BRIDGING DIGITAL SIMULATIONS, VOCATIONAL SCIENCE TRAINING, AND COMMUNITY ENVIRONMENTAL MONITORING: AN INTEGRATED MODEL FOR INDUSTRIAL CHEMISTRY AND ENVIRONMENTAL JUSTICE EDUCATION IN NIGERIA

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Abstract

This paper proposes the Integrated Industrial Chemistry and Environmental Justice Education Model to address systemic gaps in the Nigerian secondary science curriculum. Traditional chemistry instruction often emphasizes rote memorization over practical engagement, leaving learners underprepared for real-world industrial and environmental challenges. The model integrates three components: (1) digital simulation-based learning to strengthen conceptual understanding of abstract topics; (2) vocational science training for hands-on exposure to corrosion testing, water quality assessment, and environmental chemistry experiments; and (3) community-linked environmental monitoring projects that empower students to analyse and respond to local water-related health risks. Grounded in constructivist learning, experiential education, and digital pedagogy, it offers a scalable, context-sensitive approach aligned with Nigeria's National Policy on Education, WAEC/NECO syllabi, and the Sustainable Development Goals, particularly SDGs 4, 6, and 13. Expected outcomes include stronger student engagement, enhanced civic and environmental literacy, workforce-ready graduates, and improved school–community–industry partnerships. Implementation strategies cover curriculum reforms, infrastructure provision, teacher training, and funding support. This paper concludes that the model is both pedagogically sound and practically feasible, offering a timely and locally relevant pathway to reposition STEM education in Nigeria toward sustainability, employability, and environmental responsibility.

Keywords: Digital simulations, Vocational science education, Environmental monitoring, Industrial chemistry education, Environmental justice

Introduction

In the 21st century, science and technical education must respond to rapidly evolving industrial demands, environmental challenges, and technological innovations (UNESCO, 2021). In Nigeria, chemistry education, particularly in industrial and environmental applications remains heavily theory-driven, with limited exposure to practical skills that prepare learners for industry and community problem-solving (Ogunleye & Ojo, 2019). This theory–practice gap is especially pronounced in vocational and technical education, where laboratory facilities are often under-resourced and curriculum delivery rarely connects scientific concepts to real-world challenges such as water quality monitoring, corrosion control, and environmental pollution (Olatunji, 2022).

At the same time, environmental justice concerns are intensifying. Many rural and peri-urban communities in Nigeria face serious water quality issues caused by industrial discharge, agricultural runoff, and inadequate waste management (Ezeh *et al.,* 2020). The absence of systematic environmental monitoring in schools and colleges represents a missed opportunity to combine education with meaningful community service. Students could learn valuable industrial chemistry skills while helping to address pressing local environmental health concerns (Adeniran & Olayinka, 2023).

Recent advances in educational technology present new possibilities for bridging this gap. Digital simulations, ranging from molecular modelling platforms such as AutoDock and ChemSketch to interactive visualisations like PhET, offer cost-effective, safe, and highly engaging ways to teach complex industrial chemistry concepts (Huang & Lin, 2021; Olabisi *et al.*, 2024). When integrated with vocational laboratory training and community-based environmental monitoring, these tools can produce learners who are not only scientifically competent but also socially responsible (Nkwocha & Adeyemi, 2022).

This paper proposes an integrated educational model that unites three core elements: (1) Digital simulations for concept mastery and skill acquisition, (2) Vocational science training for hands-on competence, and (3) Community-based environmental monitoring to link classroom learning with real-world environmental justice. The model is grounded in the Technological, Pedagogical, and Content Knowledge (TPACK) framework and Experiential Learning Theory, ensuring that technological tools are effectively embedded in sound pedagogical practice and authentic experiential contexts (Mishra & Koehler, 2006; Kolb, 2015). By equipping students with both digital and practical skills while fostering community engagement, this model addresses Sustainable Development Goals (SDGs) 4 (Quality Education) and 6 (Clean Water and Sanitation), as well as national priorities in science and technical education (United Nations, 2019).

