Simulation-Based Learning: A Tool for Enhancing Science and Technology

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Abstract

In today's classrooms, especially across resource-constrained regions, the challenge of delivering hands-on science and technology education is more pressing than ever. Simulation-based learning (SBL) offers a powerful solution bridging the gap between theory and practice by recreating real-world scenarios in safe, accessible digital environments. This review explores how simulations enhance learners' understanding of practical activities across disciplines such as physics, chemistry, biology, agriculture, and technical education. It also highlights how simulations foster entrepreneurial thinking by equipping learners with marketable skills in areas like solar installation, computer and phone repair, and digital fabrication. The paper examines the pedagogical foundations, benefits, emerging trends, and cutting-edge tools that are reshaping how we teach and learn. Ultimately, it advocates for a blended approach one that combines the immersive power of simulations with the irreplaceable value of hands-on experience.

Keywords: Simulation-based learning, Hands-on STEM education, Resource-constrained contexts, Technical and vocational skills, Blended learning, Educational technology

Introduction

Many institutions struggle to deliver practical science education because of limited infrastructure, scarce consumables, and insufficient teaching personnel. Simulation-based learning (SBL) offers a scalable alternative by reproducing real-world scenarios in virtual environments, enabling learners to observe, manipulate, and experiment with scientific and technological processes without extensive physical resources. Empirical studies from Nigeria and internationally report that SBL improves student engagement, satisfaction, and conceptual understanding, and helps mitigate constraints associated with traditional laboratory instruction.

Science and technology education depends on experiential learning, yet many institutions particularly in developing regions struggle with inadequate infrastructure, scarce consumables, and limited qualified teaching personnel, creating persistent barriers to effective practical instructions (Adepoju & Olatunji, 2021). Simulation-based learning (SBL) offers a scalable alternative by reproducing real-world phenomena in virtual, controllable environments, allowing learners to explore, manipulate, and test hypotheses without the costs or hazards of physical laboratories (Chernikova et al., 2020). In the Nigerian context, Adepoju and Olatunji (2021) document how simulation-supported pedagogy can mitigate infrastructural constraints in technical and vocational settings and can increase opportunities for repeated practice and mastery. Empirical evidence also indicates that SBL promotes higher levels of student engagement, motivation, and satisfaction compared with traditional lecture- and demonstration-based approaches, facilitating deeper conceptual understanding and sustained interest in STEM subjects (Almasri, 2022). Beyond immediate gains in achievement and attitude, simulations support differentiated learning pathways—enabling self-paced exploration, scaffolded feedback, and adaptive challenges that address diverse learner needs (Rutten, van Joolingen, & van der Veen, 2012). When integrated with inquiry-based and constructivist instructional designs, SBL not only clarifies abstract concepts but also cultivates scientific reasoning, experimental design skills, and systems thinking that are essential for workforce readiness and for advancing Education for Sustainable Development goals. Simulation-based learning offers a promising alternative by replicating real-world scenarios in virtual environments, enabling learners to engage with scientific and technological processes without the need for physical resources (Chernikova et al., 2020; Almasri et al., 2022). Recent empirical studies, such as Agarwal et al. (2022), highlight the growing relevance of simulation-based learning in ICT-driven education, where immersive environments foster deeper engagement and skill acquisition

SBL is grounded in Kolb's Experiential Learning Theory, which emphasizes learning through concrete experience, reflective observation, abstract conceptualization, and active experimentation. Simulations support all four stages by allowing learners to interact with virtual environments, observe outcomes, and refine their understanding (Vlachopoulos & Makri, 2017). Constructivist theory also supports simulations, promoting learner-centered exploration and knowledge construction (Rutten et al., 2012).

Pedagogical Design and Learner Engagement

Effective simulations should map directly to learning goals and classroom realities to maximize engagement and transfer (Rutten, van Joolingen, & van der Veen, 2012).

- **National vocational standards** Align simulation tasks, assessment criteria, and competency outcomes with national curricula and vocational frameworks so learners practice the exact skills and procedures required for certification and the workplace (Adepoju & Olatunji, 2021).
- **Individual learning styles and modalities** Design simulation interfaces and activities that support visual, auditory, and kinesthetic learners through multiple representations,

narrated guidance, and interactive manipulatives to reduce cognitive load and increase accessibility (Vlachopoulos & Makri, 2017; Rutten et al., 2012).

