IJAAR PUBLISHING®

International Journal of Education and National Development | ISSN: 3027-0626
Vol. 4, Issue 2 (2026) | www.ijaar.org

FUTURE OF BIOLOGY EDUCATION: BALANCING CONTENT KNOWLEDGE WITH SKILLS DEVELOPMENT

BY

RUKEVWE ENID EBI-MELEYE
DEPARTMENT OF CURRICULUM & INSTRUCTIONAL TECHNOLOGY
IGNATIUS AJURU UNIVERSITY OF EDUCATION, PORT HARCOURT, NIGERIA

&

LONGINUS NWALA
DEPARTMENT OF INTEGRATED SCIENCE
IGNATIUS AJURU UNIVERSITY OF EDUCATION, PORT HARCOURT, NIGERIA

ABSTRACT

Biology education in the twenty-first century is undergoing a significant transformation driven by rapid scientific advancement, technological innovation, and increasing societal reliance on biological knowledge to address global challenges such as health crises, environmental degradation, food insecurity, and climate change. Traditionally, Biology instruction—particularly within examination-driven systems—has emphasized the mastery of factual content, terminologies, and canonical explanations. However, contemporary science education research and global curriculum reforms increasingly foreground the development of higher-order skills, including scientific inquiry, critical thinking, problem-solving, collaboration, and digital competence. This conceptual paper examines the future of Biology education through the lens of balancing content knowledge with skills development, with particular attention to the Nigerian educational context. It argues that content knowledge and skills development are not competing priorities but mutually reinforcing dimensions of meaningful Biology learning. As Biology continues to shape solutions to global challenges, education systems must prepare learners who are not only knowledgeable but also skilled, adaptable, and scientifically literate. Content Knowledge and skills in Biology Education, Skills Development in Contemporary Biology Education, Reasons for Skill Development in Biology Education, Future Directions of Biology Education and Challenges are discussed. The paper concludes that the goal is to cultivate biologists who are not merely followers of trends but creators of the next frontiers. A balanced, integrated approach to Biology education is therefore not optional but essential for the future.

Keywords: Education, Biology, Content Knowledge, Skills Development.

https://doi.org/10.46654/z8rn7854

INTRODUCTION

Biology which is the study of different forms, their evolution, structures, functions, growth, distribution and taxonomy occupies a unique position in the secondary school science curriculum. It serves as a pre-requisite to the study of other lucrative and challenging professions like; Medicine, Nursing, Pharmacy, Pharmacology, Biochemistry, Agriculture, Microbiology, Geology, Geography, Technological and other applied sciences. The vital role of the study of this discipline in the economic, industrial and public life of the learners and the general humanity cannot be overstressed (Josiah & Oguoko, 2025)

Biology occupies a strategic position within science education due to its direct relevance to human health, environmental sustainability, agriculture, biotechnology, and emerging global challenges such as pandemics, climate change, and biodiversity loss. In contemporary societies, decisions about vaccination, genetic technologies, environmental conservation, and food security increasingly require citizens to possess not only biological knowledge but also the ability to interpret evidence, evaluate competing claims, and make informed judgments. Consequently, Biology education has become central to the broader goal of developing scientifically literate citizens capable of meaningful participation in democratic and knowledge-based societies. The future of Biology education therefore demands a paradigm shift from an exclusive focus on "what students know" to a balanced emphasis on "what students can do with what they know." This shift aligns with global educational reforms that emphasize skills such as critical thinking, creativity, collaboration, communication, and scientific literacy (OECD, 2019).

The content of biology curriculum in 1985 was conceptual (i.e. arranged into concepts) and the concepts were: Concept of living; Basic ecological concepts; Plant and animal nutrition; Variations and variability; Evolution and Genetics. After a revision in 2007, the biology curriculum content became thematic and it is arranged into four themes which now include: organization of life; the organization at work; the organism and its environment; and continuity of life. The biology curriculum has a spiral arrangement of content. Based on this spiral arrangement, the concepts to be taught are arranged in such a way that topics are repeated yearly, throughout the three years of the course; to cover the 62 units in the biology curriculum. Any repeated concept is discussed in greater complexity and depth as the course matures over the three year period. The contents of the senior secondary school biology curriculum places emphasis on field studies, guided discovery, laboratory techniques and skills.