Literature Review

Digital Simulations in Science Education

Digital simulations have become an increasingly important tool in science education, offering interactive and cost-effective alternatives to traditional laboratory experiments. They allow learners to visualise abstract concepts, conduct virtual experiments, and manipulate variables without the constraints of physical laboratory resources (Huang & Lin, 2021). Platforms such as PhET Interactive Simulations, ChemSketch, and AutoDock have been used effectively to teach concepts in chemistry, molecular docking, and environmental science (Olabisi *et al.*, 2024; Adekunle & Ojo, 2022). In contexts where laboratory infrastructure is limited, simulations provide equitable access to scientific experimentation, bridging gaps in resource-poor settings (Nkwocha & Adeyemi, 2022). Furthermore, simulation-based learning aligns with constructivist principles, enabling students to build knowledge through active engagement and exploration (Mariano & Ching, 2023).

Vocational and Technical Science Education

Vocational and technical education is critical for preparing students with practical skills for the workforce. In Nigeria, the National Policy on Education emphasizes technical education as a means to promote self-reliance and industrial growth (Federal Republic of Nigeria, 2013). However, persistent challenges such as outdated curricula, inadequate facilities, and insufficient teacher training have limited its effectiveness (Olatunji, 2022; Salami & Adebayo, 2021). Integrating vocational science training into secondary and tertiary education has been shown to improve student employability, foster problem-solving skills, and increase industry relevance (Ogunleye & Ojo, 2019). In the context of industrial chemistry, vocational modules on corrosion testing, water quality analysis, and laboratory safety can prepare graduates for roles in manufacturing, environmental management, and research (Adeniran & Olayinka, 2023).

Community-Based Environmental Education

Community-based environmental education promotes experiential learning by engaging students in solving real environmental problems in their localities. This approach has been used globally to enhance environmental awareness, encourage civic responsibility, and link classroom learning with societal needs (Lee & Roth, 2020). In Nigeria, projects involving school-led water quality monitoring have demonstrated positive impacts on both student learning and community knowledge (Ezeh *et al.*, 2020; Abiodun *et al.*, 2023). Such initiatives align with the principles of environmental justice, ensuring that vulnerable communities have access to environmental information and the capacity to advocate for clean and safe environments (Agyeman *et al.*, 2016). Embedding these activities in school curricula not only develops scientific competencies but also strengthens the role of education in sustainable development (Ogunbanjo, 2022).

Theoretical Frameworks

The proposed integrated model is anchored in the Technological, Pedagogical, and Content Knowledge (TPACK) framework, which emphasises the intersection of technology, pedagogy, and subject matter expertise for effective teaching (Mishra & Koehler, 2006). TPACK has been widely adopted in science education to guide the meaningful integration of technology into instructional practice (Mariano & Ching, 2023). Additionally, Experiential Learning Theory (Kolb, 2015) supports the hands-on and community-based components of the model. According to Kolb, learning is most effective when students cycle through concrete experience, reflective observation, abstract conceptualization, and active experimentation. By merging these frameworks, the model ensures that learners acquire not only theoretical knowledge but also practical skills and real-world problem-solving abilities.

This literature review establishes the scholarly foundation for our integrated model, demonstrating that digital simulations, vocational science training, and community-based environmental education have proven value individually, and can be strategically combined to produce transformative educational outcomes.

Methodology

This paper adopts a conceptual model development approach, integrating insights from existing literature, curriculum analysis, and practical case examples. The methodology is structured into five stages:

Stage One – Needs Assessment

A preliminary review of the Nigerian Senior Secondary School Chemistry Curriculum and the National Policy on Science and Technical Education was conducted to identify gaps in the integration of industrial chemistry skills, environmental monitoring, and technology-enhanced learning. Studies by Olatunji (2022) and Ogunleye & Ojo (2019) highlight persistent deficiencies in laboratory infrastructure, teacher digital competence, and industry–school linkages. These findings informed the need for a model that bridges theoretical teaching with vocational and community-based applications.

Stage Two – Model Development

The proposed educational model draws upon two theoretical frameworks: the Technological, Pedagogical, and Content Knowledge (TPACK) model (Mishra & Koehler, 2006) and Experiential Learning Theory (Kolb, 2015). Three core components were integrated:

1. **Digital Simulations** – Incorporating accessible tools such as PhET Interactive Simulations, ChemSketch, and AutoDock to teach corrosion chemistry, molecular interactions, and pollutant behaviour.
2. **Vocational Science Training** – Embedding hands-on laboratory modules on corrosion testing, water quality analysis (pH, turbidity, conductivity), and laboratory safety protocols.
3. **Community-Based Environmental Monitoring** – Facilitating student-led water sampling and analysis in local communities, with results presented to stakeholders to promote environmental justice.