- **Inquiry-based and gamified models that foster active participation** Structure simulations around inquiry cycles and embed gamified elements—progress levels, badges, immediate feedback—so motivation supports conceptual learning rather than superficial performance (Şenyigit, Önder, & Sılay, 2021; Chernikova et al., 2020).

Implementation tips

- Offer teacher guides and lesson flows linked to learning outcomes to support fidelity of use and assessment alignment (Adepoju & Olatunji, 2021).
- Include adaptive scaffolding and pilot testing with representative classrooms to tune difficulty, language, and cultural relevance (Almasri, 2022; Agarwal et al., 2022).

Assessment alignment

- Use embedded formative assessments and summative performance tasks within simulations, and capture learning analytics (time on task, action sequences, common
- errors) to inform differentiated instruction and teacher professional development (Rutten et al., 2012; Vlachopoulos & Makri, 2017).

Applications across Disciplines

Physics Simulation in Physics Instruction

Physics simulations make abstract phenomena observable, allow learners to manipulate variables safely, and provide immediate, data-rich feedback that accelerates conceptual change and procedural fluency (PhET Interactive Simulations, n.d.; Rutten, van Joolingen, & van der Veen, 2012). When integrated with guided inquiry and targeted scaffolds, simulations reduce misconceptions about core topics such as forces, energy, and electromagnetism by making invisible interactions visible through dynamic visualisations and measurement tools (Rutten et al., 2012). Empirical studies in low-resource settings show that simulations are especially valuable where hands-on labs are limited: Wambugu and Githua (2021) found significant gains in secondary school students' physics achievement and motivation after implementation of simulation-based instruction, with larger effects for students who received structured teacher facilitation. PhET-style activities, combined with formative questioning and collaborative sense-making, support repeated experimentation, encourage hypothesis testing, and strengthen links between qualitative reasoning and quantitative problem solving (PhET Interactive Simulations, n.d.; Wambugu & Githua, 2021).

Chemistry Simulation in chemistry Instruction

Discipline-specific simulations are especially powerful in chemistry because they render the invisible microscopic world visible; animate molecular interactions, and model reaction mechanisms and laboratory procedures that are otherwise costly, time-consuming, or hazardous to run in school settings. Interactive molecular and reaction visualizations help students bridge macroscopic observations and submicroscopic explanations, reducing cognitive load by linking multiple representations (macroscopic, particulate, symbolic) and providing opportunities for repeated, scaffolded exploration of conceptually difficult topics such as equilibrium, reaction kinetics, and stoichiometry (Rahmawati et al., 2022; Palacios Ortega, Pascual, & Moreno-Mediavilla, 2024). Reviews of chemistry simulation tools show consistent gains in conceptual understanding and a reduction in common misconceptions when simulations are integrated within structured instructional sequences that include guided inquiry, prediction observation explanation cycles, and formative feedback (Palacios Ortega et al., 2024; Patel & Singh, 2020). Simulation environments also support safe practice of laboratory techniques and procedural fluency students can rehearse complex steps, observe outcomes under varied conditions, and receive immediate, data-rich feedback that tutors their experimental reasoning and interpretation skills (PhET Interactive Simulations, n.d.; Rahmawati et al., 2022). For contexts where physical experimentation is limited by cost or safety, well-designed chemistry simulations offer a pragmatic route to deeper conceptual learning, improved attitudes toward the subject, and better preparedness for later hands-on laboratory work.

Biology Simulation in biology Instruction

Simulations of mitosis, meiosis, and ecological systems strengthen inquiry-based learning by making dynamic biological processes visible, enabling manipulation of experimental variables, and supporting repeated hypothesis testing and data analysis (Labster, n.d.; ExploreLearning, n.d.; MERLOT, n.d.). Interactive cell-division simulations let students compare phases, predict genetic outcomes, and explore mechanisms behind variation, while ecosystem models allow learners to test perturbations, track energy flows, and observe population dynamics in safe, repeatable virtual labs (Labster, n.d.; ExploreLearning, n.d.). When paired with guided inquiry prompts, formative feedback, and collaborative sense-making, virtual biology labs promote deeper conceptual understanding, reduce misconceptions, and increase student engagement (Rutten, van Joolingen, & van der Veen, 2012).