According to the West African Senior Secondary School Certificate Examinations' syllabus (2019/2020), the justifications for inclusion of Biology in the senior secondary school curriculum are as follow: Understanding of the structures and functions of living organisms as well as appreciation of nature; Acquisition of necessary laboratory and fields' skills in order to carry out and evaluate experiments and project in Biology; Acquisition of necessary scientific skills like observing, grouping and interpreting biological data; Acquisition of relevant knowledge in biology needed for future and advanced studies in biological sciences; Acquisition of scientific attitudes for problem solving; Ability to apply biological principles in everyday life in matters that affect personal, social, environmental, community health, and economic problems; Awareness of the existence of interrelationships between biology and other scientific discipline. This implies that when an individual successfully acquired the objectives stated in WAEC syllabus, would facilitate such to be scientific literate with particular reference to Biology.

Despite its importance, Biology education—particularly in many developing and examination-oriented systems—has historically been characterized by content-heavy curricula and teacher-centered pedagogies that prioritize factual recall over conceptual understanding and skill acquisition (Klymkowsky & Garvin-Doxas, 2008). In Nigeria, Biology remains one of the most widely enrolled science subjects at the secondary school level, largely due to its perceived accessibility and relevance to health-related careers. However, persistent concerns have been raised regarding students' shallow conceptual understanding, poor performance in practical work, and limited ability to apply biological knowledge to real-world problems, as reflected in public examination reports by the West African Examinations Council (WAEC) and the National Examinations Council (NECO).

Globally, science education has witnessed a paradigm shift from content transmission to competence-oriented and inquiry-driven learning, as reflected in reforms such as the Next Generation Science Standards (NGSS) in the United States, competence-based curricula in Europe, and scientific literacy frameworks promoted by the OECD and UNESCO (NRC, 2012; OECD, 2019; UNESCO, 2021). These reforms emphasize not only what students know but what they can do with their knowledge. The central challenge, therefore, is how Biology education can balance robust disciplinary content with purposeful skills development without diluting academic rigor. This paper addresses this challenge by critically examining the future of Biology education from a science education research perspective, with a specific focus on Nigeria. It seeks to contribute to ongoing scholarly and policy debates by articulating an integrated framework that aligns Biology content knowledge with skills development in ways that are contextually responsive and pedagogically sound.

Despite the recognized importance of Biology in addressing global and national challenges, there remains a persistent gap between the intended goals of Biology education and actual classroom practices, particularly in Nigeria. The prevailing emphasis on examination performance and content memorization has limited the development of essential scientific skills required for meaningful learning and real-world application. Consequently, many students graduate with theoretical knowledge but lack the competencies needed for problem-solving, innovation, and participation in a knowledge-driven economy.

Furthermore, rapid advancements in science and technology, including biotechnology and artificial intelligence, demand a reorientation of Biology education toward a more skill-integrated approach. There is therefore a pressing need to critically examine how content knowledge and skills development can be effectively balanced to enhance students' academic achievement, scientific literacy, and employability. This study is justified as it seeks to contribute to ongoing educational reforms by providing a conceptual framework for integrating content knowledge with essential skills in Biology education. It also aims to inform curriculum planners, educators, and policymakers on strategies for improving Biology teaching and learning in ways that are relevant to contemporary societal needs and future global demands.

CONTENT KNOWLEDGE AND SKILLS IN BIOLOGY EDUCATION

Content knowledge in Biology includes understanding core concepts such as cell structure and function, genetics, evolution, ecology, physiology, and biotechnology. These foundational ideas are essential for advanced learning and professional practice in biological sciences and related fields. A strong content base enables learners to comprehend biological phenomena, interpret scientific data, and engage with emerging scientific issues.

