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ENHANCING PHYSICS PRACTICALITY THROUGH TECHNOLOGY: AN INVESTIGATION INTO THE USE OF VIRTUAL LABS AND SIMULATIONS IN PHYSICS EDUCATION

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Abstract

The virtual labs and simulation integration with the physics courses gives enormous potential to change the gap between the theoretical underpinnings and the real-life application of the knowledge in order to get a deeper insight and experience. This paper discusses how these technologies are effective in improving the feasibility of physics in post-primary and in tertiary education. The study evaluates the involvement of the use of virtual tools in overcoming the challenges encountered by teachers within this sector that include resource issues, lack of student interest, and unavailability of practical experimentation through a thorough synthesis of secondary literature in the form of peer-reviewed studies, education reports, and case studies published between 1970 and 2025. Among the major discoveries are that virtual laboratories enhance conceptual mastery by as much as 30 percent and make students more motivated, especially when the under-resourced environment is considered. The review identifies the weaknesses of conventional laboratory practices and suggests ways to address the limitations such as the training of teachers and access to technology. This work sheds light on the role of simulations in inquiry based learning that can be applied by teachers and policy makers to streamline physics education in an ever-changing, technology-focused world.

Keywords: Virtual Laboratories, Simulations, Physics Education, Inquiry-Based Learning, Educational Technology, Conceptual Knowledge, Student Engagement, Equity in Education.

Introduction

Physics as a science flourishes in the interactions of theory and experiment, but conventional methods of laboratory work can illuminate only enigmatic science, providing inflexible, stale, and unequal means of learning. In most learning institutions, the learners are faced with challenges like old machinery, small labs, and security problems that restrict their learning potential of relating abstract theories to practical events. These pitfalls are more acute in schools and areas under-resourced since availability of physical laboratories in under-resourced areas in continuous inequities in science education. With this growing need of scientific literacy in the society which is becoming more technologically focused, the dire necessity is to reshape the model of developing the nature of physics practicality.

One effort that is promising is virtual labs and simulations, which are enabled by the breakthroughs in digital technology. These tools are simulators that can mimic experimental settings giving students the ability to manipulate variables, observe the results and experiment on complex systems without being limited by physical infrastructure. Virtual platforms are flexible and scalable, which provides a wide

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range of learners access to physics, such as simulating gravity fields, to physics models of quantum mechanics. Nonetheless, their being integrated into education is bumpy. The aspects of teacher preparedness, technological facilities, and pedagogical objective should be considered in order to make the most out of them.

In this paper, the author is researching about the role of virtual labs and simulations in improving practicality in physics using secondary sources to researches their advantages, disadvantages, and the possibilities they present on replacing teaching and learning. The study will integrate evidence available from both a global and regional level to give a complete picture on how these technologies can fill the gaps in conventional methods to create an inclusive and more engaging physics education.

The Analects of Confucius.

Development of new technologies in teaching physics develops upon the decades worth of research on the learning process and student interaction with science. The initial research in the 1970s investigated computer-assisted instruction, and showed a small student performance improvement using simple simulations (Bork, 1978). These developments formed the basis of the current virtual labs, which make use of advanced graphics, artificial intelligence, and interactive interfaces in order to reproduce real world experiments. These tools are based on the constructivist theories which focus on active learning and constructing knowledge, according to which students will explore the phenomena through guided discovery (Piaget, 1970; Vygotsky, 1978).

The role of virtual labs and simulations has been shed light by empirical research. In a landmark experiment, Finkelstein et al. (2005) discovered a 25 percent better performance of students using PhET simulations to analyze a circuit versus those who used conventional labs based on their conceptual tests. In the same vein, Wieman et al. (2008) found that simulations were more useful in promoting the understanding of quantum mechanics because they encouraged visualization of abstract concepts. Virtual labs have also helped in resource bottlenecks, a study in India in 2017 revealed that virtual experiments have improved accessibility of physics practical in rural schools by 20 percent (Singh & Muralidhar, 2017).

Although these developments have been made, there are still gaps in the literature. Much of the studies are done on higher education and little in post-primary learning environments where basic physics skills are acquired. There is no literature on the impact of virtual labs to enhance equity, especially among the marginalized groups (Selwyn, 2022). Also, although simulations offer potential in closed research, their application in a variety of educational systems and cultures is still to be explored (Holmes et al., 2019). The issue of taking over the refinement of technology or data security in AI-based websites should also be questioned due to ethical concerns (Baki, 2020). This article will fill these gaps by bringing together both the evidence on the practice of virtual labs and simulations in all educational levels, especially regarding inclusivity and the practice.

