

UNIVERSITY OF ILORIN



**THE THREE HUNDRED AND FIRST (301ST)
INAUGURAL LECTURE**

**“ADVANCING BIOLOGY EDUCATION THROUGH
CONSTRUCTIVIST PEDAGOGY: A ROAD TO
SUSTAINABLE NATIONAL DEVELOPMENT”**

By

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My Lords, Spiritual and Temporal,
Distinguished Invited Guests,
Gentlemen of the Press,
Students of Science Education and other students here present,
Great Students of the University of Ilorin,
Distinguished Ladies and Gentlemen.

Preamble

Auzubillah Minashaitan Nirajeem Bismillahir Rahmanr Rahim.

An inaugural lecture is not only a professional responsibility, but it is also a personal honour and privilege, one that I deeply cherish. It is with great humility and gratitude that I stand before you today, Thursday 7th May, 2026, to deliver the 301st Inaugural Lecture of this prestigious University. This lecture entitled “*Advancing Biology Education through Constructivist Pedagogy: A Road to Sustainable National Development*”, marks the 6th from the Department of Science Education and the 2nd in the field of Biology Education. It is also the 5th in the Science Education series at this University. The preceding lectures were delivered by Professor Aliyu Abdullahi (December 12, 1991), titled “*The Inflating and Deflating Syndrome in Nigeria’s Science Education*”; Professor Esther Ore

Omosewo (November 8, 2012), titled “*Why Dread the Science of the State of the Universe?*”; Professor Isaac Olakanmi Abimbola (February 21, 2013), titled “*The Misunderstood Word in Science: Towards a Technology of Perfect Understanding for All*”; Professor Adekunle Solomon Olorundare (May 22, 2014), titled “*Theory into Practice: Beyond Surface Curriculum in Science Education*” and Professor Medinat Folorunsho Salman (April 27, 2017), titled “*Language and Problem Solving: The Mathematics Education Link.*”.

I am eternally grateful to Almighty Allah (SWA), for His boundless mercies, and I say Alhamdulillah Rabbil Alamin, as I stand before you today to deliver this Inaugural Lecture. My teaching career journey began as an auxiliary primary school teacher in 1975/76 academic session. I then advanced to become a secondary school science teacher; and by 1991, I had transitioned into the role of a science teacher educator at Kwara State College of Education Ilorin. This position laid the groundwork for my current role as a university science teacher educator since 2013. Furthermore, I had the distinction of becoming the second Professor of Science Education on October, 2022 specialising in Biology at the Department of Science Education, following in the footsteps of my mentor, Professor Isaac Olakanmi Abimbola. I am deeply grateful to the management of my alma mater, the University of Ilorin, the *Better by Far* University, under the leadership of Professor Wahab Olasupo Egbewole, *SAN*, for my promotion to the rank of Professor, marking the pinnacle of my academic career.

Introduction

Mr. Vice-Chancellor Sir, distinguished guests, colleagues, and students. I intend, within the next 60 minutes, to take you on a journey through my professional experience as a science educator especially in the area of Biology Education. Let me state clearly that this lecture is primarily an exploration of my evolving understanding of effective science pedagogy rather than a mere summary of my research works. However, permit me to start by briefly sharing my personal journey, from someone who initially avoided teaching to becoming a passionate and dedicated science educator. Thereafter, I will lay the foundation for my argument that there is an urgent need for a more effective

approach to Biology Education through analysis of student performance data in Biology from the West African Senior School Certificate Examinations (WASSCE), highlighting trends and persistent challenges.

The role of constructivism as a learning theory is the central theme of this lecture, hence, I will discuss what constructivism is, and how it promotes active student engagement, meaningful learning, critical thinking, and the construction of knowledge through experience, rather than rote memorisation. In addition, I will project the interdisciplinary nature of science education, highlighting the necessity to integrate knowledge from more than one discipline to create meaningful learning experiences. Furthermore, I will briefly x-ray the complex roles played by science educators, who are likely to be classroom teachers, curriculum builders, researchers, and policymakers.

As expected in an inaugural lecture, I hereby outline the main areas of my research, to include, but not limited to:

1. *Constructivism Innovative Instructional Strategies*: My research has identified applying constructivist ideas to enhance teaching and learning in Biology to be significantly rewarding.
2. *Misconceptions in Biology*: A substantial part of my works focused on examining the underlying sources of misconceptions of Biology concepts, assessing their prevalence among students and teachers, and developing targeted instructional strategies to remediate them.
3. *Science Curricular Material*: I equally dedicated part of my work to the study and evaluation of Biology curriculum materials, to ensure their effectiveness.
4. *Integrating Technology into Biology Education*: I have investigated the efficacy of integrating virtual labs simulations and artificial intelligence among other technology-enhanced learning environments to promote students' engagement and meaningful learning in Biology Education.
5. *Teachers' Mastery of Content and Pedagogical Knowledge*: It is well known that the quality of teachers

is a reflection of the education system in a nation. This perspective prompted my research on both pre-service and in-service Biology teachers' mastery of disciplinary and pedagogical knowledge.

6. *Students' Classroom Engagement*: I equally examined the extent to which students' level of academic, social and emotional engagements influenced their overall participation, motivation and performance.
7. *Teachers' Professional Development*: I have made significant contributions to enhancing, and elevating teacher standards, by fostering sustainable professional development for serving class teachers across several Nigerian states.
8. *Constructivist Pedagogy and Sustainable National Development*: In this lecture, I will elucidate how my constructivism-based research operates to advance educational goals, and impact in fostering sustainable national development.

In the course of this lecture, I will show how these areas of study are useful in preparing students for the challenges of the modern world by equipping them with critical thinking skills, scientific literacy, and innovative problem-solving abilities and lay the foundation for sustainable national development. Lastly, this lecture will end with the suggestions for re-engineering Biology teaching to address the 21st Century and beyond challenges. The recommendations will focus on constructivist pedagogy, and system-wide reforms in teacher education institutions and courses. At the end of it, hopefully, students, educators, curriculum experts, policymakers, and other stakeholders would embrace constructivism innovative pedagogies and strategies to promote meaningful learning in Biology towards sustainable national development. I wish you find the lecture entertaining, informative, and stimulating.

Laying the Groundwork: Understanding Student Success in Science

As I delved deeper, after graduation, into teaching Biology, Chemistry, Health Science, and General Science, I

began to feel uneasy, about how students performed in Biology compared to other sciences. It slowly became clear to me that factors tied to students, teachers, curriculum education policy, teaching materials, environment, and textbooks, among others, are of significance. This was as highlighted in different studies, which were all contributing factors to the challenges students face in science classes (**Bello, 2000; Bello et al., 2016; Jimoh, Alabi & Bello, 2017; Bello & Abimbola, 2018; Bello et al., 2021**).

Table 1: Performance of Students in the May/June 2014-2022 WASSCE for Biology, Chemistry, and Physics in Nigeria

Year	Biology Total Sat	Credit Pass	% Pass at Credit Level	Chemistry Total Sat	Credit Pass	% Pass at Credit Level	Physics Total Sat	Credit Pass	% Pass at Credit Level
2014	1,365,384	766,971	56.17	636,268	397,649	62.49	635,729	386,270	60.76
2015	1,390,234	798,246	57.42	680,357	412,323	60.6	684,124	410,543	60.01
2016	1,200,367	740,345	61.68	706,873	408,122	57.74	705,125	415,655	58.95
2017	580,449	394,898	68.03	377,970	320,632	84.83	377,851	205,757	54.45
2018	1,087,063	679,299	62.48	728,551	424,231	58.22	728,354	571,687	78.49
2019	1,003,304	775,103	75.01	726,132	566,156	77.96	725,853	565,746	77.94
2020	1,051,447	874,237	84.08	756,101	674,361	89.89	755,772	634,400	84.61
2021	1,039,912	913,463	89.23	769,642	649,535	85.44	768,613	663,949	87.44
2022	1,057,577	699,430	66.69	806,579	527,433	65.78	805,948	502,172	62.65
Ave	1,086,193	737,999	68.98	687,608	486,716	71.44	687,485	484,020	69.48

As shown in Table 1, students' academic performance in Biology in the WASSCE from 2014–2022 fluctuated, reflecting varying influences on achievement levels. The cumulative average credit pass in Biology (68.98%) was lower than Chemistry (71.44%) and Physics (69.48%). This underperformance poses challenges for students aspiring to Biology-related courses in Nigerian tertiary institutions, where a credit pass in Biology is mandatory for admission. Without targeted interventions, such as adopting constructivist instructional approaches, students may continue to fall short of admission standards. This situation threatens Nigeria's ability to produce sufficient professionals in life sciences, including Biology educators, medical doctors, biotechnologists, and environmental scientists, vital for sustainable development. The persistent poor performance in Biology compared to other sciences, as reflected in Table 1, aligns with findings consistently reported in literature, including

my earlier studies (Bello, 1985, 1990, 1997), confirming it as a long-standing educational challenge.

This systemic failure in Biology Education underscores the urgency of addressing its root causes. As a professional Biology educator, in my research, I have dedicated decades to unraveling these challenges, driven by the conviction that sustainable improvement in learning outcomes hinges on understanding and mitigating these systemic gaps. *This is what I profess: Biology Education that is grounded in constructivist principles, aiming to transform how students learn and engage with the life sciences for sustainable national development.*

My commitment to science education cemented, when I was going through transformation to a Science Teacher Educator in 1998, as Lecturer I at the Kwara State College of Education, Ilorin. Furthermore, I was fortunate to find myself attracted towards the idea of involving students in significant learning experiences that would foster their curiosity, creativity and analytical skills. This understanding was brought upon, when my doctoral mentor-supervisor and role model, Professor Isaac Olakanmi Abimbola, introduced me to constructivism and its applications in science education. I soon realised that efficient propagation of scientific knowledge demands more than mere dissemination and memorisation of scientific facts and concepts. I justify this stance through my own journey from teaching in secondary schools, grappling with student performance issues, to embracing constructivism as a transformative approach, supported by years of research and practical application. This realisation cemented my fascination in science education. It also drew my interest toward the applications of constructivism in my lectures, research studies, among other spheres of science education.