Simulation-Based Learning in Agricultural and Environmental Education

Simulations that model crop cycles, soil–plant interactions, pest dynamics, and management interventions make agricultural systems experimentally tractable for learners in rural schools, enabling rapid hypothesis testing, visualization of delayed outcomes, and exploration of tradeoffs among yield, labor, and inputs (Yusuf & Lawal, 2022). Students using localized simulations developed more coherent mental models of phenology, nutrient cycling, and pest–crop interactions; they moved from descriptive recall to causal explanations linking management decisions to outcomes. When simulations incorporated indigenous crop varieties, local pests, and regionally relevant climate parameters, learners reported higher engagement and perceived classroom lessons as immediately useful to family farms Simulations compressed multi-season experiments into single lessons, allowing iterative design–test–reflect loops that supported rapid refinement of hypotheses and greater exposure to seasonal variability than short school terms allow Virtual trials enabled exploration of risky interventions (high fertilizer rates, late planting, pesticide regimes) without endangering students or wasting scarce inputs, broadening access to practical experimentation in schools without demonstration plots Teacher scaffolding explicit prompts to predict, justify decisions, and interpret outputs was critical; gains were largest when instructors linked simulation results to local farmer knowledge and encouraged classroom discussion of tradeoffs.

Simulations that model whole farming systems let students test irrigation plans, pest controls, and crop-rotation strategies quickly, revealing long-term effects within classroom time and supporting climate-smart decision making (Cheng & Wang, 2021). By simulating soil moisture, nutrient flows, crop growth, and pest dynamics, these tools make tradeoffs between productivity, resource use, and environmental impact explicit, helping learners develop systems thinking and causal reasoning (Cheng & Wang, 2021). Simulated scenarios that include economic and labor constraints encourage students to weigh sustainability, cost, and community viability when choosing interventions (Cheng & Wang, 2021). Using simulations to practice drought-tolerant rotations, water-saving schedules, or integrated pest management prepares students to recommend low-risk, locally appropriate strategies for real farms (Cheng & Wang, 2021).

Technical and Vocational Training

The integration of simulation tools in technical and vocational education offers learners the opportunity to practice complex procedures in a risk-free environment. Adepoju and Olatunji (2021) demonstrated how simulation-based pedagogy significantly improves student performance in fields such as electrical installation, mechanical design, and ICT. Their findings support the argument that simulation is not merely supplementary but essential in contexts where physical laboratories and equipment are scarce.

Ali and Yusuf (2022) demonstrate the effectiveness of simulation tools in mobile phone repair training, where learners can practice diagnostics, component replacement, and circuit tracing without needing physical devices. This approach not only reduces costs but also minimizes the risk of damaging real equipment during early learning stages

Beyond electronics and engineering, simulation-based learning has also shown promise in agricultural education. Cheng and Wang (2021) illustrate how simulations can model ecological systems, crop cycles, and resource management strategies, enabling learners to explore sustainable farming practices in a controlled, risk-free environment.

Engineering: CAD-based mechanical design (Borokhovski et al., 2016)

Virtual Simulation in Electronics Education

Virtual simulations replicate circuit design, testing, and troubleshooting tasks, allowing learners to assemble components, vary parameters, and observe real-time signals without physical hardware constraints (Wang & Liu, 2020). In vocational electronics training, such tools scaffold procedural skills by providing stepwise guidance, instant error feedback, and the opportunity for repeated practice, which together accelerate mastery of soldering techniques, circuit assembly, and diagnostic workflows (Wang & Liu, 2020). Simulated environments also lower the cost and safety barriers to experimentation: learners can stress components to failure, explore fault-injection scenarios, and test rare or dangerous conditions that would be impractical in class labs (Proteus; Multisim; PhET Interactive Simulations) note: replace platform names with actual citations if using specific pages. Studies report larger learning gains when simulations are paired with teacher-led reflection, scaffolded tasks, and authentic assessment tasks that require transfer of skills to physical benchwork (Wang & Liu, 2020; Rutten, van Joolingen, & van der Veen, 2012). For resource-constrained vocational programs, virtual electronics labs provide scalable, low-maintenance practice opportunities that improve both conceptual understanding of circuit behavior and practical troubleshooting competence (Wang & Liu, 2020).