Crafting the Approach

This paper will use a secondary data analysis model to examine how virtual labs and simulations promulgate physics learning, which entails a synthesis of the peer-reviewed literature, educational policy, and case-studied publications that are published between 1970 and 2025. The methodology is systematic literature search database, as it is represented by ERIC, Scopus and Google Scholar database searches on the keywords such as virtual labs, physics simulations, and science education technology. Inclusion criteria are based on the consideration of the studies having the measurement of student

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outcomes (e.g., conceptual awareness, engagement, and skills advancement) and consideration of contextual factors such as resource-availability and teacher preparation.

They can be coded in themes and analyzed to identify commonalities (e.g., how simulations influence particular physics topics (mechanics, electromagnetism, optics) and how they apply in a variety of contexts (urban vs. rural, developed vs. developing, etc.) to interpret the data. Quantitative data, e.g. effect sizes of experimental studies, are combined in order to obtain an estimated average improvement in learning outcomes. The synthesis process of the teacher and student feedback is a knowledge based on qualitative insights to know the usability and pedagogic alignment. This methodology guarantees a solid and evidence-based investigation of the impact of virtual tools on the practicality of physics and the limitation of primary data sources and possible publication bias of secondary ones. Virtual simulation and labs revolutionize the teaching of physics to tackle major challenges and provide an open learning opportunity. The section discusses the applications, advantages, and the drawbacks of their use with the support of secondary data and the demonstrating tables.

Demographic Characteristics of the south east Nigeria participants.

Also, the recent research (20202025) of virtual labs in physics education in South East (Enugu, Anambra, Imo, Abia, Ebonyi) of Nigeria is a hint at the necessity of interventions grouping particular contexts. Challenges of acute concern include less than 2535 percent of secondary schools having working physics labs (UNESCO 2021, as well as Enugu State Education Board 2023 reports), which is aggravated by inequitable access to urban areas and unequal representation in primary and secondary education at higher educational institutions. Major empirical studies provide the demographics of participants with an overpopulation of adolescents (1417 years) constituting the majority of the population in the public secondary school and some minor male dominance with significant female increases in the case of the virtual environment. The views of urban participants tend to indicate a larger scale of tech accessibility in the base, whereas rural participants tend to have access to offline-capable simulations to the greatest advantage.

Table 1

Demographics of Participants in Virtual Labs Physics Studies, South East Nigeria (2020–2025)

Study/Year	Location (State/LGA)	Sample Size	Gender Breakdown	Age/Grade Level	School Type/Urban-Rural	Key Demographic Insight
UNIZIK Journal (2020)	Enugu State (general)	220	Males: 120 (55%) Females: 100 (45%)	15–16 (SS2)	Public secondary (mixed)	Higher male achievement with combined virtual-physical labs; rural subsample (n=98) showed 28% engagement boost
Ogunleye & Adebayo (2023)	Enugu East LGA	159	Males: 82 (52%) Females: 77 (48%)	14–17 (SS)	Co-educational public (urban-rural mix)	Females reported 22% higher interest in simulations; 60% from low-income households

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Enugu Online Guided-Discovery (2025)	Enugu North & East LGAs	351	Males: 178 (51%) Females: 173 (49%)	14–15 (SSII)	8 public secondary schools (mostly rural)	Population from 5,104 SS1; rural participants (72%) gained 25% in achievement via virtual interactive sims
PHET Virtual Lab (AJSTME, 2023)	Ogoja Zone (adjacent to SE, Cross River)	42	Males: 19 (45%) Females: 23 (55%)	16–17 (SSIII)	Public secondary (urban)	Females outperformed males by 18% in practical scores; 85% with prior device access
Anambra Simulation Flipped Classroom (2022)	Anambra State (general)	120	Males: 65 (54%) Females: 55 (46%)	15–16 (SS2)	Mixed public/private (rural focus)	Rural subsample (n=72, 60%) saw 20% interest rise; low SES dominant (78%)

Sources: Aggregated from UNIZIK Journal of STM Education (2020); Ogunleye & Adebayo (2023); Enugu State studies (2025); AJSTME (2023); local reports.
Note: South East focus prioritized; adjacent data included for comparative breadth. Sample sizes reflect experimental/control groups combined.

These demographics imply opportunities: the virtual tools decrease gender disparities (e.g., 15-20 percent more reported female motivation), and benefit rural learners (70 percent + of samples), where physical labs are of less than 30 percent use among students.

Refilling Resource gaps through Virtual Labs.
Physical experiments are simulated on virtual labs where the students are able to perform an investigation without risking their safety or spending money on expensive equipment. This can change the game in the resource-constrained environment. The virtual labs study in Nigeria revealed that practicals accessibility in secondary schools through virtual laboratories led to a 22 percent improvement in the mechanics test scores (Ojo & Adebayo, 2019). On the same note, a South African project wherein the virtual optics laboratories were applied noted that there was an increase in student confidence by 15 percent, with students being able to repeat the experiments without time limitations (Mokhine and Nkosi, 2021).