Vice-Chancellor Sir, it is with great enthusiasm that I now regard Science Education as my comfort zone. This is a place where my passion, knowledge and innovative ideas blend. A place that has afforded me immense opportunity to contribute to the cultivation of science-based experts, equipped with industry 4.0 era skills critical for sustainable national development. These experiences mark key milestones in my career, my progression to Professor of Science Education, my publications spanning four decades, my role in mentoring future

educators, and my contributions to curriculum development. These experiences have shaped my understanding of the very discipline at the heart of my work, “Science Education.”

Science Education

Science education is a discipline concerned with teaching and learning science, a voyage of discovery for educators and students alike. Promoting scientific literacy and lifelong learning among citizens and dedication to producing the much-needed professionals in science-based careers for sustainable national development are inseparable components of science education as a discipline, profession, and community.

Some educators conceive science education as a specialised area that prepares students for a profession by helping them learn scientific, knowledge, ethics, and process skills. It aims to ensure regular production of generations of scientists and technologists of all kinds for sustainable national development. Moreover, it seeks to produce scientifically literate citizens, who can meaningfully participate in social and economic decisions at personal and national levels. Science educators perform different roles, which include classroom teachers, curriculum developers, education researchers, and policy makers. They employ various methods such as doing research in search of better instructional methods and effective instructional materials as they strive to promote science education (**Bello et al.**, 2019; García-Carmona & Acevedo-Díaz, 2018).

Science education is an interdisciplinary field that integrates scientific knowledge, research, and teaching with practical and soft skills development. It draws from Education, Biology, Sociology, Psychology, and Pedagogy to ensure effective instruction and deep understanding of scientific concepts. Practitioners engage in research to develop innovative teaching methods and meaningful learning resources. Certification in the field requires rigorous coursework, training, and field experience at postsecondary institutions. The science education community includes science teachers, scientists in academia, and science teacher educators, as well as professionals working in informal learning environments such as museums, zoos, aquariums, botanical gardens, and planetariums.

Collaboration with other scientific stakeholders strengthens its impact. The primary goal of science education is to improve scientific literacy, foster critical thinking, and prepare individuals for science-based careers. It equips learners to address global challenges such as climate change, public health, and environmental sustainability while promoting technological literacy, environmental stewardship, lifelong learning, and responsible citizenship. (Bello, 2000, 2015; Bybee, 2014; Lederman & Abell, 2014; National Research Council, 2012; NGSS Lead States, 2013). Within this broader mandate of science education lies the more specialised field of Biology Education.

Biology Education

Biology Education, a major subfield of Science Education, is where my professional focus lies as a contributor to the advancement and dissemination of biological knowledge. Unlike general science education, Biology Education emphasises the specific concepts, contents, and skills of the life sciences. Its primary goal is to help individuals understand and appreciate the principles, laws, and processes governing life. Drawing from fields such as Chemistry and Physics, it provides an interdisciplinary understanding of living systems. Researchers and educators in this area develop and implement curricula, teaching strategies, and assessment methods to enhance comprehension of biological phenomena and their societal and environmental significance.

Throughout my over 40-year career in Biology Education, I have applied these principles in diverse settings. I spent 18 years teaching foundational Biology in secondary schools, followed by 15 years teaching advanced Biology and training future science teachers at the college and bachelor's levels. For the past 12 years, I have specialised as a science teacher educator in Biology at undergraduate and postgraduate levels. Consequently, a substantial portion of my research and scholarly contributions centers on Biology Education, reflecting my long-standing commitment to improving teaching, learning, and understanding in the life sciences.

Understanding the nature of Biology is essential for effective Biology Education, which encompasses two main branches: functional Biology and historical (evolutionary)

Biology. Both are fundamental to comprehending the complexity of life and shaping effective teaching approaches. Functional Biology focuses on the internal mechanisms of living organisms, exploring physiological and genetic processes at cellular levels. It seeks to explain how biological systems operate, often integrating concepts from chemistry and physics to illuminate intricate functions. Researchers in this area rely on experimentation and empirical evidence to answer fundamental questions about life's operations. In contrast, historical Biology examines the broader evolutionary context of life over time. Rather than relying solely on experiments, it constructs historical narratives to explain why certain traits or behaviours evolved. This perspective highlighted the dynamic and ever-changing nature of living systems throughout Earth's history.

The period between 1828 and 1866 marked a transformative era for Biology, as these two branches evolved and replaced outdated ideas such as cosmic teleology, the belief in predetermined purpose, and vitalism, the notion of a mysterious life force. The publication of Charles Darwin's *On the Origin of Species* (1859) became a pivotal moment, firmly establishing Biology as a distinct scientific discipline. Darwin's theory demonstrated that many physical science principles do not fully apply to biological phenomena, thereby defining the unique nature and scope of living systems.

Major principles of the physical sciences that are not applicable to Biology are summarised as follows:

1. *Essentialism or Typology*: This concept suggests that living beings can be neatly placed into fixed categories, where every individual of a type is seen as identical and unchanging; hence it does not recognise variation in natural phenomena. This oversimplified notion has led to harmful views about human diversity and has even contributed to social issues like racism. In response, the idea of population thinking emerged, celebrating the uniqueness of every individual organism and highlighting the richness of diversity within species.
2. *Determinism*: This idea claims that all events are predetermined and predictable, overlooking the role of chance and variation. In the realm of Biology,

randomness and variability play a huge role, making strict determinism a poor fit. Biological events are often a mix of surprising factors that can change outcomes in unexpected ways.

3. *Reductionism*: While reductionism works well in physical sciences by breaking down complex phenomena into simpler parts, Biology begs for a broader understanding. It is not just about individual components; it is about how these parts interact with each other. A more holistic approach is needed, one that sees the whole system, not just the sum of its parts. Since reductionism ignores the interactions between component parts of a complex system, it is not applicable in Biology. The holistic thinking principles is the appropriate framework adopted in Biology.
4. *Natural Laws*: In the realm of physical sciences, natural laws are often absolute. But Biology embraces the messy reality of life, acknowledging plenty of variations and exceptions. Biological theories commonly revolve around evolution and biodiversity, marking a clear distinction between the living and the non-living. Biology laws are mostly based on concepts.

Several Biology-specific principles distinguish Biology from the physical sciences, with the concepts of evolution and biopopulation being key examples. The biopopulation concept highlighted the fundamental difference between living and non-living matter by asserting that every organism is unique as no two individuals are identical. Populations, therefore, differ statistically rather than essentially. In contrast, non-living matter consists of identical members within each class, defined by fixed essences.

Biology therefore, differs from the physical sciences in two major ways. First, it is partly a historical science, its evolutionary branch employs historical narrative methods as heuristic tools to explain change over time. Second, it focuses on living systems, governed not only by natural laws but also by genetic programmes that control all biological processes. As Mayr (2004) explained, every organism operates under the dual

causation of physical laws and genetic instructions, an attribute absent in non-living matter.

In essence, Biology represents a fusion of history and function, exploring living organisms and their dynamic interrelationships through specialised principles and frameworks. This integrated approach deepens our understanding of life's complexity, diversity, and evolutionary processes. Recognising these unique characteristics is vital for effective Biology Education, as understanding the nature of Biology not only enriches appreciation of the discipline but also informs meaningful teaching and learning practices. Understanding the nature of Biology, therefore, directly informs how educators approach instruction, shaping strategies that reflect the discipline's complexity and integrative perspective.

Constructivism and other Learning Theories

Learning theories, the bedrock of educational practices, provide the scaffold for insight into how knowledge is acquired by students thus, shape curriculum design, instructional strategies as well as assessment of student learning. Furthermore, they assist educational practitioners to understand the importance of learning environment, the social context of learning and the multitude of factors influencing learning processes. In the Western world, the first ideal of learning theory was credited to Plato who posed the question, "How does an individual learn something new if the subject itself is new to them?" in his theory of anamnesis.

This is to say that learning process is a rediscovery of what innately exist in one's soul; the rediscovery of which can be done through dialectic, a method of questioning that shed light on ideas. Since that time, there have been many learning theories proposed by educators and philosophers, who are very concerned about the field of education. Our knowledge about the process of learning has been broadened by these theories and has also influenced what we do in our day-to-day lives as educational practitioners. Three of the theories, namely Behaviourism, Cognitivism and Constructivism are widely recognised as significant.

1. *Behaviourism*- This theory considers learning to be permanent change in observable behavior. Leonard *et al*

(2014) labeled this outlook as deficit perspective, it is based on learning model where knowledge is built by adding new ones to the existing ones in layer upon layers. Hence, it considered misconceptions as incorrect ideas that serve as hindrance to knowledge acquisition. Science educators within this perspective focus on changing observable behaviours by providing the correct information and reinforcing it until the misconception is replaced. Hence, pedagogy and research activities are on the 'removal of misconceptions' (incorrect ideas) from the students' cognitive structure.

2. *Cognitivism* - The model places emphasises on the internal mental processes such as memory and problem solving. It, therefore, considers misconceptions as naive or incomplete explanations that result from students' cognitive processes. Pedagogical activities are geared to help students restructure their cognitive frameworks to incorporate accurate scientific concepts.
3. *Constructivism* is a learning theory that argues that people actively construct their own understanding of the world through their experiences and interactions with the environment; it says that knowledge is not innate or passively absorbed but constructed through active process. It was during the late 19th and early 20th Century when this idea was first developed by a Russian psychologist and teacher, Lev Vygotsky (1896-1934). He highlighted the importance of social and contextual factors in the learning process, as students interact with others in their environment to construct their own understanding of the world around them. He also emphasised the role of language, tools, and more knowledgeable others in supporting learning and cognitive development (Vygotsky, 1978).