According to Akpan (2022), Teachers' Content knowledge is defined as the concepts,

principles, relationships, processes, and applications a teacher should know within a given academic subject, appropriate for him/her and organization of the knowledge. Content knowledge (CK) is knowledge about the actual subject matter that is to be learned or taught. The content to be covered in social studies or algebra is very different from the content to be covered in computer science or art and history. Teachers must know and understand the subjects that they teach, including knowledge of central facts, concepts, theories, and procedures within a given field; knowledge of explanatory frameworks that organize and connect ideas; and knowledge of the rules of evidence and proof. Teachers must also understand the nature of knowledge and inquiry in different fields. For example, how is a proof in mathematics different from an historical explanation or a literary interpretation? Teachers who do not have these understandings can misrepresent those subjects to their students.

Parker and Heywood in Akpan (2022), stated that studies have consistently revealed no relationship between subject matter knowledge and pedagogic content knowledge. This therefore, implies that irrespective of a secondary school biology teachers' subject content knowledge, he still needs to develop his pedagogic content knowledge in order to function effectively. The teacher is to impartknowledge to his students', this is important because the teachers' content knowledge is very crucial in impacting the needed knowledge to the students. The teacher has to have the necessary content knowledge to impart successfully to the students' the necessary knowledge in biology. Teachers' access to textbooks, journals, conference proceedings; online materials and eBook will go a long way to improve the content knowledge of the teachers'. Invariably educational discussions also go a long way to improve the content knowledge of the teachers because everything cannot be found in books alone as workshops, seminars, conferences, and lectures go a long way to sharpen the teachers' content knowledge in biology. What the child knows shows the time and energy the teacher had put in the teaching and learning. Furthermore, Aina and Olaonipekun (2015) research showed that a teachers' subject content cannot contribute to the professional development of that teacher but a teacher that is very sound in content Knowledge (CK) and can impart well to the students' will teach any concept in the curriculum and bring about the needed achievement in students.

Teachers' skills are done systematically by professionals who have acquired some skills and knowledge either by training or experience or both. To make desirable impact, teaching must aim at total development of the individual, that is, to enhance intellectual capabilities, developmental and cognitive intellectuality, foster psycho-social skills, and draw out neuro-physical aptitude of the learners. Akanji (2015), opined that the biology curriculum which is in use in Nigeria for teaching and learning in senior secondary school had built in strategy where learners are required to be involved in inquiry and related activities that can develop critical thinking skills. Teachers are charged with the responsibility with respect to improvisation of educational resources and effective use of these resources. If this task would be realized, then, science teachers in schools are faced with the challenge of possessing appropriate skills for the improvisation. For effective improvisation of instructional resources, there are two major types of skills teacher should possess, basically the creative and practical technical skills.

Olagunju and Babayemi (2015), defined creative skills to refer to the behaviour such as imaginativeness, originality, flexibility, dynamism, persistence, independence and observance while practical technical skills are developed through the use of some basic tools. Creative skills are the ability of an individual to bring into a purposeful form something which is partly in existence or has never been in existence. For effective instructional performance, science

teachers must be creative and resourceful. To be creative is to bring into being something which is never in existence or has gone into extinction. Basic practical skills include graphical, metal-work, wood-work and ceramic skills.

Content knowledge remains an indispensable component of Biology education. Core concepts such as cell theory, genetics, evolution, homeostasis, and ecological interdependence form the intellectual backbone of the discipline. Mastery of these ideas is essential for advanced study in biological sciences and related fields such as medicine, agriculture, and environmental science.

However, science education research consistently cautions against equating extensive content coverage with meaningful learning. Overcrowded Biology curricula—common in Nigerian secondary schools—often result in superficial engagement with concepts, encouraging memorization rather than understanding. Examination syllabi frequently emphasize recall of definitions, labeling of diagrams, and reproduction of textbook explanations, thereby reinforcing surface learning approaches. Emerging scholarship advocates for organizing Biology curricula around core ideas and explanatory frameworks, enabling students to develop deep, transferable understanding (NRC, 2012; Schwartz et al., 2017). In this reconceptualization, content knowledge is not abandoned but repositioned as a tool for reasoning, explanation, and problem-solving.

Science teachers are expected to think outside the box so as to be able to perform its duty effectively and teach the students so as not to teach them science as an abstract subject. They have to be creative in bringing these items to showcase to their students so as to improve their knowledge and invariably drive home the needed information to the students. The practical technical skills are developed when both the teacher and students make use of basic tools and will improve the learning abilities of the students.