Simulation Pedagogy in Engineering Disciplines

Kumar and Sharma (2020) provide a comprehensive pedagogical review of simulation use in electrical engineering education, highlighting its role in enhancing conceptual clarity, problem-solving skills, and technical proficiency. Their analysis underscores the importance of aligning simulation tools with curriculum objectives and learner needs, particularly in domains requiring high levels of abstraction and system modeling. This discipline-specific insight complements broader findings in STEM simulation research (e.g., Finkelstein et al., 2005; Haertel et al., 2014), reinforcing the argument that simulation-based learning is most effective when tailored to the cognitive demands of the subject matter. In the context of Nigerian technical education, adopting such pedagogical frameworks could elevate the quality of instruction in engineering programs and better prepare students for industry challenges.

Simulation-Based Training in Electrical and Mechanical Trades

Simulation-based learning is increasingly adopted in skilled-trades education because it supports safe, repetitive practice of high-risk tasks, develops procedural fluency, and improves troubleshooting and diagnostic reasoning (Chukwuma & Ibrahim, 2022; Rutten, van Joolingen, & van der Veen, 2012). In electrical trade programs, virtual labs let learners assemble circuits, practise wiring and earthing procedures, inject and diagnose faults, and observe transient behaviours without endangering equipment or people (Chukwuma & Ibrahim, 2022). In mechanical trades, simulations model machine operations, maintenance procedures, and assembly sequences so apprentices rehearse motor skills and develop error-recognition patterns before working on real equipment (Azid et al., 2023; Juera, 2022). Studies report stronger learning gains when simulation practice is paired with guided reflection, instructor scaffolds, and authentic assessment tasks that require transfer to physical bench-work (Wang & Liu, 2020; Rutten et al., 2012). For resource-constrained vocational colleges, simulation modules reduce training bottlenecks, lower consumable and safety costs, and provides consistent exposure to rare fault conditions, supporting integration of simulation into national technical curricula to improve workforce readiness (Chukwuma & Ibrahim, 2022; Juera, 2022).

Microcomputer-Based Laboratories in Life Sciences

Lazarowitz and Huppert (1993) conducted one of the earliest empirical studies on the use of microcomputer-based laboratories (MBLs) in biology education. Their findings revealed that students who engaged with MBLs demonstrated significantly higher conceptual understanding of biological processes compared to those taught via traditional methods. This study underscores the pedagogical value of digital lab environments, particularly in facilitating inquiry-based learning and real-time data analysis. When viewed alongside more recent simulation research in physics and engineering (e.g., Finkelstein et al., 2005; Kumar & Sharma, 2020), it becomes evident that simulation-based learning is a cross-disciplinary tool capable of transforming STEM education at multiple levels.

Simulation-Based Learning in Renewable Energy Education

The global transition toward sustainable energy has intensified the demand for skilled professionals in solar and other renewable technologies. In this context, simulation-based learning has emerged as a transformative pedagogical tool, enabling learners to engage with complex energy systems in virtual environments that replicate real-world conditions. Nguyen and Pham (2020) demonstrate that simulation tools in solar energy education significantly enhance learners' ability to model photovoltaic systems, analyze energy outputs, and optimize configurations. Their findings underscore the dual value of simulation in fostering conceptual understanding and technical proficiency—particularly in regions where access to physical solar infrastructure is limited or cost-prohibitive.

This approach aligns with broader trends in vocational simulation research. Kumar and Sharma (2020) emphasize the pedagogical benefits of simulation in electrical engineering, while Lee and Park (2021) highlight its role in construction management training. Together, these studies reinforce the argument that simulation tools are essential for bridging theoretical instruction with industry-relevant competencies across technical disciplines. Moreover, Morris and Lee (2021) show that gamified simulations can further enhance skill acquisition and learner motivation, especially in hands-on vocational contexts.

In Nigeria, where solar energy is both a strategic priority and a practical necessity, integrating simulation-based modules into technical and vocational curricula could accelerate workforce readiness. Such tools would not only prepare students for careers in renewable energy but also support national goals for sustainability, energy access, and climate resilience. By adopting simulation-based learning frameworks, Nigerian institutions can cultivate a generation of technicians and engineers equipped to lead the country's green transition.

Scaffolding and Learner Readiness in Simulation-Based Learning

Simulation-based learning is not universally effective by default it requires thoughtful instructional design that accounts for learners' prior knowledge, cognitive load, and engagement strategies. Chernikova et al. (2020) conducted a meta-analysis of 145 empirical studies across higher education disciplines, revealing that simulation-based instruction has a large positive effect on the development of complex skills ($g = 0.85$). However, the magnitude of this impact is significantly influenced by how simulations are scaffolded and tailored to learner readiness.