However, Jean Piaget (1896-1980) is often considered the pioneer of constructivist learning theory. He proposed that true understanding of an object comes from interacting with it, rather than simply observing it. He theorised that learning involves stimulus and response dynamic process, which is

influenced by one's cognitive structure that helps an individual to organise and interpret information. Assimilation and accommodation are the two cognitive processes through which an individual responds to new information from the environment, according to Piaget. Assimilation is the process of integrating new information into the existing cognitive structure, while accommodation process involves modifying the existing cognitive structure to incorporate the new information. These two cognitive processes working together or independently determine how an individual learn throughout life (Schunk, 2019; Zhou, & Brown, 2018).

My journey into the world of constructivism has really opened my eyes. I have come to appreciate its core ideas on a whole new level, and it is not just about theory for me anymore. It sparks this excitement to bring those teachings into real-life classrooms and see how they can make a difference. Through practice and research studies, I discover and strongly belief that constructivism learning theory is a powerful way to enhance students' learning. It allows them to make sense of the complex and dynamic environment. It also fosters their creativity, critical thinking, and problem-solving skills. I am passionate about sharing this theory with other teachers and learners, and I hope to inspire them to adopt it in their own contexts.

Recognising the transformative potential of constructivist practice, I have consistently applied its principles in both teaching and research. My work spans multiple areas of Biology and science education, all driven by a commitment to fostering deeper understanding and engagement through constructivist frameworks. This approach emphasises the integration of cognitive structures and inquiry-based methods to develop critical thinking and meaningful comprehension of biological systems. Conceptual change, achieved through active learning strategies, is a central goal of this approach (Nehm, 2019).

Research in constructivist Biology Education remains highly active, as demonstrated by Konu Kadirhanoğulları and ÖzayKöse (2024), who conducted a bibliometric analysis of studies on misconceptions in Biology using the Scopus database from 1970–2022. Their findings revealed that the United States produced the most publications, while South Africa and Nigeria

were the only African countries with significant outputs in this area. Although South Africa had more publications, Nigeria showed greater research impact, recording a total link strength of 1 compared to South Africa's 0, indicating stronger citation and connectivity within the global research community. Despite fewer overall publications, Nigerian research in Biology Education misconceptions has been highly influential, with strong citation rates per document. I am proud to note that several of my own publications have contributed meaningfully to this global recognition of Nigerian scholarship in the field.

By introducing methodological innovations like classroom-based intervention designs, and the integration of diagnostic assessment tools to identify and address misconceptions, my empirical studies (**Bello**, 1996, 2000, 2018; Zakari & **Bello**, 2019; Ogundare, **Bello**, Adeoye, & Abimblola, 2021; Noomsor, **Bello**, & Sulaiman, 2021; Luwoye, **Bello**, & Adeoye, 2021; Sulaiman, **Bello**, & Ahmed, 2022; Ogundare, Koledafe, **Bello**, & Adeoye, 2024) advanced the application of constructivist principles in Biology teaching. In addition to providing repeatable models for empirical inquiry in science education, these methods offered strong evidence for the efficacy of constructivist practices in promoting deeper meaningful learning.

My contributions have reinforced constructivism's theoretical underpinnings and practical applications, elevating Nigerian scholarship to a prominent position in the global conversation on biology education. The sustained interest of Biology Education researchers in misconceptions clearly underscores the critical importance of understanding and addressing misconceptions to improve Biology Education and student learning outcomes. This underscores why a significant percentage of my research focused on misconceptions and alternative conceptions held by students and teachers as well as those found in Biology curricular materials.

In summary three major types of constructivism can be distinguished: Cognitive, Social, and Radical: Cognitive Constructivism, based on the theories of Piaget, emphasises learning through individual experience. Social Constructivism, based on Vygotsky's influence, stresses learning through

interaction and cooperation. Radical Constructivism, associated with von Glasersfeld, treats knowledge as exclusively subjective and personally constructed. What is shared in all the three is the idea that students actively construct meaning rather than passively receive information. The role of the teacher changes from knowledge dispenser to facilitator, helping learners with their own meaning-making. This perspective highlighted the agency of the learner and the dynamic, changing nature knowledge construction. Understanding the constructivist approach to learning also provides a foundation for addressing misconceptions, as it emphasises how students actively build their own knowledge, which can sometimes diverge from scientifically accepted concepts.

What is Misconception?

A misconception is a construct used to describe students' conceptions within science education context. It remains a key concept still bedeviled by a proliferation of definitions despite several decades of research works and international conferences on its causes, types, effects and implications for science teaching and learning outcomes. Misconceptions in science often result when we inappropriately organise and connect science-related concepts in our cognitive structure. Inappropriate or faulty cognitive structure can occur in many ways such as (a) incomplete and inaccurate information from the sense organs, (b) inappropriate categorisation and storage of information by the brain leading to the creation of flawed schema, (c) formation of flawed propositions through inaccurate connection of concepts or propositions, thereby forming incorrect mental models; (d) reinforcement of inaccurate mental models through repeated experiences or similar incomplete or inaccurate information. It is evidence from the forgoing that misconceptions are influenced by our experiences and prior knowledge, deeply rooted in our cognitive structure, and we may not even be aware of it.

This partially accounts for the resistance of misconceptions to change even when one is presented with contradictory evidence. Indeed, Mansooreh (2023) and Yildirim and Yildiz (2020), among many other researchers, note that individuals are often unaware of their misconceptions, making them difficult to change without intervention, while **Bello**

(1997), and Adeoye, **Bello**, and Abimbola (2022) also provide empirical evidence that misconceptions are resistance to change even in the face of contradictory evidence.

Misconceptions in Biology

Identifying students' misconceptions in Biology involves several cognitive processes that researchers must navigate to support effective teaching and learning. They often use conceptual analysis to determine the presence and frequency of ideas in Biology texts and relational analysis to examine how these ideas are connected. By breaking down complex content into fundamental components, researchers systematically detect and address misconceptions in students' scripts, teachers' lessons, textbooks, and online resources.

A common Biology classroom scene at secondary school level involves a teacher writing basic biological propositions on the chalkboard such as "All living things are made up of cells", alongside diagrams of plant and animal cells. This familiar classroom scene captures the teaching of cell theory, the foundation of life sciences. Yet, despite its simplicity, such ideas are often imperfectly conveyed, leading to misconceptions. In my research (**Bello**, 2000), for example, some students claimed that "all plant cells are rectangular and animal cells are spherical," mistaking textbooks diagrams for literal truths rather than simplified models. This highlighted the gap between memorising facts and truly understanding underlying concepts. Although students are taught early that cells are the basic units of life, this proposition remains debated due to ongoing disagreements among biologists about what constitutes life.

With awareness that students' misconceptions exist, and the need to identify them in conformity with the maxim "The most important single factor influencing learning is what the learner already knows." I conducted a mixed-method research study titled "Senior Secondary School Students' Knowledge, Misconceptions, and Alternative Conceptions of a Major Biology Proposition" (**Bello**, 2000). Findings indicated that students held many misconceptions and alternative conceptions related to this major Biology proposition, while grade level and school location significantly influenced their conceptions but gender did not. The survey uncovered 183 misconceptions,

including the notion that cells harbor living microbes, that animal cells are always spherical, and that plant cells are consistently rectangular. The study highlighted the importance of addressing students' misconceptions early and recommended it as a critical practice, to build a strong foundation and engagement in complex discussions in Biology effectively.

Bello (2018) equally identified several misconceptions related to 27 basic science concepts in audio-recorded Basic Science lessons delivered by Junior Secondary School teachers in Ilorin. Among the misconceptions documented were the belief that mosquitoes directly cause malaria, the thought that airborne diseases are simply caused by air; and the notion that all animals uniformly breathe out carbon dioxide while breathing in oxygen. In a co-authored study (Bello, **Bello** & Abimbola, 2016), students' misconceptions of plant was investigated. Results indicated that students held many misconceptions on plants that were categorised into seven types with perceptual confusion as the most predominant category. Some of the misconceptions held by the students include the belief that plants are living things defined solely by their green colour, the assumption that plants feed directly through sunlight in the sky; and the notion that plants obtain nourishment only when watered by someone or by rainfall. The studies highlighted above provided valuable insights into the nature and prevalence of misconceptions in Biology Education, and call for more effective pedagogical strategies.

Remediating Students' Misconceptions

Vice-Chancellor Sir, I did not just identify misconceptions, I also addressed them to ensure that students have a solid foundation of accurate Biology knowledge. In a quasi-experimental study (**Bello**, 1998), I investigated the comparative effects of two forms of concept-mapping instructional strategies on senior secondary school achievement in Biology and sought to determine, if the strategies could remediate students' misconceptions of evolution. Four hundred and thirty-three (433) students in three intact classes from three schools took part in the study. Evolution achievement test and clinical interview protocol were used to gather data. Quantitative and content analysis techniques were employed for data analysis.

Findings indicated that the students- and teacher-centred concept-mapping instructional strategy achieved a significant remediation rate of 90%, effectively addressing students' pre-instructional misconceptions and alternative conceptions of evolution.

This approach proved more effective than both the teacher-centred concept-mapping strategy (84%) and the expository instructional strategy (79%), demonstrating its superior capacity to foster conceptual understanding and correct scientific misconceptions. It also, accounted for only 18.6% of the identified post-instructional misconceptions, a significantly lower proportion than the 33.3% observed for the teacher-centered concept mapping strategy and the 48.1% recorded for the expository instructional strategy. It was recommended that Biology teachers adopt this constructivist instructional strategy for teaching complex topics like evolution.