Practical activities to Usman et al. (2017), are the method of teaching and learning process in the outdoors for exploration and discovery about the environment using first-hand experience involving all courses of study. Therefore, one can say that outdoor education is that instruction either formal or informal that takes place outside the school class room or laboratory with natural or built materials or places to attain the objective of teaching and learning through direct experiences. Therefore, to summarize, outdoors activities are practical activities or activity-oriented teaching strategy that complements the traditional teaching. It is a lesson on itself that is based in the role of nature and environment. Therefore, when teachers and educators teach science concepts indoors (that are best taught outdoors), the concept is isolated from its natural context, thereby limiting the full use and potential of a child's brain. This may lead to de-contextualization of the concepts. The new curriculum calls for acquisition of basic knowledge and skills in science which can only be achieved by exposing students to more of practical activities when teaching all science concepts. This in turn will equip the learners to apply what they learnt to meet societal need and prepare for further studies. For science to be meaningful and relevant, it must reflect the nature of science. This clearly shows that reflecting nature of science means using activities to explore the processes and products of science.

SKILLS DEVELOPMENT IN CONTEMPORARY BIOLOGY EDUCATION

Skill development in the digital era have surfaced are crucial aspect of modern education purposely to meet up the today's fast changing job requirement. This is supported by the newly emerged online education platforms like UDEMY and Coursera that allow students to up-skill or transit completely to new fields of expertise (Calonge, et al., 2019) AI integration

into biology education has the potential to harness massive data sets, skill gaps and workface requirement. The information obtained can be used to design training programs that match the demand of the world economy. Al has the capability to facilitate efficient up skilling and reskilling of individuals to adapt more effectively to technology advancement that encourages self directed skill acquisition and continuous intellectual growth (Ajibike 2025).

Biology education in particular can benefit from AI integration, as it can enhance student learning outcomes, improves engagement and develop essential skills for digital era. The field of Biology is dynamic with new discoveries and advancements being made regularly. As such, biology education must adapt to these changes and provide students with the skill and knowledge necessary to succeed in this field.

Skills development has emerged as a defining priority of twenty-first-century science education. In Biology, these skills include scientific process skills—such as observing, hypothesizing, experimenting, analyzing data, and drawing conclusions—as well as broader competencies such as critical thinking, collaboration, communication, ethical reasoning, and digital literacy. Creative thinking is one of the most important skills of the 21st Century and students are demanded to not only be able to solve the cognitive problems, but also to face the life problems (Nurhamidah et al., 2018).

Natalia (2021), posited that creative thinking skills should be developed in all possible contexts and should take into account the personal characteristics of each student, so that the students are able to generate creative products in a variety of contexts. Teachers then have an Allimportant role in developing creative thinking in students during pedagogy because learning had hitherto emphasized intelligence and paid less attention to creative thinking. Students learning Biology in school should be practicing their thinking skills alongside the learning process so as to obtain, analyze and evaluate information into productive use to be able to survive in a dynamic and competitive environment. Job availability and job creation are challenges many nations are grappling with and every year students' graduate from institutions into a society that has limited jobs for them therefore, frustration and depression may set in as a consequence.

The development of creative thinking among students has become imperative for nations if the challenges of job creation are to be solved creative thinking skills can be developed using active and creative learning strategies that engage students in mental exercises, which will enable the students to practice their skills in problem-solving from different perspectives and to utilize the knowledge acquired during pedagogy for meaningful and productive purposes thereby adding value to society. The potency of creative thinking among secondary school Biology students is such that when armed with the requisite creative thinking skills at that level of life, it is hoped that this skill will mature as the students grow and develop. When confronted with challenges, the students would have been well prepared to face complex situations and problems in everyday life thus reducing the burden on society.

The essential skills in Biology education can be broadly categorized and explained as follows:

1. Scientific Process Skills: These are foundational skills that enable learners to function like scientists. They include: *Observation*: The ability to use the senses and tools to gather information about biological phenomena. *Classification*: Grouping organisms or data based on similarities and differences. *Measurement*: Using standard instruments to obtain accurate data. *Hypothesizing*: Formulating testable predictions based on prior knowledge. *Experimentation*: Designing and conducting experiments to test hypotheses. *Data Analysis and Interpretation:* Organizing data into tables, graphs, and drawing meaningful conclusions.

