INNOVATIVE AND SUSTAINABLE APPROACHES TO DELIVERING HANDS-ON SCIENCE CONTENT IN OPEN AND DISTANCE LEARNING

By

Olawale Mutiat Yetunde

yolawale@noun.edu.ng

Department of Science Education

National Open University of Nigeria

+2347031301101

Abstract

Building sustainable and inclusive science education systems requires innovative strategies that ensure equitable access to hands-on learning experiences, particularly within Open and Distance Learning (ODL) environments. Science education is inherently experiential; however, ODL institutions often struggle to deliver practical components due to limited physical laboratory access, infrastructural constraints, and dispersed learner populations. Using the National Open University of Nigeria (NOUN) as a case study, this research investigates innovative and sustainable approaches to delivering hands-on science content in ODL. A descriptive survey research design was adopted, targeting 300-level science education students enrolled in SED305 (Practicum in Science Teaching) at NOUN. Data were collected from 157 students across ten study centres using a validated questionnaire on innovative and sustainable approaches to hands-on science content delivery. Descriptive statistics were used for data analysis. Findings reveal that limited access to laboratory equipment, inadequate technical support, and unstable internet connectivity constitute major challenges to effective practical science delivery. Despite these constraints, emerging tools such as smartphone-based experiments, simulations, virtual laboratories, and immersive technologies were perceived as effective in enhancing learner engagement, conceptual understanding, problem-solving skills, and retention of scientific concepts. Learners demonstrated strong positive perceptions and confidence in using innovative and sustainable instructional approaches. The study concludes that integrating technology-enhanced, pedagogically sound, and sustainability-oriented strategies is essential for strengthening hands-on science education in ODL contexts. Recommendations are provided to guide institutional investment, curriculum integration, capacity building, and policy development to support sustainable science education delivery.

Keywords: Open and Distance Learning, Hands-on Science, Virtual Laboratories, Sustainability, Innovative Pedagogy

Background of the Study

Advancing science education through Open and Distance Learning (ODL) is vital for ensuring accessible, transformative, and sustainable learning aligned with the Sustainable Development Goals (SDGs) (UNESCO et al., 2021–2023). The delivery of hands-on science content in Open and Distance Learning (ODL) institutions presents a unique pedagogical challenge. Science learning traditionally relies on laboratory-based experiments and tactile engagement to foster understanding, yet many ODL students lack access to physical lab environments. To bridge this gap, virtual and remote laboratories, along with smartphone-based experiments, have emerged as viable alternatives. Science disciplines inherently rely on experiential learning students build deep conceptual understanding, develop inquiry skills, and drive innovation through hands-on experimentation. Yet, ODL institutions often struggle to facilitate these practical components effectively, especially where laboratory infrastructure and direct supervision are limited (Ukhurebor, Onyancha, and Adewuyi 2025).

Recent systematic reviews confirm the pedagogical efficacy of hands-on learning in STEM education: learners who engage actively via “learning by doing” show significantly higher conceptual understanding, problem-solving abilities, motivation, and retention in comparison to passive lecture formats (Kazu and Yalçın, 2021; Kanapathy and Azhari, 2024). Similarly, a meta-analysis of active learning in STEM reports a nearly 0.5 standard-deviation gain in performance and substantial reduction in failure rates (active learning over traditional lectures), strongly endorsing student-centered instructional designs (National Academy of Sciences, Freeman et al., 2014). In distance learning contexts, online and remote labs, as well as virtual simulations, have become increasingly important. Sharpe and Abrahams (2019) and Hlescu, Klement, and Slavíček, (2020) note that online laboratories allow students to conduct experiments virtually or via remote control, enabling access to experiments otherwise inaccessible due to physical, safety, or resource constraints. When physical labs are unavailable, virtual and remote lab platforms have been shown to deliver comparable gains in scientific process skills and motivation (Chan, Lee, and Yeung, 2021; Lynch and Ghergulescu, 2017). Specifically in Nigeria, virtual laboratory instruction in Bonny Local Government Area of Rivers State significantly improved students' performance and retention in basic science, outperforming field-trip methods (Chado, Okwuduba, and Okorie, 2021; Uwitonze and Nizeyimana, 2022; Bazie, Mohammed, and Ahmed 2024), although some studies note better retention with real-world field experiences.