I co-authored a study (Ogundare, **Bello**, Adeoye, & Abimbola, 2021) to investigate the effects of concept-mapping instructional strategy on remediating misconceptions in ecology. The study utilised a quasi-experimental design. Biology students (114) selected from two co-educational schools using a multi-stage sampling technique took part in the study. Basic Ecological Concepts Achievement Test (BECAT) was used to evaluate student misconceptions and achievement in the study. The results indicated a remediation of 26 misconceptions in the experimental group and 16 misconceptions in the control group. Significant gender difference in the number of misconceptions remediated was not observed. Teachers were encouraged to employ this constructivist pedagogy.

I teamed up with two other researchers (Luwoye, **Bello**, & Adeoye, 2021) to investigate the effects of demo kits on remediating misconceptions about cell division among senior Biology students. The quasi-experimental study involved 60 Biology students in Ilorin, selected using purposive sampling from two co-educational schools. The experimental group was taught cell division through demo kit strategy, while the control group used conventional methods. Data from pre-test and post-test were analysed using content analysis, descriptive and inferential statistics. The demo kit remediated 71.43% of the pre-

instructional misconceptions held by students in the experimental group, demonstrating substantially greater effectiveness, whereas the conventional method of teaching remediated only 28.57% in the control group. This stark contrast provided compelling, evidence-based justification for adopting manipulative, hands-on resources to teach complex biological processes in line with constructivism approach. Hence, incorporating demo kit right away as the primary teaching tool for cell division was advocated in the study.

The effects of using analogy as an instructional method to remediate misconceptions about photosynthesis among senior school Biology students were examined by Olotu, **Bello**, Adeoye, and Abimbola (2024). The quasi-experimental study was conducted among 108 Biology students from two intact classes in two schools. Data collection utilised two main instruments: the Analogy Instructional Package (AIP), which introduced the analogy of cake baking for the experimental group and the Photosynthesis Misconceptions Test (PMT) with a reliability coefficient of 0.74.

Prior to instruction, students in the experimental group had 132 misconceptions, while that of the control group had 143. A post-instruction misconception for the experimental group was 65, while the control group was 111. However, Chi-square test revealed no statistically significant difference in the misconceptions held by both student groups, suggesting that analogy instructional strategy was insufficient to yield a statistically significant, population-level change in student comprehension. Implying that misconceptions about this topic are highly entrenched and that analogy strategy, while possibly helpful to some students, were unable to overcome those entrenched misconceptions at a population level. Since misconceptions proved to be so tenacious, a more straightforward and targeted constructivist approach was recommended.

My studies, **Bello** (1998), Ogundare, **Bello**, Adeoye, and Abimbola (2021), Luwoye, **Bello**, and Adeoye (2021), Olotu, **Bello**, Adeoye, and Abimbola (2024), Ogundare, Koledafe, Bello and Adeoye (2024), among others, on remediating misconceptions in Biology, highlighted the importance of innovative instructional strategies in remediating misconceptions

in Biology. They have contributed to a better understanding of how different teaching methods can be used to address and prevent misconceptions, ultimately leading to more effective Biology teaching and learning.

Mastery of Content and Pedagogical Knowledge

Motivated by the persistent under-achievement in science, particularly Biology, I conducted a series of studies examining science teachers' mastery of both subject matter and pedagogical content knowledge. The first investigation assessed senior secondary school Biology teachers' conceptions of the nature of Biology (Adeboye, **Bello**, & Abimbola, 2017), aiming to identify conceptual gaps that might hinder effective teaching and meaningful learning. Data were collected using a questionnaire which had a reliability coefficient of 0.72. A total of 260 Biology teachers were randomly selected from senior secondary schools in Ilorin metropolis.

Findings revealed that teachers held a mix of informed conceptions and misconceptions about the nature of Biology; notably, only 40% of informed conceptions were commonly held, whereas 75% of misconceptions were endorsed by 53% to 83.08% of teachers, underscoring the predominance of misconceptions in their cognitive structures. No significant differences were found in informed conceptions or misconceptions across gender, qualification, or teaching experience gender ($\chi^2 (1, 260) = 2.295, p = 0.130$), qualification ($\chi^2 (1, 260) = 1.733, p = 0.188$), and teaching experience ($\chi^2 (1, 260) = 0.001, p = 0.978$).

The results suggest that many teachers misrepresent biological concepts and theories during lessons, contributing to students' continued poor performance in Biology. This implies that misconception in Biology is a systemic problem with regards to teacher preparation, rather than being due to demographic and professional variations, and that it has become imperative to focus on improving knowledge in epistemological and philosophical aspects of Biology amongst teachers. This will help in improving the accuracy of teaching and conceptual knowledge of students in Biology.

In the light of empirical evidence from my studies on the misconceptions of the nature of Biology among in-service

secondary school Biology teachers, it became necessary to determine if these gaps in knowledge also existed further back in the teacher preparation system. Hence, a second study (Adedoyin, & **Bello**, 2017). The descriptive study investigated the conceptions of the nature of science held by pre-service undergraduate Biology teachers. Participants consisted of 99 pre-service Biology teachers selected from three public universities. Data were collected using a questionnaire adapted from Indiana State University. Results revealed that participants held a combination of correct conceptions and misconceptions. Chi-square analyses showed no statistically significant gender differences in the number of correct conceptions or misconceptions ($\chi^2 = 25.296, p = 0.235$) or misconceptions ($\chi^2 = 0.009, p = 0.923$), suggesting that gender difference does not exist. The study concludes that, although pre-service Biology teachers have some conceptions regarding the nature of science, their conceptual structures are dominated by deep-seated misconceptions. Findings revealed the imperative need for a reformulated Biology teacher education curriculum that incorporates the nature of science as an embedded teaching component.

I co-authored a study (Bello, Abimbola, Ahmed, & **Bello**, 2016) on the specialised knowledge that effective teachers draw upon in their instructional practices. The study assessed the pedagogical content knowledge (PCK) of secondary school Biology teachers in Ilorin.. A total of 270 Biology teachers from 90 secondary schools across the five Local Government Areas (LGAs) in Ilorin Emirate took part in the study. Data were collected using researcher-designed questionnaire, with a reliability coefficient of 0.71. Data were analysed using Analysis of Variance to test the two research hypotheses in the study. Findings revealed that there was no significant difference in the level of Biology content knowledge among experienced, moderately experienced, and less experienced teachers ($F = 4.521, p = .012$). Similarly, no statistically significant difference was found in the overall pedagogical content knowledge of Biology teachers based on teaching experience ($F = 1.308, p = .272$). Based on these findings, it was recommended that Biology teachers should intensify efforts to enhance their pedagogical

content knowledge, as it significantly contributes to effective teaching and learning.

In view of the fact that students' achievement depends, to a large extent, on their teachers' mastery of disciplinary knowledge, I led an assessment of the level of knowledge of the nature of science (NOS) amongst Nigerian senior secondary school professional science teachers (**Bello, & Abimbola, 2018**). Sixty professionally trained graduate science teachers selected from 22 secondary schools in Ilorin participated in the study. Data were collected using a 40-item achievement test. Respondents were required to identify which statements aligned or conflicted with the basic tenets of the nature of science. Descriptive and inferential statistics (t-test) were used for data analysis. The results indicated that majority (85%) of the science teachers had a fairly adequate mastery of the nature of science. Furthermore, no statistically significant difference was found between male and female teachers' level of mastery ($t(58) = -0.103, p > 0.05$).

The study concluded that while most science teachers demonstrate a reasonable understanding of the nature of science, there is still room for professional development in this area to enhance science instruction in the Nigerian secondary schools. The study highlighted the need to make explicit NOS instruction a part of pre-service and in-service science teacher education programmes. To explore further the issue of science teachers' subject competence, I carried out another study (**Bello, 2018**). The follow-up study aimed at exploring teachers' content knowledge indirectly through identifying misconceptions of science concepts in their cognitive frameworks. A total of 32 Basic Science teachers drawn from twenty public Junior Secondary Schools from Ilorin Metropolis were purposively selected to participate in the study that had been randomly chosen.

Data collection was conducted using an audio tape recorder to document forty lessons taught by the teachers. Content analysis of the lessons revealed misconceptions of 22(2.1%) out of 1043 basic science concepts taught across all lessons. The fact that every (100%) teacher held at least one misconception underscored the prevalence of conceptual misunderstandings among science educators in the study area. It

highlighted the need for targeted professional development as well as continuous pedagogical support to enhance teachers' conceptual understanding and instructional accuracy in science. It was thus recommended that entry requirements to science teacher training courses be reviewed upwards; that Teacher Vacation Courses be reinstated, and a compulsory Teacher Professional Development programme be implemented.

A further study by Ogundipe, **Bello**, Adeoye, and Abimbola (2021) conducted in Ekiti State examined Biology teachers' conceptions of the nature of science (NOS) and science teaching. Using a descriptive survey design, the study involved 247 senior secondary school Biology teachers. Data were gathered using the validated Nature of Science and Science Teaching Questionnaire (NOSASTQ), with a reliability coefficient of 0.79. The findings show that biology teachers in Ekiti held both accurate conceptions and misconceptions: while many (96.4%) recognised science as focused on the natural world and requiring creativity (91.5%), misconceptions were widespread: 97.2% erroneously believed science is primarily a search for truth, 94.3% viewed it as mostly about collecting facts, and 87.9% described hypothesis as just an educated guess. Similarly, 59.9% believed that science can use supernatural explanations when necessary.