Stage Three – Proposed Implementation

The model is designed for senior secondary schools, vocational/technical colleges, and teacher training institutions. A 6–8 week module is proposed within a school term, structured as follows:

- **Weeks 1–2:** Theoretical instruction supported by digital simulations.
- **Weeks 3–4:** Laboratory-based vocational skills training.
- **Weeks 5–6:** Fieldwork for environmental sampling and data analysis.
- **Week 7:** Community presentations and policy dialogue.
- **Week 8:** Final assessment and reflection.

Stage Four – Evaluation Strategy

Evaluation will be both formative and summative:

1. **Formative:** Simulation-based quizzes, lab performance checklists, teacher observation.
2. **Summative:** Project reports, oral presentations, and community feedback surveys.

Indicators of success include student proficiency in using digital tools, competency in basic industrial chemistry laboratory skills, and evidence of community environmental awareness.

Stage Five – Ethical Considerations

Ethical approval would be sought from relevant educational authorities before implementation. Participation of students and community members would be voluntary, with informed consent obtained. Environmental sampling would follow safe and non-invasive procedures, ensuring respect for community customs and ecological sustainability.

The sequence of activities for implementing the model is summarised in Figure 1, outlining the stages from model conceptualisation to classroom integration and community engagement.

This methodological approach ensures that the proposed model is pedagogically sound, technologically appropriate, and socially relevant, with the potential for replication across diverse educational contexts in Nigeria.

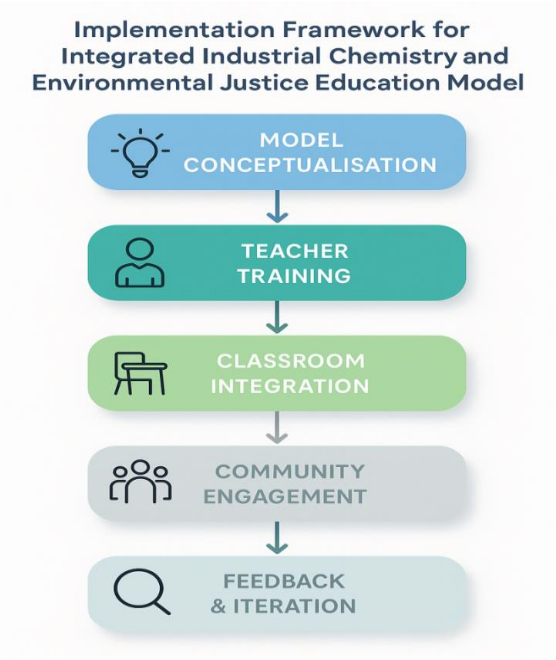

Figure 1. *Implementation framework for the Integrated Industrial Chemistry and Environmental Justice Education Model, outlining the sequential stages from model conceptualisation to feedback and iteration.*

Proposed Model

The proposed Integrated Industrial Chemistry and Environmental Justice Education Model is designed to merge three interconnected components into a cohesive instructional framework: digital simulations, vocational science training, and community-based environmental monitoring. The synergy of these elements ensures that students gain conceptual mastery, technical competence, and civic engagement skills simultaneously.

Component 1 – Digital Simulations

Digital simulations provide a cost-effective and interactive platform for teaching complex chemistry concepts. Tools such as PhET Interactive Simulations, ChemSketch, and AutoDock enable learners to:

1. Visualise molecular interactions relevant to corrosion processes and pollutant behaviour.
2. Model chemical reactions and predict experimental outcomes.
3. Explore scenarios that may be unsafe or costly to replicate in school laboratories.

By introducing these tools in the early weeks of instruction, students develop foundational understanding before engaging in physical experiments.

Component 2 – Vocational Science Training

Vocational training focuses on laboratory-based competencies essential for industrial chemistry and environmental science careers. This includes:

1. Corrosion testing techniques (e.g., weight loss method with mild steel samples).
2. Water quality analysis (e.g., pH, turbidity, conductivity, and microbial counts).
3. Safe laboratory practices and equipment handling.

These activities are structured in alignment with the National Vocational Education and Training Standards, thereby ensuring both academic rigor and industry relevance. Beyond skill acquisition, vocational training enhances learners' confidence in applying theoretical knowledge to real-world contexts, bridging the persistent gap between classroom instruction and industrial practice. In addition, such training cultivates transferable skills such as critical thinking, teamwork, and problem-solving, which are highly valued by both industry and academia. The incorporation of modern laboratory technologies and simulation tools also prepares students for the digital transformation currently reshaping the global workplace. By embedding these competencies into the curriculum, learners are better positioned to meet national development goals, support environmental sustainability initiatives, and contribute meaningfully to their communities. Figure 2 demonstrates how corrosion studies can be integrated into the model by linking virtual simulations with vocational skill applications and community-based projects, thereby fostering holistic learning and employability.