Virtual Laboratories (VLs) have shown considerable promise in enabling remote experimentation for ODL learners. A meta-analysis by Li and Liang (2024) reports that VLs significantly enhance engineering education outcomes boosting learning motivation (effect size $g = 3.571$), engagement ($g = 2.888$), and overall performance ($g = 0.686$). Furthermore, Ukhurebor et al. (2025) highlight how cloud-based VLs mitigate challenges such as student dispersion and inadequate equipment, positioning them as critical tools for ODL science education. Zhao's 2025 review demonstrates that smartphone-based experiments leveraging built-in sensors and video analysis achieve gains comparable to, or better than, traditional labs in conceptual understanding, process skills, and student engagement, particularly in remote and resource-constrained settings. Perez and Keleş (2025) introduced embodied VR-based labs for engineering students, enabling tactile interaction with virtual specimens. Their modular VR framework significantly improved students' comprehension and retention compared to non-embodied VR environments.

There is a growing recognition that integrating sustainability principles within hands-on instruction enhances learning's transformative impact. Sustainability-focused science education cultivates critical thinking, systems perspectives, and stewardship developing learners who can tackle real-world challenges. Despite technological advancements, the lack of systemic, pedagogically-aligned frameworks remains a central gap. Many institutions adopt innovations like VLs or SmartIPLs in an ad hoc manner, without ensuring instructor readiness, curricular alignment, or local adaptability. For instance, blended bioengineering pedagogy in developing countries shows positive promise but lacks standardized integration. To address these constraints, innovative and sustainable instructional approaches such as virtual laboratories (VLs), smartphone-integrated labs, and immersive technologies have been increasingly advocated. These methods offer flexibility, cost-effectiveness, and scalability, meeting the needs of decentralized learning environments. challenges like inadequate infrastructure, unstable electricity, limited digital literacy, and weak technical and administrative support impede effective VL adoption in under-resourced settings. Innovative technologies such as the use of virtual laboratories, smartphone-based experiments, and immersive VR have shown substantial educational promise, their strategic incorporation into ODL curricula remains inconsistent. There is a pressing need to develop innovative and sustainable instructional approaches that integrate technological affordances with sound pedagogical principles and real-world contexts. Such an approach will support inclusive, scalable, and transformative hands-on science learning in ODL institutions ultimately serving both educational quality and sustainable development imperatives.

Statement of the Problem

Hands-on learning is essential for developing scientific understanding and skills, yet Open and Distance Learning (ODL) institutions often lack physical laboratories, direct supervision, and cohesive strategies to deliver practical science effectively. Innovative tools such as virtual labs, remote labs, smartphone-based experiments, and immersive technologies can bridge this gap, but their adoption in ODL remains inconsistent and poorly integrated. Persistent challenges including inadequate infrastructure, unstable electricity, limited digital literacy, and insufficient institutional support further hinder effective implementation. Consequently, there is a pressing need for a comprehensive, innovative, and sustainable instructional approach that combines emerging technologies with sound pedagogy to ensure equitable access to experiential science learning in ODL settings.

Purpose of the Study

The main objective of this study is to develop and evaluate an innovative and sustainable instructional approach for enhancing the delivery of hands-on science content in Open and Distance Learning (ODL) institutions.

The study seeks to:

1. Identify the challenges hindering effective delivery of hands-on science content in ODL institutions.
2. Examine the current instructional strategies and technologies used for practical science teaching in ODL contexts.