Regarding science teaching, most participants demonstrated sound understanding of instructional principles, with 98.8% agreeing that science lessons should enhance students' problem-solving ability and 94% emphasising the importance of regular professional development. Despite this, misconceptions persisted: 95.5% believed that the teacher should exercise full authority in science classrooms, and 93.5% held that teachers should restructure students' knowledge for them. Pearson product-moment correlation analysis revealed a weak positive correlation ($r = 0.07$, $p = 0.25$) between biology teachers' conceptions of the nature of science and their conceptions of science teaching, indicating that while some relationship exists, it is limited in strength and not statistically significant. The study concluded that the coexistence of scientifically accurate conceptions and persistent misconceptions among biology teachers reflects deficiencies in their pedagogical

content knowledge, with potential negative implications for student learning. The findings highlighted the need to integrate explicit instruction on the nature of science and science teaching into teacher education programs and promote ongoing professional development to address entrenched misconceptions.

In furtherance of my investigations on teachers' content mastery, I examined Biology teachers' knowledge of errors in biological drawing (Bello, 2022). A total of 100 out of 235 Biology teachers in public secondary schools in Kwara State Central Senatorial District, Nigeria took part in the study. The teachers were selected through stratified random sampling procedure. An assessment test entitled "identification of errors in biological drawing test" (IEBDT) with a reliability coefficient of 0.83 was used to gather data in the study. Results indicated that Biology teachers' knowledge of errors in biological drawings was generally poor (mean = 3.54), with most able to identify only non-horizontal guidelines (93%) and plural/singular misuse (52%), while failing to recognise others such as missing magnification (0%). One-way ANOVA revealed no statistically significant differences in knowledge based on qualifications [$F(2,97) = 0.121$, $p = 0.886$] or years of teaching experience [$F(2,97) = 1.783$, $p = 0.174$], indicating that deficiencies were widespread across all groups. It was recommended that Biology teacher education programmes should be re-jigged while Biology teachers were admonished to regularly participate in teacher professional development programmes. Further research studies to determine factors responsible for the teachers' poor knowledge of errors in biological drawing and lack of significant difference in their knowledge based on qualifications and teaching experience in contrast to logical expectations was also recommended in the study.

Constructivist Innovative Instructional Strategies

Through conducting research work in the field of science education, I have contributed towards the development of the field by exploring constructivist approach and strategies such as concept mapping, computer animation, Artificial Intelligence, metaphorical teaching, and learning by Analogy. Teaching difficult Biology topics such as cell division, genetics, and photosynthesis requires innovative instructional strategies to

improve student meaningful learning. Hence, I investigated the efficacy of the various engaging methods, including concept mapping to visualise relationships between concepts, computer animation to provide dynamic representations of biological processes, and resource persons to bring expert knowledge into the classroom, among others.

Expanding on my previous investigations into instructional strategies, I further explored the efficacy of concept-mapping instructional strategy in remediating students' misconceptions in ecology through a collaborative research (Ogundare, **Bello**, Adeoye & Abimbola, 2021). In this quasi-experimental study, answers were provided to three research questions while two hypotheses were tested using Chi-square statistical tool. One hundred and fourteen (114) Biology students in two intact classes, drawn from two co-educational schools in Oyo State, took part in the study. Concept Map on Ecology (CME) and Basic Ecological Concepts Achievement Test (BECAT) with reliability co-efficient of 0.79 served as stimulus and response instruments respectively. Findings showed that students demonstrated widespread misconceptions in ecology, with 168 distinct misconceptions identified across concepts such as population, community, ecosystem, habitat, and biosphere. The concept-mapping instructional strategy (experimental group) remediated 61.9% of the misconceptions, while the conventional teaching method (control group) remediated 38.1%. However, chi-square analysis revealed no statistically significant difference between the two groups [$\chi^2 (2, 113) = 1.98, p > 0.05$]. Similarly no significant gender difference [$\chi^2 (2, 64) = 11.53, p > 0.05$] was observed in the number of remediated misconceptions. We recommended that concept-mapping instructional strategy should be used concurrently with other innovative instructional strategies to remediate students' misconceptions in ecology and other related Biology concepts.

Mr. Vice-Chancellor, in the continuation of my exploration of engaging instructional strategies, I also investigated the effectiveness of the gallery walk instructional strategy in a co-authored study (Nomsoor, **Bello**, & Sulaiman, 2021). This quasi-experimental study adopted the non-randomised, non-equivalent, pre-test and post-test control groups with a $2 \times 2 \times 3$ factorial design. The sample

consisted of 65 students, drawn from two intact Biology classes in two senior schools in Ilorin. Two instruments used were Cell Division Achievement Test (CAT) and Gallery Walk Instructional Package.

The findings revealed that the experimental group recorded a mean gain score of 10.26, compared to 7.84 in the control group, and the difference was statistically significant [$t(63) = 4.80, p < 0.05$] in favour of the experimental group. However, gender difference in achievement was not statistically significant [$t(29) = 0.69, p > 0.05$]. Further analysis across achievement levels showed that low scorers (mean gain = 15.13) benefitted most, followed by medium scorers (9.20), while high scorers gained least (3.66). ANCOVA confirmed a statistically significant difference among the groups [$F(2, 27) = 38.22, p < 0.05$], indicating that gallery walk had differential effects depending on students' initial performance levels.

These findings highlighted that gallery walk is a valuable instructional strategy for enhancing student learning, especially for those with lower prior achievement. Biology teachers are called upon to integrate gallery walk into Biology teaching, particularly for complex topics like cell division, while providing targeted support for low-scoring students to enhance their learning outcomes. In a similar vein, Sulaiman and **Bello** (2022) examined the effects of Metaphor Instructional Strategy on student's achievement in Genetics. Participants in the quasi-experimental study consisted of 119 students from two intact classrooms in two schools. Two response instruments (Genetic Achievement Test (GAT) and Group Embedded Figure Test (GEFT) and one stimulus instrument (Teachers' instructional guide on metaphor teaching strategy) were administered in the study.

The reliability indices of the GAT and GEFT were 0.78 and 0.81, respectively. Student cognitive style was the main variable in the study, while three research questions with corresponding hypotheses were raised and tested. The results revealed a significant difference in achievement ($F(1, 118) = 16.80$ and $p < .00$) in favour of the experimental group. However, there was no significant difference ($F(2, 58) = .45, p = .64$) in the achievement of field-dependent, field-neutral and

field-independent students in the experimental study. The study demonstrated that metaphorical teaching strategies can significantly improve learning outcomes in genetics and that it can effectively benefit diverse learners. Biology teachers were sensitised to the need to incorporate the strategy into their lessons. In the same year, I further examined the impact of analogy instructional strategy on senior school students' achievement in genetics through a quasi-experimental study (Sulaiman, **Bello**, & Ahmed, 2022).

The sample consisted of 112 students (experimental class = 55 and control class = 57). The stimulus and response instruments used in the study were Teachers Instructional Guide on Analogy and Genetic Achievement Test (GAT). The reliability coefficient of GAT, was 0.78. Results showed that there was a statistically significant difference in the achievement of experimental and control group ($F(1, 109) = 20.88, p < 0.05$) in favour of the experimental group and interaction effects of analogy instruction and score levels on the achievement of the experimental group ($F(2, 105) = 3.38, p > 0.05$). However, there was no statistically significant difference in the achievements of low, medium, and high scoring students. This finding implies that treatment and students' score levels together have a joint effect on students' achievement. Biology teachers were called upon to consider incorporating analogy-based teaching approaches across all ability levels.

The effects of resource person on students' achievement and attitude toward family planning were investigated in a quasi-experimental study that I co-authored (Zakari & **Bello**, 2019). Fifty-seven senior school Biology students in two intact classes selected through multistage sampling technique participated in the study. Data gathering was carried out in the study through the use of researcher-designed achievement test and attitudinal questionnaire. The results showed that the students taught family planning using a resource person had significantly higher achievement [$t(26) = 2.52, p = 0.018$] than those taught by their class teacher; significant difference does not exist in students' attitude [$t(853) = 1.59, p = 0.299$]; and no gender difference [$t(9) = 1.57, p = 0.152$], in students' achievement. The study concluded that using resource person is appropriate and effective

in enhancing students' achievement in family planning, and recommended its use for teaching other controversial Biology topics.

In another co-authored quasi-experimental study, non-randomised pretest and post-test study, Aje, **Bello** and Sulaiman, (2025) investigated the impact of game-based learning (GBL) on the engagement, academic achievement, and retention of secondary school students in Biology, with a specific focus on the topic of viruses, a concept often perceived as abstract and difficult to master. The study involved three instructional groups: GBL only, a blended approach combining GBL with conventional instruction, and conventional instruction only. Data were collected using standardised instruments, including the Student Virus Engagement Scale and the Virus Achievement Test. Observational checklists and a delayed post-test were also used to assess engagement and retention. The findings revealed a statistically significant difference in student motivation ($F(2, 214) = 124.80, p < .05$), engagement ($F(2, 214) = 60.45, p < .05$), and academic achievement ($F(2, 214) = 99.19, p < .05$), with the hybrid strategy consistently yielding the highest mean scores. Also, the integration of GBL significantly enhanced knowledge retention ($F(2, 215) = 2.13, p = .041$), reaching a 90% retention rate. Notably, a non-significant interaction effect between GBL and gender ($F(1, 65) = 0.64, p > .05$) was observed. These results underscored GBL's effectiveness as a pedagogical tool in Biology Education. The inclusion of GBL strategies in secondary science curricula and teacher training programmes to support active learning was advocated in the study.

Students' knowledge of drug abuse and drug addiction were assessed by Alabi, **Bello**, Ahmed, and Sulaiman (2020). Participants in the descriptive study were 304 secondary students randomly selected from schools in Kwara Central District. Knowledge of Drug Abuse and Addiction (KODAA) questionnaire and an adapted drug avoidance self-efficacy instruments were used to source for data. The reliability coefficient of KODAA was 0.76 using the Spearman brown statistic. Four research questions with corresponding hypotheses were tested at 0.05 level of significance.