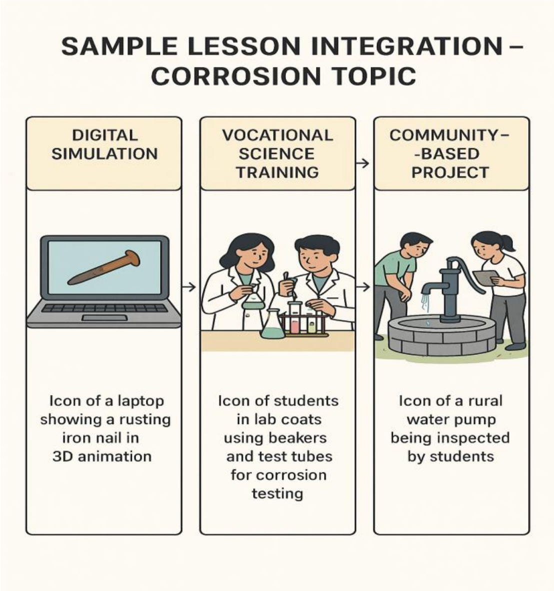

Figure 2. *Example of a corrosion lesson plan integrated across digital simulation, vocational science training, and community-based project work.*

Component 3 – Community-Based Environmental Monitoring

Students apply their digital and laboratory skills in real-world contexts by engaging with local communities. Activities include:

1. Collecting and analysing water samples from streams, boreholes, and storage tanks.
2. Interpreting results in plain language for community stakeholders.
3. Designing environmental awareness campaigns to promote safe water practices.

This component reinforces civic responsibility and supports environmental justice, particularly in under-served rural areas.

Synergistic Interaction of Components

The three components are mutually reinforcing:

i. Digital simulations prepare students for vocational tasks.
ii. Vocational training equips them to carry out community projects effectively.
iii. Community projects motivate deeper engagement with simulations and laboratory work by providing authentic problems to solve.

Visual Representation of the Model

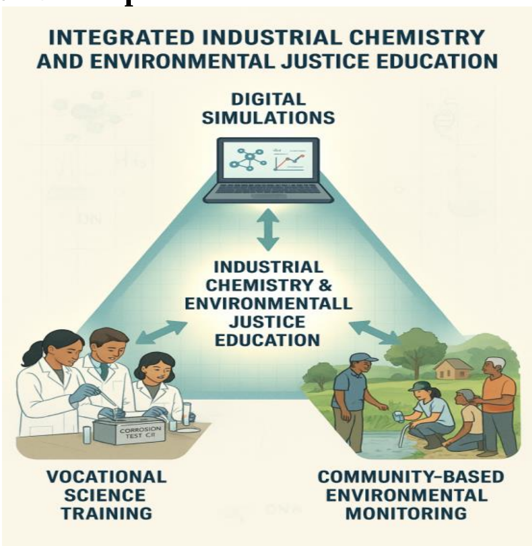

Figure 3*. Integrated Industrial Chemistry and Environmental Justice Education Model.*

Figure 3 presents the proposed Integrated Industrial Chemistry and Environmental Justice Education Model, showing the relationship between digital simulations, vocational science training, and community-based environmental monitoring. At the core of this triangular framework lies Industrial Chemistry & Environmental Justice Education, which serves as the integrative hub for all activities.

Each vertex of the triangle represents a strategic entry point for intervention:

- **Digital Simulations** provide cost-effective, scalable learning environments for chemistry concepts that would otherwise require expensive laboratory setups.
- **Vocational Science Training** focuses on equipping learners with hands-on skills relevant to industrial applications and environmental monitoring.
- **Community-Based** Environmental Monitoring links learners to real-world environmental justice issues, fostering civic engagement and applied problem-solving.

Bidirectional arrows illustrate the mutual reinforcement between all three elements, highlighting the cyclical and integrated nature of the approach. By combining technological tools, practical vocational skills, and community engagement, the model offers a holistic pathway for enhancing science education while addressing local environmental justice challenges.