These skills are essential for developing inquiry-based learning and promoting deep understanding of biological concepts. (National Research Council, 2012; American Association for the Advancement of Science, 2011).

2. Critical Thinking Skills: Critical thinking involves the ability to: Analyze biological information logically; Evaluate evidence and arguments; Identify misconceptions; Make informed decisions on issues such as health, environment, and biotechnology. This skill is crucial in helping students navigate complex biological issues such as genetic engineering, disease control, and environmental sustainability.

3. Problem-Solving Skills: Problem-solving skills enable learners to: Apply biological knowledge to real-life situations; Develop solutions to environmental, health, and agricultural challenges; Engage in scientific reasoning and decision-making. For example, students can apply knowledge of ecology to solve problems related to pollution or climate change. (Iwuanyanwu, 2020). Problem-solving is recognized as a core competency for STEM learners in the twenty-first century.

4. Practical and Laboratory Skills: These include: Handling laboratory equipment (microscopes, test tubes, slides); Conducting experiments safely; Following scientific procedures; Recording observations accurately. Practical skills enhance experiential learning and improve retention of theoretical knowledge (Hofstein & Lunetta, 2004).

5. Digital and Technological Skills: With the integration of technology and Artificial Intelligence in education, students must develop: Ability to use virtual laboratories and simulations; Data analysis using digital tools; Information literacy (searching, evaluating, and using online resources); Basic bioinformatics awareness. These skills prepare learners for modern scientific environments and global competitiveness (World Economic Forum, 2015).

6. Communication Skills: Students should be able to: Present scientific findings clearly (oral and written); Use appropriate biological terminology; Engage in scientific discussions and debates; Effective communication is essential for collaboration and dissemination of scientific knowledge.

7. Collaboration and Teamwork Skills: Biology often involves group-based investigations. Students must learn to: Work effectively in teams; Share responsibilities; Respect diverse perspectives; Contribute to collective problem-solving; This skill mirrors real-world scientific research environments.

8. Creative Thinking and Innovation Skills: Creative thinking involves: Generating new ideas and solutions; Designing experiments; Innovating with limited resources (e.g., improvisation of lab materials). This is particularly important in resource-constrained environments like many Nigerian schools (Tijani & Adeduyigbe, 2025).

9. Ethical Reasoning Skills: Students must develop the ability to: Evaluate ethical issues in biology (e.g., cloning, genetic modification); Make responsible decisions. Understand the societal implications of scientific advancements

10. Entrepreneurial Skills: Biology education can foster: Skills in agriculture, aquaculture, and biotechnology; Self-reliance and job creation; Application of biological knowledge for economic productivity. Entrepreneurial competence supports national development and workforce sustainability (Federal Ministry of Education, 2013; Olabiyi et al., 2021). These skills collectively ensure that students are not only consumers of biological knowledge but also active contributors to scientific and societal development.

REASONS FOR SKILL DEVELOPMENT IN BIOLOGY EDUCATION

In the Nigerian context, skills development is particularly critical given national aspirations for technological advancement, innovation, and sustainable development, as articulated in policy documents such as the National Policy on Education and Nigeria's Vision 2030. Biology education, when effectively designed, can contribute significantly to developing a scientifically skilled workforce and informed citizenry. Skill development in biology education is essential for fostering scientific literacy, practical expertise, and employability in a rapidly evolving, technology-driven world. Based on the provided research, key reasons for developing these skills include:

- **Promoting Employability and Self-Reliance:** Skill acquisition prepares students for self-employment and reduces reliance on limited government jobs, especially in areas like biotechnology, agriculture, and horticulture. A skilled workforce is required to drive technical innovations, biotechnology, and agricultural production. Beyond subject knowledge, biology education develops skills valued by employers, such as critical thinking, problem-solving, resilience, and data analysis. (World Economic Forum, 2015).