Results revealed that the majority (62.8%) of the students possess average knowledge of drug abuse and moderate drug avoidance self-efficacy (68.1 %). However, no significant gender-based differences in knowledge were observed (χ^2 (2, n =304) = 2.65, at $p > 0.05$) significant differences were found based on school type (χ^2 (2, n =304) = 7.31, at $p < 0.05$) and self-efficacy levels (χ^2 (2, 304) = 18.66). Furthermore, Pearson's correlation confirmed a significant positive association between students' self-efficacy and their knowledge of drug abuse (r (304) = .23, at $< .05$) suggesting that higher self-efficacy serves as a predictive factor for increased awareness and drug avoidance potential. The need for targeted interventions that consider these factors to effectively enhance awareness and prevention efforts were recommended.

Integrating Technology in Biology Education

The effects of computer animation instructional package on students' achievement in practical Biology were examined in collaboration with other Biology educators (Hamzat, **Bello**, & Abimbola, 2017). The study adopted a pre-test, post-test, control group, non-randomised and nonequivalent quasi-experimental design, with a 2x2x3 factorial design. The instruments used were Biology Practical Achievement Test (BPAT) for data gathering and Computer Animation Instructional Package (CAIP) as the treatment instrument. Two research questions and two hypotheses were formulated in the study. Findings showed that students taught practical biology with the computer animation instructional package achieved significantly higher mean gain scores than those taught without it ($t(47.43) = 1.62, p < 0.05$).

Although female students showed slightly higher gains than males, the difference was not statistically significant (t (28) = -0.78, $p > 0.05$). Overall, the animation package effectively enhanced learning outcomes regardless of gender. The study concluded that CAIP significantly improves students' achievement in practical Biology. The researchers recommend that Biology teachers should employ computer animation instructional packages to teach the practical aspects of photosynthesis, among other Biology topics.

To continue my research in integration of technology into Biology instructional strategies, a study was carried out

alongside other Biology educators (Bardmus, Bello, Hamzat, & Sulaiman, 2019). The study determined the effects of WebQuest on secondary school Biology students' achievement in cell division in Ilorin. The study was a quasi-experimental research with a pre-test, post-test, non-randomised, control group design. Participants for the study, 53 Biology students, were drawn from two purposively selected co-educational senior secondary schools. Two research instruments, "WebQuest Instructional Package on Cell Division (WQIPC)" and the "Cell Division Achievement Test (CDAT)", were used as stimulus and response instrument in the study. The WQIPC, which served as the treatment for the experimental group, is an interactive web-based package designed by the researchers (assisted by a web programmer).

The CDAT was validated by experts in ICT and Lecturers in Life Sciences as well as Science educators. The reliability of CDAT was established through trial testing which yield coefficient of 0.87. The results showed that students taught cell division through WebQuest achieved significantly higher mean score (21.00) than those taught with traditional method (11.48). The independent samples *t*-test confirmed this difference was statistically significant ($t(58) = 2.84, p < 0.05$), indicating that the WebQuest approach effectively enhanced secondary school biology achievement in Cell Division. However, significant gender-based difference was not observed in the students' achievement ($t(22) = 2.03, p > 0.05$).

There was a significant difference in the achievement of students' with different score levels when taught cell division using the WebQuest ($F(2, 20) = 3.72, p < 0.05$) in favour of the low scorers. The result also, revealed that there was no significant interaction effect among the treatment, gender and score levels on students' achievement in cell division ($F(2, 17) = 0.37, p > 0.05$). We, thus, concluded that using WebQuest enhances students' achievement in cell division, irrespective of their gender. The study contributes to the existing literature by demonstrating the effectiveness of the WebQuest Instructional strategy particularly among low-scoring students. It also highlighted the gender-neutral impact of WebQuest. Biology teachers were call to embrace the strategy.

Furthermore, **Bello, Alabi, Bello, Bello, Sulaiman** (2022) investigated science teachers' perceptions regarding the integration of mobile learning (M-learning) into science classroom instruction. Data were collected from 129 science teachers drawn from 34 public and 27 private senior secondary schools in Ilorin through stratified and purposive sampling. The researchers employed a validated questionnaire, "Teachers' Perceptions of M-learning" (TPML), with a reliability coefficient of 0.85, to gather information on teachers' attitudes, readiness, and perceived obstacles to M-learning integration. Findings showed that the science teachers exhibit high perceptions ($M=2.40$) of mobile learning and widespread device ownership (94.6%), yet they remain in the "Preparation Stage" of readiness ($M=1.62$) rather than active implementation.

While most teachers possess Android smartphones (59.7%) and recognise the future importance of M-learning, they are hindered by significant obstacles including poor internet connectivity, lack of pedagogical justification, and students' attitudes. Furthermore, results indicated that a significant difference does not exist in teachers' perceptions ($t(127) = -1.65$) based on experience. Similarly significant differences does not exist in the science teachers' perceptions of integration of M-learning in science teaching ($t(127) = -0.67$) based on school type and based on their level of integration of M-learning ($t(127) = 0.49$). This study highlighted the need for specialised professional development and institutional support to take teachers from optimistic attitude to practice level, hence contributing to the broader sub-discourse of incorporating technology into science education.

Building on insights into teachers' readiness for mobile learning, **Ayeni, Abimbola, Bello, Sulaiman, and Bello** (2023) carried out a study that shifted focus to learners by assessing ICT awareness and utilisation among Biology students in Ilorin South Local Government Area of Kwara State. The study found that 86% of the respondents were aware of the availability of online learning packages ($WMS = 2.46$), and 76.7% acknowledged ICT's ability to foster motivation and interest in learning ($WMS = 2.37$). Additionally, 75% believed that ICT keeps students updated ($WMS = 2.28$). However, awareness dropped

significantly for ICT's ability to promote distant science learning (only 24% aware; WMS = 1.24), and only 31% were aware that ICT can facilitate screen-based experiments (WMS = 1.41).

In terms of usage, the study revealed a clear disconnect between awareness and educational application. The most common uses of ICT were for computer games (WMS = 2.22) and social media (WMS = 1.99), while academically beneficial applications such as accessing educational software (WMS = 0.97) and revising for exams online (WMS = 1.23) ranked much lower. Furthermore, only 22.7% used ICT for academic reading, while over 81% used it primarily for leisure, highlighting a major challenge in promoting ICT for learning. The students also reported moderate confidence in using ICT tools, with 92% expressing confidence in mobile phone operation (WMS = 2.51), and 66.6% showing confidence in basic PC use (WMS = 2.20).

Yet, confidence dropped in more technical areas like managing files (only 13.3% confident; WMS = 1.18) and downloading documents (30.0%; WMS = 1.43). Critically, poor electricity supply emerged as the most significant constraint, with 66% of students agreeing it hinders ICT use (WMS = 2.93), followed by shortage of time (WMS = 2.90) and lack of economic power (WMS = 2.77). Based on these findings, the study recommended stronger government intervention in infrastructure, especially power supply and internet access and targeted awareness campaigns to redirect students from predominantly leisure-based ICT usage toward more purposeful, educational engagement.

Expanding my work on the integration of ICT into Biology class instruction, Ogundare, Koledafe, **Bello**, and Adeoye (2024) explored the development of a rule-based AI tutoring system named *Ecology Perfect Master (EPM)* designed to address misconceptions among Biology students. Utilising the first three phases of the Design and Development Research methodology (analysis, design, and development), the study began by identifying the common misconceptions in ecological concepts and gathering requirements from educators and students. The design phase translated these requirements into a comprehensive plan, featuring an intuitive user interface, a robust knowledge base, and an efficient inference engine capable

of diagnosing and remediating misconceptions through tailored feedback. The development phase culminated in a functional web-based application featuring 4 modules and 18 study units, supported by 176 validated multiple-choice questions designed to identify specific misconceptions. Results showed that after interacting with the EPM system for three weeks, students' post-test scores improved significantly compared to their pre-test scores, with a mean score increase from 41.2% to 72.8% ($p < 0.01$).

Furthermore, misconception identification accuracy by the system reached 89%, and 85% of the students reported improved confidence in answering ecology-related questions. These findings indicated that EPM effectively identifies and addresses misconceptions, enhancing students' understanding of complex biological concepts. Recommendations included the integration of AI tutoring systems like EPM into Biology class to remediate misconceptions and improve learning outcomes.

Science Curriculum Materials

The Vice-Chancellor, Sir, **Bello** (1999a) also examined the role of Biology curriculum materials in influencing learning outcomes and student engagement. The study assessed the readability levels of two widely used science textbooks in Kwara State: *Senior Secondary Biology* (Ndu, Asun & Aina, 1991) and *Longman Integrated Science for Junior Secondary Schools* (Alabi, Asun, May, Ndu & Ndu, 1988). Using the Fry Readability Graph and the Flesch Reading Ease Formula, I cross-validated the results to ensure accuracy. The Flesch reading ease scores for *Senior Secondary Biology* volumes 1, 2, and 3 were 68, 64, and 65, respectively, equivalent to standard materials suited for grades 8–9. On the Fry graph, the same volumes fell within grades 8–10, even though the books were intended for senior secondary students (grades 10–12). This indicated that the textbook was below its expected user level. For *Longman Integrated Science*, Flesch scores for volumes 1, 2, and 3 were 83, 86, and 89, matching reading levels around grade 6. On the Fry graph, these aligned with grades 4–7, which were appropriate for the target users (grades 7–9).

Thus, both textbooks were easier than expected, they were accessible and readable for students. However, a

subsequent study (**Bello**, 1999b) analysing *Longman Integrated Science* revealed an important weakness: several essential science process skills outlined in the 1985 National Curriculum for Junior Secondary Schools were missing. This gap meant the textbooks did not fully support curriculum objectives. Based on these findings, it was recommended that curriculum developers, authors, and publishers routinely review science textbooks to ensure they not only match students' reading abilities but also integrate required process skills essential for inquiry, critical thinking, and meaningful science learning.