3. Assess the effectiveness of emerging tools such as virtual laboratories, smartphone-based experiments, and immersive technologies in promoting experiential science learning in ODL.
4. Explore the perceptions of learners toward innovative and sustainable approaches to hands-on science delivery.

Research Questions

1. What challenges hinder the effective delivery of hands-on science content in Open and Distance Learning (ODL) institutions?
2. What instructional strategies and technologies are currently used for practical science teaching in ODL contexts?
3. How effective are emerging tools in promoting experiential science learning in ODL?
4. What are the perceptions of learners toward innovative and sustainable approaches to delivering hands-on science content in ODL institutions?

Methodology

This study adopted a descriptive survey research design. The target population consisted of all 300-level science education students of the National Open University of Nigeria (NOUN) who registered for SED305 practicum in science teaching for the 2024_2 and 2025_1.

A stratified random sampling technique was used to select 300 science education students who registered SED305 for 2025_1 from 10 study centres.

The instrument used was subjected to face and content validity which were established by the opinions of three experts in Measurement and Evaluation and Science Education, to ascertain the clarity of purpose in the instrument in measuring what they were supposed to measure.

Pilot test was carried out by administering instrument to 20 SED305 students who were not part of the study to test the reliability and the coefficient of 0.88 was obtained using Cronbach alpha.

The data collected from this study were analysed using descriptive statistics of mean and standard deviation to answer the research questions.

The instrument for the data collection was twenty (20) items of adapted questionnaire in innovative and sustainable approaches to delivering hands-on science content in open and distance learning (ISADHSC). The response for the questionnaire was measured on a 4 Likert- scale of Strongly Agree (SA) Agree(A) Disagree(D) and Strongly Disagree (SD). Section A of the questionnaire contained items seeking information about personal data of the respondents while section B consisted of the 20 items all in a google form. The google form was sent to the students through their email addresses and WhatsApp respectively. The instrument (ISADHSC) which was in a google form was used to obtain data on the SED305 from the students and were filled and submitted immediately. At the end of the exercise the, 157 SED305 students filled the google form and submitted as instructed.

RESULTS

Table 1: What challenges hinder the effective delivery of hands-on science content in Open and Distance Learning (ODL) institutions?

Descriptive Statistics						
	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Lack of physical laboratory facilities limits practical science learning in ODL institutions.	157	1.00	4.00	293.00	1.8662	.98121
Limited access to laboratory equipment negatively affects hands-on science learning.	157	1.00	4.00	482.00	3.0701	1.00712
Inadequate technical support reduces the effectiveness of science practicals in ODL.	157	1.00	4.00	403.00	2.5669	1.00813

Poor internet connectivity and unstable electricity make virtual laboratory adoption difficult.	157	1.00	4.00	342.00	2.1783	.90230
Dispersed student populations hinder effective supervision of hands-on activities.	157	1.00	4.00	286.00	1.8217	.88798
Valid N (listwise)	157					

This table identifies the most critical infrastructural and logistical barriers. Highest Rated Challenge: "Limited access to laboratory equipment" (Mean = 3.07) is the most severe challenge. Inadequate technical support" (Mean = 2.57) and "Poor internet connectivity and unstable electricity" (Mean = 2.18) are also agreed-upon as substantial barriers. "Lack of physical laboratory facilities" (Mean = 1.87) and "Dispersed student populations" (Mean = 1.82) have the lowest means.

Table 2: What instructional strategies and technologies are currently used for practical science teaching in ODL contexts?