- **Enhancing Scientific and Practical Competence:** Students develop hands-on skills in observation, measurement, experimentation, and classification, which are foundational for scientific research. The integration of AI and digital technologies in biology curricula helps students master virtual laboratories and data analysis. Skills developed in practical settings improve the retention of theoretical knowledge.

- **Addressing Global and Societal Challenges:** Biology skills are crucial for understanding ecosystems, promoting sustainability, and addressing global issues like climate change and pollution. Education in this field provides practical knowledge for managing personal/community health and improving living conditions. Biology is a panacea for national development through applications in bio-fermentation, biofuels, and bioinformatics.

- **Improving Pedagogical Outcomes:** Skill-based approaches (like team projects) are more effective than traditional lectures for increasing student engagement and academic achievement. Developing skills ensures that education remains relevant to modern scientific advancements and the needs of the 21st-century workforce. (Tijani, 2024; Hassan et al., 2022).

Conversely, skills are the mechanisms through which abstract content is internalized, applied, and retained. The "Tools and Inquiry Process" model in modern biology syllabi exemplifies this integration, where experimental techniques, technology, and mathematics (Tools) are systematically linked to exploring, designing, and evaluating biological questions (Inquiry) (National Research Council, 2012). Engaging in experimental design forces students to operationalize theoretical concepts, thereby revealing misconceptions and deepening understanding. Research indicates that students often think more like experts when evaluating "what to trust" from data but struggle with deciding "what to do" next—a skill gap that directly inhibits their ability to advance biological inquiry

FUTURE DIRECTIONS OF BIOLOGY EDUCATION AND CHALLENGES

The future of biology education focus on student-centered learning and real-world applications to shape the future of biology education. It is evolved with trends like personalized learning, interdisciplinary approaches, and tech integration. Challenges include accessibility, resources, and programme quality.

- **Responding to Rapid Technological Change:** Biology education cannot continuously append new topics (e.g., AI, spatial omics). Instead, it must foster adaptive expertise—the ability to learn and apply new tools flexibly. Core concepts should be taught with forward-looking examples, and curricula should emphasize the fundamental principles underlying new technologies.
- **Ensuring Equity and Access:** High-quality, skills-based education requires resources, lab equipment, consumables, software, and faculty training. A reliance on virtual labs must be balanced with awareness of the digital divide . A key challenge is ensuring that all students, regardless of institution, have access to authentic laboratory experiences and skill-validation opportunities.
- **Redefining Success for Students and Programs:** Success metrics should expand beyond content-based exams to include portfolios of research,competency badges, and performance on validated critical thinking assessments. Program quality should be judged by how well graduates can apply knowledge in novel situations and navigate the evolving biotech landscape.

CONCLUSION

The future of Biology education depends on achieving a deliberate balance between content knowledge and skills development. Rather than viewing these dimensions as competing priorities, they should be understood as complementary components of meaningful Biology learning. Content knowledge provides the conceptual foundation, while skills development empowers learners to apply, analyze, and extend that knowledge in diverse contexts. As Biology continues to shape solutions to global challenges, education systems must prepare learners who are not only knowledgeable but also skilled, adaptable, and scientifically literate. The goal is to cultivate biologists who are not merely followers of trends but creators of the next frontiers. A balanced, integrated approach to Biology education is therefore not optional but essential for the future.

SUGGESTIONS

- Curriculum planners and Biology educators should begin to devise strategies to be inculcated in pedagogy that could develop the creative thinking skills of Biology students to enhance the students' learning of the subject and subsequently enhance the productivity of the students to participate in national development.
- Teachers should be trained in the creative and practical technical skills needed to build low-cost lab equipment from local materials.
- Integrating practical skills in biotechnology, horticulture, and aquaculture to promote self-reliance and job creation
- Provide teachers with the skills to use AI and online platforms for their own continuous professional growth.
- AI-powered tools and technologies should be designed to be accessible to all students, regardless of their background or abilities.