Their findings show that students with high prior knowledge benefit most from reflection phases**,** where they analyze their decisions and outcomes post-simulation. In contrast, novice learners perform better when supported by worked examples and guided prompts during the simulation itself. This differentiation underscores the importance of adaptive instructional strategies that respond to individual learner profiles.

Moreover, the study highlights that cognitive overload can occur when simulations are overly complex or lack sufficient guidance. To mitigate this, educators should embed scaffolding elements such as:

- Step-by-step instructions
- Real-time feedback
- Visual cues and prompts
- Opportunities for peer collaboration

These design features not only enhance comprehension but also foster metacognitive awareness, allowing students to monitor and regulate their own learning processes.

Chernikova et al.'s (2020) work reinforces the idea that simulation-based learning is most effective when it is intentionally structured and responsive to learner diversity. Their insights provide a compelling case for integrating differentiated scaffolding into simulation pedagogy, ensuring that all students—regardless of prior experience—can benefit from immersive, skill-building environments.

Emerging Trends

Hybrid models that combine physical and virtual labs are gaining traction as a resilient, cost-effective approach to STEM instruction, blending the authenticity of hands-on experimentation with the flexibility and safety of simulations (Rutten, van Joolingen, & van der Veen, 2012). These models let students' pre-explore procedures and predict outcomes in a simulated environment, perform critical steps on real apparatus to gain tactile skills, and then return to virtual tools for further data exploration and analysis, which increases time-on-task and supports mastery learning (Vlachopoulos & Makri, 2017). Evidence suggests hybrid approaches improve learning transfer, reduce resource bottlenecks, and support differentiated pacing for diverse learners while lowering overall costs and safety risks for institutions with limited laboratory capacity (Agarwal et al., 2022; Patel & Singh, 2020). Successful implementations pair clear curricular alignment, teacher facilitation strategies, and assessment scaffolds that require learners to demonstrate competence both in simulation metrics and in physical performance tasks.

Multimedia-Driven Simulation

Multimedia-enhanced simulations that combine video, animation, interactive diagrams, and embedded assessments create richer contextual cues and multiple representations, which support deeper engagement, improved retention, and stronger transfer when paired with scaffolding and feedback (Sanina, Ivanova, & Petrova, 2020). Rich media helps learners integrate verbal and visual channels, reducing extraneous cognitive load and enabling focused attention on core relations and causal mechanisms, while embedded prompts and formative checks guide sense-making and reflection (Mayer, 2009; Sanina et al., 2020). Technology-enabled, simulation-based tasks also produce detailed process data (action sequences, timing, prediction–observation responses) that assessment frameworks can use to generate real-time diagnostics and targeted feedback, strengthening the loop between practice and assessment (Quellmalz & Pellegrino, 2009). Empirical evidence indicates the largest learning gains occur when multimedia simulations are used within structured pedagogies guided inquiry cycles, prediction opportunities, and explicit opportunities for learners to explain and justify results rather than as stand-alone entertainment (Sanina et al., 2020; Quellmalz & Pellegrino, 2009).

Inclusive Design for Simulations

Inclusive simulation design provides multiple modes of interaction and representation so learners with diverse sensory, cognitive, and physical needs can access the same learning objectives (CAST, 2018; PhET, n.d.). Multimodal features — synchronized visualizations, descriptive audio, keyboard-accessible controls, tactile or haptic options where available, adjustable pacing, and captions — support learners who are visually impaired, hearing impaired, neurodivergent, or motor-limited while aligning with Universal Design for Learning principles (CAST, 2018).

- **Multimodal representation** Offer equivalent visual, auditory, and tactile presentations of key phenomena so learners choose the modality that suits them best (PhET, n.d.; Rutten, van Joolingen, & van der Veen, 2012).
- **Flexible interaction** Provide keyboard navigation, adjustable control sensitivity, alternative input methods, and clear affordances to reduce barriers for motor-impaired users and those using assistive technologies (CAST, 2018).

- **Scaffolding and customization** Include adjustable difficulty, stepwise guidance, optional hints, and language supports to meet varied prior knowledge and processing speeds (Vlachopoulos & Makri, 2017; Rutten et al., 2012).
- **Assessment and analytics** Capture multiple evidence types (interaction logs, annotated screenshots, audio reflections) so learners can demonstrate understanding through accessible modalities and teachers can deliver targeted feedback (Rutten et al., 2012).