5. Expected Outcomes and Benefits

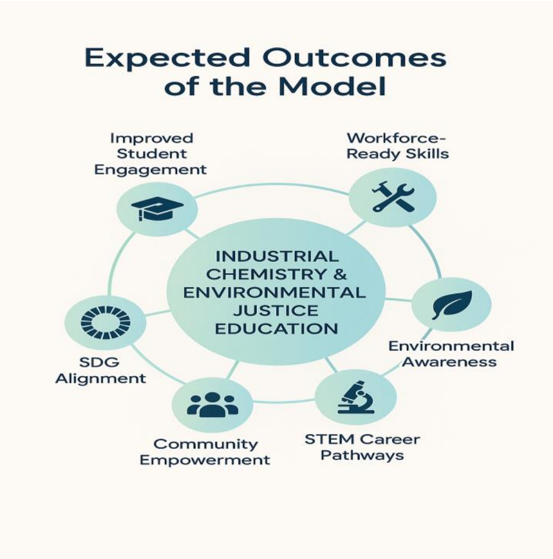

Figure 4. *Potential impact map showing the interconnected educational, vocational, environmental, and societal outcomes of the model.*

The integrated model is designed to deliver outcomes that benefit multiple stakeholders within the educational, industrial, and community sectors. As shown in Figure 4, the model is designed to deliver multiple interconnected outcomes, from improved science literacy to alignment with Sustainable Development Goals (SDGs).

For Students

a. **Enhanced Conceptual Understanding**: Mastery of complex chemistry concepts through interactive digital simulations.
b. **Technical Competence**: Acquisition of hands-on skills in corrosion testing, water quality analysis, and laboratory safety procedures.
c. **Problem-Solving Skills**: Ability to link classroom learning with authentic environmental challenges.
d. **Civic Engagement**: Increased awareness of environmental justice issues and a sense of responsibility toward local communities.

For Teachers

1. **Capacity Building**: Improved competence in integrating technology with pedagogy and subject matter expertise.
2. **Curriculum Enrichment**: Access to a model that incorporates digital tools, vocational tasks, and community projects into science instruction.
3. **Professional Relevance**: Strengthened ability to produce graduates who meet both academic and industrial needs.

For Industry

1. **Workforce Readiness**: A pipeline of graduates equipped with both theoretical knowledge and practical laboratory skills relevant to industrial chemistry and environmental management.

2. **Innovation Linkages**: Opportunities for collaboration with educational institutions on training and research initiatives.

For Communities

1. **Environmental Awareness**: Increased knowledge about water quality and safe water practices.
2. **Citizen Science Participation**: Engagement in monitoring and advocating for local environmental improvements.
3. **Social Equity**: Empowerment of under-served communities through access to environmental information and action plans.

By producing graduates who are digitally literate, technically skilled, and socially responsible, the model contributes directly to national education goals and the Sustainable Development Goals (SDGs), particularly Goal 4 (*Quality Education*) and Goal 6 (*Clean Water and Sanitation*). Furthermore, the model supports long-term sustainability by fostering school–industry–community partnerships that can be replicated across diverse contexts in Nigeria. As shown in Figure 4, the model is designed to deliver multiple interconnected outcomes, from improved science literacy to alignment with Sustainable Development Goals (SDGs).

Policy and Implementation Recommendations

The successful adoption of the Integrated Industrial Chemistry and Environmental Justice Education Model requires supportive policies, institutional commitment, and multi-sectoral collaboration. The following recommendations are proposed:

Education Policy Reforms

a. **Curriculum Integration**: The Nigerian Senior Secondary School Chemistry Curriculum should explicitly include modules on environmental monitoring, corrosion chemistry, and digital simulation use.

b. **Assessment Diversification**: Incorporate project-based assessments and community engagement projects into WAEC/NECO practical evaluations to reward applied skills.

c. **Teacher Professional Development**: Establish mandatory digital pedagogy and vocational laboratory training workshops for science teachers.

Institutional Capacity Building

i. **ICT Infrastructure**: Equip schools with basic ICT facilities (laptops, projectors, internet access) to enable the use of simulation software.

ii. **Low-Cost Laboratory Setups**: Provide modular laboratory kits for corrosion testing, water quality analysis, and environmental sampling.

iii. **Partnership Development**: Facilitate Memoranda of Understanding (MoUs) between schools, local industries, and environmental agencies for resource sharing and expertise exchange.