REFERENCES

American Association for the Advancement of Science. (2011). Vision and change in undergraduate biology education: A call to action. *American Association for the Advancement of Science.*

Akanji, C. A. (2015). Enhancing teaching and learning biology through the use of video clips in selected senior secondary school in Lagos state. *Science Teachers' Association of Nigeria (STAN) Lagos State chapter.*

Aina, J. K., & Olanipekun, S. S. (2015). A review of teacher self-Efficacy, pedagogical content knowledge (PCK) and out-of-field teaching: focusing on nigerian teachers. *International Journal of Elementary Education. 4*(3), 80 – 85.

Akpan, E. E. (2022). Teachers' content knowledge and skills as correlates of students' attitude to biology in Akwa Ibom State. *East African Scholars Joirnala of Education Humanity Literacy, 5*(5), 127-132.

American Association for the Advancement of Science. (2011*). Vision and change in undergraduate biology education:* A call to action. AAAS.

Biggs, J., & Tang, C. (2011). *Teaching for quality learning at university (4th ed.)*. Open University Press.

Bybee, R. W. (2013). *The case for STEM education: Challenges and opportunities.* NSTA Press.

Calonge, D.S., Aman, Shah, M., Riggs, K. & Connor, M. (2019). Moocs and upskilling apllalling in Australia, A qualitative literature study. *Cogent Education. 10*, (1), 16-20.

Fatima A. T. (2025) AI-enhanced Skill Development: Leveraging AI in Biology Education to Develop Skills in Digital Era (*JESTP), Journal of Educational Studies, Trends & Practice. 8*(8)144-152.

Federal Ministry of Education. (2013). *National policy on education (6th ed.).* Government Press.

Hmelo-Silver, C. E., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in inquiry learning. *Educational Psychologist, 42*(2), 99–107.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*(1), 28–54.

Iwuanyanwu, P. N. (2020). *Nature of problem-solving skills for 21st century STEM learners: What teachers need to know*. Springer.

Josiah, O. O & Oguoko, R. A. (2025) Assessment of Biology Content Knowledge on Academic Performance among Senior Secondary Schools in Kwara State, Nigeria. Zamfara International *Journal of Education (ZIJE) 1*(3)343-350.

Klymkowsky, M. W., & Garvin-Doxas, K. (2008). Biology concept inventories. *PLoS Biology, 6*(1), 3.

National Research Council. (2012). *A framework for K–12 science education*. National Academies Press.

National Research Council. (2012). Education for life and work: *Developing transferable knowledge and skills in the 21st century.* National Academies Press.

Natalia, L.B. (2021). Development of creative thinking skills in teacher training process.*https://www.intechopen.com/books*

Nurhamidah, D., Masykuri, M. & Dwiastuti, S. (2018). Profile of senior high school Students' creative thinking skills on biology material in low, medium and high academic perspective. *Journal of Physics Conference Series. 10* (5)1-7

Olabiyi, O. S., Ojo, B. A. Y., & Olayinka, F. O. (2021). Managing students' learning challenges through integration of STEM education for developing 21st-century skills in changing global workforce. *African Journal of Science, Technology and Mathematics Education, 7*(1), 45–58.

Organisation for Economic Co-operation and Development (2019). *OECD future of education and skills 2030.* OECD Publishing.

Olagunju, A. M., & Babayemi, J. O. (2015). A survey of Pre-service teacher's skills for Improving Educational Resources for Effective Instruction in Basic Science. *African Journal of Educational Research, 19*(1),1-2, 10–16

Parker, J., & Heywood, D. (2000). Exploring the relationship between subject knowledge and pedagogic content knowledge in primary teachers' learning about forces. *International Journal of Science Education, 22*(1), 89-111

Shulman, L. S. (1986). Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Tijani, B. E. (2024). Beyond memorisation: Investigating the influence of open inquiry on chemistry students' scientific process skills. *Journal of Research in Environmental and Science Education, 2*(2).

UNESCO. (2021*). Reimagining our futures together.UNESCO*.

Usman, A., Ali, A., Abdullahi, M., Linda, D., Daniel, M.B., & Immi, B. U. (2017). Effects of practical activities method on junior secondary student's achievement in basic science in Gombe metropolis, Gombe state. (Conference) Science *Teachers' Association of Nigeria.*

WAEC. (2021). *Chief examiners' reports on Biology.* WAEC.

World Economic Forum. (2015). *New vision for education: Unlocking the potential of technology.*