Design process recommendations

- Co-design with diverse learners and accessibility experts to surface real needs and prototype multimodal solutions early (CAST, 2018).
- Map features to UDL checkpoints (multiple means of representation, engagement, and expression) and test with common assistive technologies and screen readers (CAST, 2018; PhET, n.d.).
- Provide teacher guides showing how to configure accessibility options and accept alternative forms of evidence for assessment (PhET, n.d.; Vlachopoulos & Makri, 2017).

Simulation for Rural Entrepreneurship Training

Suleiman and Bello (2022) investigate the use of simulation-based learning to foster entrepreneurship in rural Nigerian communities. Their findings show that simulations—especially those tailored to local business models—can enhance entrepreneurial skills, decision-making, and confidence among learners with limited formal education. This supports the broader argument that simulation is not just a high-tech tool, but a scalable strategy for inclusive development and grassroots innovation.

Gamified Simulation for Vocational Skill Development

Morris and Lee (2021) explore the use of gamified simulations as a strategy for enhancing technical skill development in vocational education. Their findings suggest that integrating game mechanics—such as scoring, feedback loops, and challenge-based progression—into simulation environments leads to higher learner engagement and improved skill acquisition. This approach is particularly effective in training scenarios that require repetitive practice and decision-making under pressure. When viewed alongside broader gamification studies (e.g., Matute-Vallejo & Melero-Polo, 2019), their work reinforces the argument that gamified simulations are not only motivational but also pedagogically robust tools for preparing learners for real-world tasks. In the Nigerian context, such tools could be transformative in bridging the gap between classroom instruction and industry readiness.

Matute-Vallejo and Melero-Polo (2019) argue that integrating gamification into simulation-based science education significantly boosts student engagement and learning outcomes. Their study highlights how game mechanics—such as scoring, competition, and progression—can transform simulations from passive instructional tools into dynamic, learner-centered experiences. This approach not only fosters motivation but also encourages deeper cognitive processing and sustained attention. When combined with pedagogically sound simulation design (e.g., Haertel et al., 2014), gamified simulations offer a powerful framework for STEM education, particularly in environments where traditional labs are inaccessible or under-resourced.

Uzuegbunam (2022) examines the use of serious games in entrepreneurship education, focusing on how play-based simulations can model complex business scenarios and foster experiential learning. His study provides case analyses of simulation games that promote strategic thinking, risk assessment, and emotional engagement. This aligns with Morris & Lee (2021), reinforcing the idea that gamified simulations are powerful tools for cultivating entrepreneurial mindsets—especially among youth and non-traditional learners.

Simulation and Technology-Enabled Assessment in Science Education

While simulation-based learning has gained traction for its instructional benefits, its potential for **assessment** is equally transformative. Traditional assessments often fail to capture the depth of conceptual understanding or the dynamic nature of problem-solving in STEM subjects. Technology-enhanced simulations offer a solution by embedding assessment directly into the learning experience.

Quellmalz and Pellegrino (2009) argue for a shift toward interactive, diagnostic assessments that leverage digital platforms to evaluate students' reasoning processes, not just their final answers.

Their framework supports multilevel assessment systems—classroom, district, and national—that use simulations to generate real-time feedback and performance analytics. This approach aligns with the goals of formative assessment, helping educators tailor instruction based on individual learner needs.

In chemistry education, Patel and Singh (2020) highlight how simulation tools can assess students' understanding of molecular behavior, reaction mechanisms, and lab safety protocols. These tools allow learners to manipulate variables, observe outcomes, and receive instant feedback creating a loop of learning and evaluation that is both engaging and pedagogically sound.

For Nigeria, where standardized testing often dominates classroom practice, integrating simulation-based assessment could revolutionize science education. It would enable educators to move beyond rote memorization and toward competency-based evaluation, where students demonstrate mastery through interaction, experimentation, and reflection.

Simulation in Online Science Education

Scanlon, Jones, and Waycott (2004) explore the role of simulations in online science education, emphasizing their capacity to replicate laboratory experiences and support inquiry-based learning in digital environments. Their study highlights how simulations can compensate for the absence of physical labs, making science education more accessible and scalable especially in remote or underserved regions. This insight is particularly relevant for Nigeria, where online learning platforms are expanding but often lack interactive science components.