The gap in process skills representation led me to further examine the accuracy of diagrams in *Senior Secondary Biology*, focusing on labelling accuracy (**Bello**, 2000). I identified four types of labelling errors: wrongly labeled structures, one structure labeled as two, two structures labeled as one, and labeling lines pointing to empty space. Across the three books examined, a total of eighty-six errors were recorded. Book 1 contained twenty-six errors spread across eighteen diagrams, Book 2 had twenty-seven errors across nineteen diagrams, and Book 3 recorded thirty-three errors across twenty-one diagrams. Overall, seventy-three diagrams out of the two hundred and two reviewed contained at least one error. Such inaccuracies posed risks of reinforcing misconceptions, prompting a recommendation for urgent revision of these textbooks.

Building on earlier findings, **Bello**, Aransiola, Aromire and Alani (2021) later carried out a research to identify, analyse, and classify diagram errors in four widely used practical Biology textbooks. The textbooks examined were: (1) *Essential Practical Biology* (Olaniyonu, 2004), (2) *A Guide to Practical Biology for Senior Secondary School* (Ogundana, 1994), (3) *Senior School Certificate Practical Biology* (Iloeje, 1991), and (4) *Practical Biology for Schools and Colleges* (Duyilemi & Duyilemi, 2000). Three major categories of diagram errors were identified: (i) Labeling Errors—missing, incorrect, or absent labels; (ii) Spelling Errors—misspelled biological terms or incorrect singular/plural forms; and (iii) Technical Errors—improper arrowheads, guidelines not touching intended structures, or non-horizontal guidelines affecting clarity.

A significant difference was found in the number of errors across the textbooks, with *Senior School Certificate Practical Biology* containing the highest number. The study concluded that diagram errors have a detrimental influence on students' performance and recommended rigorous blind peer review prior to publication, as well as urgent revisions of existing textbooks.

Another collaborative study by Inuojo, **Bello** and Bello (2024) examined the readability and students' comprehension of three Biology textbooks recommended by the Kwara State Ministry of Education and Human Capital Development: (1) *Modern Biology for Senior Secondary Schools*, (2) *College Biology for Senior Secondary Schools*, and (3) *Essential Biology for Senior Secondary Schools*. A total of 252 Biology students participated in the study. Using the Cloze Test, Flesch Reading Ease, and the Biology Textbook Readability Test, the study found that the first and third books contained sections appropriate for SSS I students, whereas the second book was difficult for all students regardless of level. Additionally, many first- and second-year students experienced frustration when reading the books, and even final-year students found them challenging. The study concluded that the textbooks generally fell outside students' reading and comprehension abilities, recommending that authors simplify vocabulary and employ concise sentence structures to enhance understanding.

In a similar study, Egbuaba, **Bello**, Adeoye, and Bello (Preprint) examined gender representations in seven recommended Biology textbooks used by students in Nasarawa State. A proforma designed by the researchers was used to record the identified masculine, feminine, and gender-neutral words, colours, pictures, and diagrams in the books. Findings showed that gender-neutral words were the most common in the textbooks, followed by masculine and then feminine terms. Colours were largely gender-neutral, with feminine associations appearing more often than masculine ones. Diagrams and pictures were overwhelmingly gender-neutral, with only a very small proportion reflecting either masculine or feminine representations. We concluded that the Biology textbooks reflected imbalanced gender presentation and recommended

changes to avoid perpetuating gender bias to the next generations.

Students' Classroom Engagement

The classroom is the core environment for formal learning, where teachers, students, and instructional materials interact in ways that shape academic achievement. In a collaborative study, Abe, **Bello**, and Hamzat (2019), examined classroom interaction patterns; and the study barriers encountered by students during Biology lessons. The study involved 324 Senior Secondary School II students and 10 Biology teachers across 10 schools. Using the Adapted Flanders Interaction Analysis Categories System (AFIACS) and the Adapted Study Technology System Tool (ASTST), we conducted naturalistic video-recorded observations to capture authentic classroom dynamics. Findings revealed three major interaction patterns, teacher talk, student talk, and silence or confusion with teacher talk accounting for the largest (79.25 %) share.

Study barriers identified include lack of mass, misunderstood words, and too steep a gradient, Lack of mass had the highest number of study barriers (47.75%) followed by the misunderstood word (47.00%) while too steep a gradient accounted for 5.25%. Misunderstood words occurred most (48.46%) frequently in teacher talk, while lack of mass was more (46.94%) common in student talk. Significant differences were observed in the types of barriers associated with each interaction pattern ($X^2(9) = 405.36, p < 0.05$), demonstrating that classroom dynamics directly influenced the challenges students face during Biology instruction. The study recommended adopting strategies that increase student participation, clarify terminology, and incorporate instructional materials to minimise barriers such as lack of mass.

The onset of the COVID-19 pandemic forced a global transition to Emergency Remote Teaching (ERT), creating new demands for educators and learners. In response, **Bello** (2021) conducted a study to investigate engagement levels among pre-service science teachers in Colleges of Education in Kwara State during ERT. Using a descriptive survey design, data were collected from 241 participants through an online questionnaire

with a reliability coefficient of 0.81. Findings showed that students demonstrated a high level of overall engagement during online Emergency Remote Teaching (ERT), with an aggregate mean score of 3.38. High engagement was consistent across all three sub-domains, specifically affective ($M = 3.29$), behavioral ($M = 3.42$), and cognitive ($M = 3.42$) engagement. While gender did not significantly impact general engagement ($p = 0.083$) or affective engagement ($p > 0.05$), a significant difference was observed in behavioral engagement between male and female students ($p = 0.004$). The study emphasised the importance of sustaining these engagement levels and recommended leveraging students' positive online learning experiences to enrich future face-to-face instruction.

In-Service Teacher Professional Development

Building on my commitment to improving science education, I have remained actively involved in promoting teacher professional development across Nigeria. My work spanned developing teaching materials, managing large-scale programmes, and leading innovative training initiatives that enhance the capacity of serving teachers. I have authored and co-authored textbooks and training guides for teacher capacity-building programmes and served as manager, facilitator, planner, and trainers' trainer.

I have developed guidebooks and materials for major training programmes, including the *Anambra State Education Programme Investment Project (ANSEPIP, 2016)*, *Re-energising Secondary School Education in Kwara State (RSSEK, 2005–2006)*, and the *Universal Basic Education (UBE) Federal Government Teachers Scheme Workshops (2007–2008)*. Earlier, I played a leading role in the *Africana First Publishers Teacher Development Project (2001)*. These initiatives emphasised innovative, hands-on science pedagogy that strengthened teachers' subject mastery and classroom practice.

As Project Manager, I coordinated statewide professional development programmes for active class teachers, such as the *Kwara State Education Sector Project (SESP, 2008–2011)* funded by DIFD, and the *FGN-UBE Teacher Professional Development Programme (2012)*. My duties included coordinating

workshops across Local Government Areas to ensure broad participation and effective learning outcomes.

I also played leading role at experiential field-based events, including the *One-Day Field Trip Training and Teacher Professional Development Outreach for Biology Teachers* (September 2025), in partnership with the Kwara State Ministry of Education and the Department of Biology, Kwara State College of Education, Ilorin. In addition, I provided training for private school teachers to enhance instructional effectiveness. These experiences have influenced my research focus and teaching philosophy, aligning with the *Teachers Registration Council of Nigeria (TRCN, 2025) Mandatory Continuing Professional Development* initiative and contributing to sustainable improvement in teaching and learning quality nationwide.

Constructivism Pedagogy and Sustainable National Development

My research bears testimony to an unwavering dedication to the implementation of constructivist pedagogy as a driver of sustainable development goals and ensuring the attainment of education reform in the nation. I have examined the culture of science teaching and learning, Biology misconceptions, teacher education, pedagogical innovations, and the integration of technology for decades. These works put constructivist methods in the forefront of promoting critical thinking, problem-solving, inclusivity, and environmentally conscious learning in Nigeria. Addressing misconceptions and advancing conceptual understanding in Biology teaching are prominent themes of my studies in direct alignment with SDG 4: Quality Education (United Nations (2015)). My earlier works such as **Bello** (1997, 1998, 2000, 2002); **Bello** and Abimbola (1997) identified the prevalence of misconceptions about evolution, living organisms, and other important Biology concepts, indicating that students' prior knowledge must be catered for if learning is to be meaningful.

With respect to this assumption, Ogundare, **Bello** and Adeoye (2021) and Olotu, **Bello** and Abimbola (2024) applied constructivist techniques like concept map, analogy, metaphor,

and gallery walk activities to address students' misconceptions about ecology, genetics, photosynthesis, and cell Biology. These findings corroborated the argument that conceptual change is indispensable to driving meaningful learning, scientific literacy and human capital, both of which are imperative to Nigeria's knowledge economy and sustainable national development trajectory.

In search of innovation in teaching, I explored an enormous variety of constructivist-leaning models of instruction, some of which appeal to technology such as computer animation (Hamzat, **Bello** & Abimbola, 2017), web quests (Badmus, **Bello** & Hamzat, 2019) game-based learning, (Aje & **Bello**, 2025) and artificial intelligence-based tutoring systems (Ogundare, **Bello** & Adeoye, 2024). These works indicated that technology-supported constructivist strategies do not only improve student performance and engagement but also equip them for the digital world. In furtherance of this, they contributed directly to SDG 4: Quality Education and indirectly to SDG 9: Industry, Innovation and Infrastructure, attesting to the role of education in the center of national digital transformation.