Descriptive Statistics						
	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Instructors use virtual laboratories to deliver practical science lessons.	157	1.00	4.00	300.00	1.9108	.92248

Smartphone-based experiments are integrated into science courses for hands-on learning.	157	1.00	5.00	465.00	2.9618	.84645
Video-based demonstrations are a common instructional strategy for practical science teaching.	157	1.00	4.00	349.00	2.2229	.99742
Collaborative online tools are used to facilitate group-based hands-on science tasks.	157	1.00	4.00	302.00	1.9236	.95099
Simulation-based platforms are regularly used to supplement laboratory-based experiments.	157	1.00	4.00	458.00	2.9172	1.04367
Valid N (listwise)	157					

This table measures the current level of adoption of various innovative teaching strategies. "Smartphone-based experiments" (Mean = 2.96) and "Simulation-based platforms" (Mean = 2.92) are the most commonly employed strategies. "Video-based demonstrations" (Mean = 2.22) are used to a moderate extent. "Virtual laboratories" (Mean = 1.91) and "Collaborative online tools" (Mean = 1.92) are the least adopted.

Table 3: How effective are emerging tools in promoting experiential science learning in ODL?

Descriptive Statistics						
	N	Minimum	Maximum	Sum	Mean	Std. Deviation
Virtual laboratories improve students' understanding of science concepts.	157	1.00	4.00	381.00	2.4268	1.02033
Smartphone-integrated experiments enhance student engagement in practical science learning.	157	1.00	4.00	382.00	2.4331	1.02703
Immersive technologies (VR/AR) make science learning more interactive and realistic.	157	1.00	4.00	455.00	2.8981	1.02647
Emerging tools improve students' problem-solving and critical-thinking skills in science.	157	1.00	4.00	445.00	2.8344	1.06125
Use of innovative technologies leads to better retention of scientific concepts.	157	1.00	4.00	498.00	3.1720	.98175
Valid N (listwise)	157					

Table 3 shows how effective are emerging tools in promoting experiential science learning in ODL. "Use of innovative technologies leads to better retention of scientific concepts" (Mean = 3.17). This is the strongest agreement in the entire dataset. Respondents firmly believe that these tools help students remember what they learn. High Effectiveness for Skills and Engagement: "Immersive technologies (VR/AR)" (Mean = 2.90) and "improving problem-solving skills" (Mean = 2.83) are also seen as highly effective. "Smartphone-integrated experiments" (Mean = 2.43) and "Virtual laboratories" (Mean = 2.43) are perceived as moderately to highly effective for understanding and engagement.

Table 4: What are the perceptions of learners toward innovative and sustainable approaches to delivering hands-on science content in ODL institutions?This table gauges learner attitudes and motivation. "Innovative approaches make science learning easier and more enjoyable" (Mean = 3.22). "I am confident using virtual laboratories." (Mean = 3.11) and "Innovative and sustainable methods are essential." (Mean = 3.12) show that learners feel competent using these tools and view them as crucial for their education. "Students are motivated to participate more." (Mean = 2.69) and the importance of "Integrating sustainable practices" (Mean = 2.77) are also agreed upon, though slightly less strongly.

The data reveals a clear narrative: While significant challenges impede practical science education in ODL, there is strong recognition of the potential of emerging technologies to overcome these hurdles. Learners perceive these innovative tools positively and see them as essential for the future, even though their current adoption is moderate.

Discussion of Findings

The results highlight a clear tension between the need for experiential science learning and the structural constraints of ODL environments. While infrastructural and technical challenges persist, learners recognize the strong potential of innovative technologies to address these limitations. The prominence of smartphone-based and simulation tools reflects their accessibility and adaptability in low-resource contexts. The strong perceived impact of innovative tools on knowledge retention and engagement supports constructivist learning theories and reinforces prior empirical evidence on active learning in STEM education.

Learners' positive attitudes toward innovative and sustainable approaches indicate readiness for broader adoption and integration. However, the relatively low use of virtual laboratories and collaborative tools suggests the need for stronger institutional support, policy alignment, and capacity building to fully harness these technologies.

Conclusion

This study concludes that innovative and sustainable instructional approaches are critical for effective delivery of hands-on science content in Open and Distance Learning institutions. Although significant challenges remain, emerging technologies such as virtual laboratories, smartphone-based experiments, simulations, and immersive tools offer practical and scalable solutions. Learners' positive perceptions and demonstrated confidence underscore the feasibility and sustainability of these approaches. Strategic integration of technology, pedagogy, and institutional support is therefore essential for strengthening science education and advancing sustainable development goals.