These instruments also make access democratic. Virtual classrooms such as Labster have also allowed 80 percent of students to perform experiments in villages in Enugu State, where there are no physical physics laboratories in schools, and only a third of them have access to tech-powered bands (Enugu State Education Board, 2023). This is to solve the disparity in equity in conventional labs, as the urban schools tend to possess a monopoly of resources.

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Table 2
Impact of Virtual Labs on Physics Learning Outcomes

Context	Outcome	Evidence	Source
Nigeria (Secondary)	22% higher mechanics scores	Increased access to practicals	Ojo & Adebayo (2019)
South Africa (Secondary)	15% rise in confidence	Flexible experiment repetition	Mokhine & Nkosi (2021)
India (Rural Schools)	20% increase in pass rates	Cost-effective lab access	Singh & Muralidhar (2017)

Fostering Conceptual Mastery through Simulations
Developing the Conceptual Mastery with the Simulations.
Simulations enable students to graphically view and interact with phenomena in physics which makes them more likely to comprehend concepts that are abstract. As an example, PhET simulations of electromagnetism allow learners to manipulate variables such as current and see how the magnetic field changes which lead to intuitive understanding. According to Wieman et al. (2008), undergraduates who utilize such tools improved their conceptual understanding by 30 percent, which was also realized at a secondary level (Adams et al., 2011).

Simulations of light refraction assist students in light optics to disclose the misunderstandings related to the field, for example, the confusion of reflection and refraction. In a 2015 experiment, using simulations, students had an 18 percent higher performance in conceptual tests compared to traditional labs (Chen et al., 2015). Such gains can be seen in the possibility of simulation to give instant feedback, as well as enabling exploration by trial and error which is a principle of inquiry based learning.

Improving the Customer Experience and Response.
Virtual tools also alleviate the problem of student detachment that has been a constant trend in physics. In a 2020 meta-analysis, it was established that simulations led to a 25 percent boost in motivation, with the students finding digital experiments more interesting compared to textbook exercises (Rutten et al., 2020). Kinematics virtual labs had a 10 percent attendant increase in one UK secondary school since learners liked the game-centered interface (Smith and Brown, 2022).

Reducing Limitations and Barriers.
Virtual labs also have challenges in spite of their benefits. One of the serious obstacles is teacher training, with a 2018 study revealing that two out of five physics teachers were not confident in using digital platforms, which would help to integrate (Baki, 2020). Unequal access to technology continues, as 40 percent of schools in the rural areas of the world do not have the right internet connection (UNESCO, 2021). Also, virtual reliance can lead to a decline in practical ability, and a 2016 critique of simulation-intensive curricula (Hodson, 2016) has expressed this.

Table 3
Barriers to Virtual Lab Implementation and Mitigation Strategies

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Barrier	Prevalence (%)	Impact	Mitigation Strategy	Source
Limited Teacher Training	60	Reduced tool adoption	Professional development	Baki (2020)
Internet Access Gaps	40 (rural)	Excludes marginalized students	Offline simulation tools	UNESCO (2021)
Over-Reliance Risk	N/A	Lower hands-on skills	Blended lab approaches	Hodson (2016)

Reflecting on the Journey

As demonstrated in the evidence, virtual labs and simulations can be used in teaching physics in a transformative manner. These tools can fill the most significant gaps in conventional laboratories by solving resource limitations, improving conceptual knowledge, and increasing interactions. Their gaining of access democratization, especially in under served areas, agrees with international demands of fair education (UNESCO, 2021). Nevertheless, to achieve successful integration, it is necessary to overcome the obstacles with specific practices, including teacher training courses, offline-supportive tools and blended learning systems integrating virtual and real experiments.

Their efficacy is conditioned by the contextual factors. Virtual platforms provide an affordable option to a limited investment in laboratories in Enugu State where the budget restrictions restrict investments in laboratories, yet the internet issues are a bottleneck. Urban schools, conversely, which also have a higher quality of infrastructure, can use simulations to enhance inquiry-based learning indicating a need to be implemented in a specific way. The issue of gender is important as well; a 2023 study discovered that female students were more likely to take advantage of virtual laboratories, and thus close the gender disparity in participation of STEM (Ogunleye and Adebayo, 2023).

Charting the Way Forward

In order to fully utilize virtual labs and simulations, there are a number of steps that are required. To start with, teachers should be trained to use such tools by learning how to address these tools based on the goals of the curriculum. Second, to prevent unequal access, policymakers should be investing in infrastructure including broadband development and offline solutions. Third, the curriculum designers need to take blended options combining the virtual experiments with the practical activities to retain professional skills. Future studies must address the long-term effects of using virtual labs on career readiness and enrolment in STEM programs, especially in underrepresented groups. The implementation strategies can also be improved through comparative studies in the cultural context, and analysis of AI-oriented simulations can unlock the new possibilities of pedagogy. With the consideration of these technologies, physics can become an active, inclusive, and practical field that helps students to realize a fast-evolved world.

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