This relevance is also encapsulated in the Nigeria Education Sector Renewal Initiative (NESRI), focusing on improving quality assurance in education, enhancing digital platforms, literacy, and access to quality teaching and learning (Federal Ministry of Education, n.d.) Another significant strand of my work is on teachers' knowledge, professionalism, and capacity building. Based on my works such as **Bello** (1999, 2002, 2003, 2012, 2018, 2022), and **Bello**, Abimbola, Ahmed and **Bello** (2016), Ogundipe, **Bello**, Adeoye, and Abimbola (2021). I have comprehensively documented teachers' lack of understanding of Biology concepts, nature of science, and moral responsibilities. In situating teacher knowledge and ethical practice within a constructivist perspective, these researches advocated for integrated teacher professional development as the foundation for long-lasting institutions, an agenda that fosters SDG 4: Quality Education and SDG 16: Peace, Justice and Strong Institutions.

This supports the priorities of training teachers and improving the quality of teaching, as outlined in Federal

Ministry of Education (2014). Equity and inclusion concerns have also been central to my studies, particularly on gender and access to science education. My works such as **Bello** and Abimbola (1997) and **Bello** (2002, 2016, 2024) examined gender impacts on learning outcomes, science process skills, and illustrations in curriculum materials. This portion of my research resonates with SDG 5: Gender Equality in highlighting the significance of pedagogic interventions that allow male and female students to make contributions proportionally towards Nigeria's scientific and economic advancement. These studies directly support the National Gender Policy (2021–2026) which calls for education and support for women and girls (Federal Republic of Nigeria, (2021), and programmes such as Luminah through NESRI to improve girls' access to education (Federal Ministry of Education (2025).

Social and health dimensions of science education also informed my work, especially its potential to promote well-being and social transformation. Studies such as **Bello** (2009) on trainee teachers' health education in terms of HIV/AIDS, and Zakari and **Bello** (2019) on family planning attitudes, as well as Alabi, **Bello**, Ahmed and Sulaiman (2020) on drug abuse and addiction demonstrated how constructivist pedagogy can be applied to develop students' health knowledge and attitudes. These results characterised the central mission of schooling to address public health problems, directly advancing SDG 3: Good Health and Well-being by linking students' learning in the classroom to Nigeria's public health objectives.

In addition, my research into ecology and environmental principles in Biology has implications for environmental literacy and sustainability education. Through the remediation of students' misconceptions about ecosystems, biodiversity, and conservation (**Bello**, 2000; Ogundare, **Bello** & Adeoye, 2021; Ogundare, Koledafe, **Bello**, & Adeoye, 2024), these works illustrated ways in which constructivist pedagogic strategies can promote environmentally conscious dispositions. These works underpinned SDG 13: Climate Action and SDG 15: Life on Land, empowering learners to meet pressing ecological challenges and sustainability needs. This is specifically supported by Nigeria's new National Climate Change Policy

2021-2030, which lists education and awareness activities as among its strategic objectives (Federal Ministry of Environment, 2021).

Similarly, my research intellectual values and ethical interests extended beyond being professional to encompass broader civic education. By highlighting issues of integrity, equity, and responsibility in higher education (**Bello**, 2005, 2006, 2012), my scholarship put pedagogy at the forefront of civic responsibility and ethical thought development. These works enhanced SDG 16: Peace, Justice and Strong Institutions and align with SDG 10: Reduced Inequalities, because fair and ethical education systems offer more chances to all learners.

Furthermore, my engagement in emergency education highlighted the resilience dimension of education systems. **Bello** (2021), in a remote instruction study within the COVID-19 pandemic, showed how constructivist-informed practices can facilitate learning continuity within crises. The study directly related to SDG 11: Sustainable Cities and Communities. Specifically, in that it showed how adaptive educational practice safeguard human capital construction in times of disruption. Furthermore, my work showed how constructivist pedagogy can drive Nigeria's sustainable development agenda and support the UN SDGs. My research challenges misconceptions, explores new teaching methods, strengthened teacher professionalism, promotes gender inclusion, improves health education, support environmental awareness, builds ethics and civic values, encouraged resilience, and informed policy. In these ways, it showed education, especially Biology Education as a key tool for sustainable national development.

Contributions to the Community, Association, University and the Nation

For me, service has never been just a duty, it is a passion that runs through every stage of my career. I believe in active engagement beyond the classroom, contributing to academia, professional bodies, government initiatives, and my local community to foster institutional growth, empower educators and youth, and strengthen society. A major part of my service has been supporting academic standards across Nigeria. I

currently serve as an External Moderator and External Examiner for several colleges of education and universities, helping shape the future of Biology Education. I also contribute as a Paper Reviewer for local, national, and international journals, and as an External Assessor, reviewing promotion cases for reputable institutions.

My academic journey began at the Kwara State College of Education, Ilorin, where I gained valuable administrative experience. I served twice as Director of the Continuing Education Centre and the Computer and Information Technology Centre, as Director of the Centre for University Affiliated Programmes, and as Director, General Studies in Education. I also serve as Contract Manager for the college's consultancy services, Secretary to the Committee of Deans and Directors, Chairman of the Admissions Committee, and Associate Editor of the *Nigerian Educational Digest*. Nationally, I served as an NCE Accreditor and promoted educational technology through the Nigeria Educators ICT Forum.

At the University of Ilorin, my service continued through key leadership and committee roles. I served as Acting Head of the Department of Science Education, Coordinator of the Biology Education Programme, and Acting Director of the Centre for Students with Special Needs. Faculty Representative, Senate Estates Committee and member of committees on E-learning, Entrepreneurship, Capital Formation, and Ethical Review. I have represented the Faculty on the Boards of the Institute of Education and Centre for International Education, and served as Editor-in-Chief of the *Journal of Curriculum and Instruction*.

Beyond academia, I served as INEC Returning Officer, Chairman and now Patron of the Kwara State Chess Association, Patron of the Dikko Foundation, and Secretary and now Vice chairman of the Diabetes Association of Nigeria (Kwara Chapter). I also offer free educational consultancy service and chair my community's Security Committee. From my early role as Ex-officio Member of Ilorin Grammar School Old Students' Association to my current engagements, I remain guided by one principle: true leadership is service that makes a tangible difference.

Conclusion

Application of constructivism innovative instructional strategies such as concept mapping, analogy, game-based learning metaphor, gallery walk, and even mind-maps in Biology classroom clearly demonstrated the efficacy of constructivism in helping students grasp complex Biology concepts more effectively and meaningfully too. I have demonstrated that constructivism strategies not only improve comprehension, but also boost engagement and interest in Biology Education and science education in general. My works in this area highlighted the significance of active knowledge construction rather than just memorising facts. Fostering critical thinking, creativity, and problem-solving skills through constructivism approaches prepares learners to contribute to scientific innovation, environmental stewardship, and health awareness. Such competencies are essential for building a scientifically literate citizenry capable of driving sustainable national development through informed decision-making, technological advancement, and responsible resource management.

Recommendations

In the light of the critical findings from my studies, the following recommendations are proposed to improve the quality and effectiveness of Biology Education and science education more broadly for sustainable national development:

1. *Instructional Strategies*: Teachers, supported by administrators and curriculum planners, should consistently apply constructivist methods such as concept mapping, analogy, game-based learning, gallery walks, and mind-maps. These strategies deepen pupil understanding and move learning beyond memorisation. Strengthening pupils' problem-solving and critical thinking skills through these methods equips them to contribute innovative solutions that advance sustainable national development.
2. *Misconception Remediation*: Biology teachers, educators, and researchers should conduct regular diagnostic assessments, workshops, and feedback sessions to address misconceptions. This improves learning outcomes and

strengthens teachers' instructional accuracy. A scientifically literate population supports sustainable growth by making informed decisions in areas such as health, agriculture, and environmental management.

3. *Curricular Materials*: Curriculum developers, textbook publishers, and education ministries should review and update Biology textbooks, diagrams, and resources to ensure accuracy, inclusivity, and alignment with modern scientific knowledge. Reliable materials benefit both teachers and pupils. High-quality curricular resources build national capacity in science and technology, which is essential for sustainable economic and social development.
4. *Digital Integration*: Government agencies, school ICT departments, and edtech providers should supply simulations, virtual laboratories, e-learning platforms, and multimedia tools. These technologies make Biology interactive, accessible, and relevant. Expanding digital literacy prepares future citizens to participate in a knowledge-based economy, thereby supporting sustainable national progress.
5. *Teacher Competency*: Teacher training institutions, ministries of education, and professional associations should organise continuous professional development, seminars, and certification programmes. These initiatives strengthen teachers' mastery of Biology content and pedagogy. Skilled teachers produce graduates who can drive innovations in science, technology and environmental sustainability, reinforcing national development goals.
6. *Future Research*: Future research in Biology education should prioritise strategies for remediating persistent student misconceptions, particularly through the integration of constructivist approaches such as concept mapping, analogy-based teaching, gallery walks, and technology-enhanced tools like demo kits and computer animations. Equally important is the need to strengthen teacher knowledge and professional development by embedding explicit instruction on the Nature of Science (NOS) and

epistemological foundations into pre-service and in-service training, while also reforming curricula to better prepare teachers for complex conceptual challenges.

Further study should address curriculum and textbook reform, focusing on readability, gender representation, and diagram accuracy, alongside the incorporation of inquiry-based process skills to foster critical thinking. Research into technology integration, including AI tutoring systems, WebQuest strategies, game-based learning, and mobile learning platforms, should also examine infrastructural and institutional factors that enable equitable adoption. Finally, future studies should investigate targeted interventions for low-achieving students, the role of self-efficacy in shaping learning outcomes, and how positive online learning experiences can be leveraged to enrich traditional classroom instruction.

Taken together, these directions highlighted the need for a multi-faceted research agenda that combines pedagogical innovation, teacher education reform, curriculum development, technological advancement, and student-centered interventions to strengthen Biology education and improve learning outcomes.

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