Recommendations

Based on the findings of this study, it is recommended that:

1. ODL institutions should invest in robust digital infrastructure and technical support systems to facilitate experiential science learning.
2. Innovative tools should be systematically embedded into science curricula with clear pedagogical alignment.
3. Regular capacity-building programs should be provided for instructors and learners to enhance effective technology use.
4. Sustainability principles should guide instructional design through the adoption of low-cost, scalable, and locally adaptable technologies.
5. Policymakers should develop supportive frameworks and partnerships to promote innovation in ODL science education.
6. Further research should employ experimental and mixed-method approaches to assess long-term learning outcomes.

References

Bazie, H. A., Mohammed, S. A., & Ahmed, I. M. (2024). Effect of virtual laboratory instruction on students' achievement and retention in basic science. *Journal of Science Education and Technology*, 33(2), 215–228. https://doi.org/10.1007/s10956-023-10045-7

Chan, K. K. H., Lee, C. K., & Yeung, Y. Y. (2021). Virtual laboratories and their effectiveness in developing students' scientific inquiry skills. *International Journal of Science Education*, 43(9), 1475–1494. https://doi.org/10.1080/09500693.2021.1905694

Chado, J. M., Okwuduba, E. N., & Okorie, E. U. (2021). Effects of virtual laboratory and field trip methods on students' achievement and retention in basic science. *African Journal of Educational Research*, 25(1), 89–102.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America*, 111(23), 8410–8415. https://doi.org/10.1073/pnas.1319030111

Hlescu, M., Klement, M., & Slavíček, K. (2020). Remote laboratories in distance education: Opportunities and challenges. *Education and Information Technologies*, 25(5), 4283–4301. https://doi.org/10.1007/s10639-020-10163-5

Kanapathy, R., & Azhari, A. (2024). Learning by doing: A systematic review of hands-on learning in STEM education. *Journal of STEM Education*, 25(1), 34–48.

Kazu, H., & Yalçın, S. (2021). The effect of experiential learning on students' academic achievement and retention. *Educational Research Review*, 33, 100387. https://doi.org/10.1016/j.edurev.2021.100387

Li, X., & Liang, J. C. (2024). Effects of virtual laboratories on engineering education: A meta-analysis. *Computers & Education*, 196, 104708. https://doi.org/10.1016/j.compedu.2023.104708

Lynch, T., & Ghergulescu, I. (2017). Review of virtual laboratories as tools for distance science education. *Journal of Interactive Learning Research*, 28(4), 419–438.

Perez, J. R., & Keleş, E. (2025). Embodied virtual reality laboratories for engineering education: Design and learning outcomes. *Computers & Education: Artificial Intelligence*, 6, 100195. https://doi.org/10.1016/j.caeai.2024.100195

Sharpe, R., & Abrahams, I. (2019). Laboratory work in science education: A review of online and remote laboratories. *School Science Review*, 101(374), 59–66.

Ukhurebor, K. E., Onyancha, R. B., & Adewuyi, S. O. (2025). Cloud-based virtual laboratories for sustainable science education in developing countries. *International Journal of Educational Technology in Higher Education*, 22(1), 15. https://doi.org/10.1186/s41239-024-00468-9

UNESCO, UNICEF, & World Bank. (2021–2023). *Education for sustainable development: Global monitoring reports*. UNESCO Publishing.

Uwitonze, J., & Nizeyimana, G. (2022). Virtual laboratory learning and students' retention in science subjects. *African Journal of Science, Technology and Mathematics Education*, 7(2), 112–126.

Zhao, Y. (2025). Smartphone-based experiments in science education: A systematic review. *International Journal of Science Education*, 47(3), 401–420. https://doi.org/10.1080/09500693.2024.2341123