advancement in science education by utilizing the nexus of culture, technology, and context. It equips students with the necessary skills to navigate and address real-world challenges, preparing them for future academic and professional success. The approach enhances biology students' process skills to become competent individuals capable of critical thinking and innovative problem-solving.

RECOMMENDATIONS

Within the limitations of the study, we recommend the:

1. Implementation of CTCA2.0 in secondary schools to further enhance the teaching and learning of biology.
2. Revision of the biology curriculum to integrate cultural elements and more practical applications of scientific concepts.
3. Organization of regular training sessions on the implementation of CTCA2.0, culturally responsive teaching strategies, to equip biology teachers with the skills required for effective use

4. Provision of technological tools in schools to support students and teachers interaction and learning experiences.
5. Inclusion of indigenous-based hands-on activities that familiarize the students with the cultural practices to promote process skills acquisition.
6. Promotion of indigenous project-based exhibitions, science fairs and competitions among schools to promote knowledge and skills acquisition

Ethical Consideration

Following research ethics, we secured required approvals from the ministry of education, education district one and the school authorities to conduct the study. All participants gave their informed consent by signing a consent form, confirming their understanding of the study's purpose and the assurance of confidentiality regarding their responses. Participation in the study was entirely voluntary, with the option to withdraw at any point without any repercussions. Additionally, it is noteworthy that no participants experienced any form of harm or distress, whether physical or psychological, throughout the research process.

Limitations And Future Direction

The study's design led to several limitations. Among are the use of intact classes which limited the randomization of participants, this may affect how broadly the findings can be applied. Variations in student attendance during pre-tests and post-tests reduced the sample size, possibly influencing the reliability of the conclusions. Additionally, insufficient learning resources such as students' inadequate access to internet enabled phones, resulted in group-based rather than individualized activities. This constraint may have lessened the specific impact of CTCA2.0 on individual student. Addressing these issues in future research will provide a clearer understanding of the approach's effectiveness.

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