Challenges and Opportunities for Simulation-Based Learning in Nigeria

Nwankwo and Okeke (2022) provide a critical analysis of simulation-based learning in Nigerian secondary schools, identifying both systemic challenges and promising opportunities. Their study highlights infrastructural limitations, lack of teacher training, and inconsistent policy support as major barriers to effective implementation. However, they also note growing awareness among educators and policymakers about the pedagogical benefits of simulation, particularly in enhancing student engagement and practical understanding. This dual perspective complements earlier findings by Eze and Okonkwo (2020), reinforcing the need for targeted interventions such as teacher capacity building, curriculum integration, and investment in digital infrastructure to unlock the full potential of simulation-based learning in Nigeria's science and technology education.

Technology-Enabled Assessment: Real-time Feedback and Diagnostic Insights

Technology-enabled assessment delivers immediate, actionable feedback and diagnostic information that helps learners correct errors, guides next steps, and supports teachers' formative decision-making (Trajkovski & Hayes, 2025; Huang, Stephens, & Brown, 2025). Real-time scoring, automated hints, and error-pattern detection let students receive scaffolding at the moment of struggle, which increases time-on-task and promotes incremental mastery of skills (Huang et al., 2025). At the classroom level, dashboards and analytics surface common misconceptions, mastery trajectories, and at-risk learners so instructors can target small-group instruction or adapt pacing and content (Picasso, 2024). AI-augmented assessment systems extend these capabilities with adaptive item selection, natural-language feedback for constructed responses, and early-warning signals for disengagement, but they require human oversight to check fairness, validity, and interpretability (Trajkovski & Hayes, 2025). Integrating technology-enabled assessment into simulation-based learning closes the feedback loop: simulations supply rich interaction logs and process data that feed diagnostic models, enabling personalized remediation, automated formative checkpoints, and evidence-based reporting of procedural competence (Rutten, van Joolingen, & van der Veen, 2012; Huang et al., 2025).

Implementation Framework for Nigeria

Pillar	Action Steps	Stakeholders
Infrastructure	Deploy low-cost, mobile-accessible simulation platforms	Ministry of Education, EdTech firms
Teacher Capacity	Launch training and certification programs	Teacher Colleges, NGOs
Curriculum Integration	Embed simulations into STEM syllabi aligned with WAEC/NECO standards	Curriculum Council
Policy & Funding	Allocate budgets and incentivize adoption	UBEC, TETFund
Monitoring & Evaluation	Track performance and scale best practices	NERDC, School Administrators

Conclusion

Simulation-based learning is a transformative tool for enhancing science and technology-related practicals. As Adepoju and Olatunji (2021) illustrate, its application in Nigerian technical education has yielded promising results, offering a blueprint for broader adoption across educational levels. By investing in simulation infrastructure and teacher capacity, institutions can bridge the gap between theory and practice, fostering a more competent and confident workforce.

As demonstrated by Agarwal et al. (2022), simulation-based learning foster critical thinking, problem-solving, and decision-making skills. Its integration into science and technology curricula is not only timely but essential for preparing students for real-global challenges.

Ali and Yusuf's (2022) work reinforces the argument that simulation is not just a theoretical tool, it is a gateway to hands-on mastery in fields like mobile phone repair, where access to real devices may be limited. Their findings support broader adoption of simulation in technical education. "Almasri's (2022) research adds a psychological and pedagogical dimension to the value of simulations, showing that when tailored to students' learning styles, they can significantly enhance both affective and cognitive outcomes in science education."

Bell and Smetana's (2016) reinforces the pedagogical value of simulations in science education, advocating for their use as supplements to hands-on activities and highlighting their role in fostering inquiry and conceptual clarity.

Bhullar and Aggarwal's (2022) emphasised the value of simulation-based pedagogy as a cross-disciplinary tool. Their findings support the integration of simulations not only in entrepreneurship but also in technical and scientific education, where experiential learning is key.

Borokhovski et al.'s (2016) meta-analysis streghtens the argument that simulation-based instruction is not only pedagogically sound but empirically validated. Their work supports the broader adoption of simulations in technical education to enhance learning outcomes.

Campos et al. (2020) provide a comprehensive overview of simulation-based education trends, offering valuable insights into its evolution and future potential. Their work supports the continued expansion of simulation pedagogy across STEM disciplines, especially in underexplored areas.

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