Funding and Resource Mobilisation

1. **Government Funding**: Allocate a portion of the Universal Basic Education Commission (UBEC) intervention funds to support STEM–vocational integration projects.
2. **Private Sector Sponsorship**: Encourage industries to sponsor school–community environmental monitoring projects as part of Corporate Social Responsibility (CSR) initiatives.
3. **Grant Opportunities**: Leverage international funding streams such as UNESCO's Education for Sustainable Development (ESD)

grants and the Commonwealth Education Fund.

Implementation Roadmap

1. **Pilot Phase (Year 1)**: Select three schools (urban, semi-urban, and rural) to test the model over one academic term.
2. **Evaluation Phase (Year 2)**: Assess impact using pre- and post-intervention tests, community feedback, and teacher performance metrics.
3. **Scale-Up Phase (Year 3–5)**: Expand to all states in Nigeria, with state-level adaptation for local contexts.

Figure 5 presents a tentative timeline for implementing the model in a pilot secondary school setting.

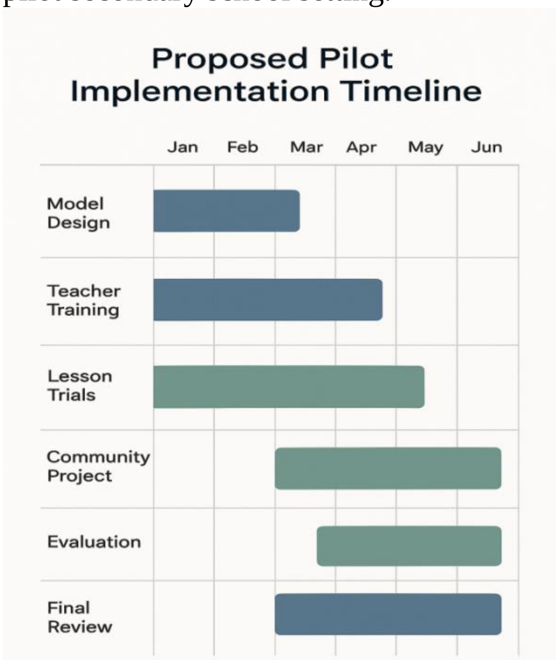

Figure 5. *Proposed Gantt chart for a six-month pilot implementation of the Integrated Industrial Chemistry and Environmental Justice Education Model in a secondary school setting.*

Alignment with National and Global Priorities

The model directly supports:

- ✓ **National Policy on Education (NPE)** objectives for technical and vocational education.
- ✓ **Nigeria's Vision 2050** emphasis on science, technology, and innovation for development.
- ✓ **Sustainable Development Goals (SDGs)**, particularly Goals 4 (*Quality Education*), 6 (*Clean Water and Sanitation*), and 13 (*Climate Action*).

Conclusion

The Integrated Industrial Chemistry and Environmental Justice Education Model provides a transformative approach to STEM teaching and learning in Nigeria by merging digital simulations**,** vocational science training, and community-based environmental monitoring. This integration not only bridges the gap between theoretical understanding and practical application but also embeds civic responsibility and environmental awareness into the core of science education.

By producing graduates who are technically skilled, digitally literate, and socially engaged, the model addresses national educational priorities, supports sustainable industrial growth, and empowers local communities. The approach is adaptable to resource-limited settings, making it scalable across Nigeria and other developing contexts.

Successful implementation will depend on curriculum reforms**,** teacher training**,** infrastructure investment, and multi-sectoral partnerships involving schools, industries, and community stakeholders. When institutionalised, this model has the potential to redefine how industrial chemistry and environmental education are delivered, positioning Nigeria as a leader in innovative STEM pedagogy within sub-Saharan Africa.

Disclosure Statement

The authors declare that there is no conflict of interest regarding the publication of this paper. No funding was received for the development of this manuscript, and there are no financial, personal, or institutional relationships that could be perceived to influence the content of this work. All opinions, interpretations, and recommendations expressed herein are solely those of the authors and are based on the available literature and conceptual analysis.

Ethical Considerations

This study did not involve direct experimentation with human participants or animals. All concepts and recommendations are based on a synthesis of existing literature and publicly available data. Where examples of educational practice are discussed, they are hypothetical and not drawn from identifiable individuals or institutions. The research complies with the principles of academic integrity and ethical scholarship, Therefore, No Formal ethical approval was required for this study

Data Availability Statement

All data supporting the findings of this study are contained within the manuscript and can be accessed through the cited and referenced sources.

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