TRANSFORMING MATHEMATICS EDUCATION WITH VIRTUAL AND ONLINE LABORATORIES IN THE ARTIFICIAL INTELLIGENCE ERA

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Abstract
This paper is on Transforming Mathematics Education with Virtual and Online Laboratories in the Artificial Intelligence Era. A narrative literature review was used in the study. The study considered an overview of Mathematics education in Nigerian institutions, the virtual and online laboratories for mathematics education and their potentials in the artificial intelligence (AI) era. Further, the benefits of virtual and online laboratory, the challenges and opportunities for mathematics education regarding artificial intelligence were discussed. Moreover, the Implementation and Evaluation of virtual and online laboratories regarding mathematics education was discussed. The paper finally considered the best practices for virtual and online laboratories that integrate AI and math education. The paper recommended that all tiers of Government and Heads of institution should consider designing virtual and online laboratories that integrate AI and mathematics education in their institutions to enhance learning of mathematics. Institutions should train mathematics educators in the use of virtual and online laboratories. Institutions should upgrade their remote laboratories by complimenting them with virtual and online laboratories to transform mathematics pedagogy.
Keywords: Artificial intelligence, transforming, mathematics, education, laboratories

Introduction

Mathematics education globally has undergone significant transformation in recent years, driven by technological advancements and evolving pedagogical approaches. The globalization of education has already necessitated the

application of digital technologies. Online platforms are available for conducting classes, sharing resources, assessment and managing the day-to-day activities of academic institutions (Momozoku et al., 2024). Consequently, there is a shift toward the Technology-Enabled Learning Method (TELM). Technology-Enabled Learning Method (TELM) is the use of technology, platforms, systems and digital content to extend and enhance student-centered learning. It is the development and application of tools (including software, hardware, and processes) intended to promote education (Jotheeswaran, 2022). Another reason for the shift of pedagogy to TELM is because the world has moved from the traditional methods to technologically driven methods of learning which were observed to be result oriented (Cleveland-Innes *et al*, 2019; Timayi et al., 2024). These technologies have in no small measure impacted mathematics education pedagogy whether seen in Bring Your Own Device (BOYOD), Performance Support, Micro-learning, Gamification, Flipped Classroom, On-Demand Training and other technology supported methods. These methods according to Timayi et al. (2024) are further enhanced by the advent of artificial intelligence (AI) and machine language models (MLm).

The AI and Mlm have affected the way mathematics is taught and learnt worldwide among students and teachers. This is observed in the shift to some notable AI tools such as Google Socratic, Microsoft Math Solver, Photomath, Symbolab, Nerd AI, Question.AI, Answer.AI, ChatGPT and MathGPT Chat (Stefanova & Georgiev, 2024). Timayi and Mashina (2025) see Mathematics Education as the process of teaching and learning mathematics, with a focus on understanding, problem-solving, and the construction of mathematical knowledge and cognitive skills. A key area in mathematics education is the use of laboratories known as 'mathematics laboratories. With the invasion of AI and Mlms, it is expedient to change the narrative about mathematics laboratory (ML). This is because AI has bought a new concept referred to as the 'online and virtual laboratories.

Nivalainen et al. (2013) and Tokatlidis et al. (2024) identified two types of laboratories: hands-on or physical laboratory environments and simulation or virtual laboratory environments. The latter believed to have stemmed from the need to mitigate difficulties and limitations related to physical ones. The 'Online and virtual laboratories are digital environments accessible via the internet that simulate real-world scientific experiments, offering flexibility, safety, and cost savings by allowing users to perform scientific procedures and learn complex concepts without physical equipment or dangerous materials (Tokatlidis et al., 2024). They enable students to conduct experiments repeatedly, visualize abstract phenomena, and develop practical skills from any location at any time, bridging the gap between theory and practical application in various scientific fields. Timayi and Mashina

(2025) believed that both types of laboratories complement each other. Hence, defined the mathematics laboratory as a space (physical or virtual) where students can learn, practice and explore various mathematical concepts and verify different mathematical facts and theories using varieties of activities and tools (physical, AI and machine) with or without the aid of a qualified technologist (p6). With the virtual laboratories featuring in the mathematics education space, there will be a transformational change in the field with implication in the artificial intelligence era. This paper is on transforming mathematics education with virtual and online laboratories in the artificial intelligence era.

Mathematics Education in the Artificial Intelligence Era

Mathematics education has taken a new dimension in the artificial intelligence (AI) era. This is because the invasion of AI has brought about a shift in paradigm about pedagogy, tools, assessment, philosophy and psychology among students and teachers across all levels of education worldwide (Opesemowo, 2025). Problem-solving has been at the core of mathematical education for decades and its development within a realistic and interdisciplinary framework has not been achieved to the expected extent. Learners often seek external assistance when facing difficulties in solving mathematical problems. However, this role has been taken over by AI as learners are observed to leverage their capabilities in an ethical and effective manner, including adaptive assessment and self-assessment tools, immediate feedback, identification of errors in mathematical thinking, and suggestions for alternative courses of action (Panaoura, 2025). These AI tools have been very helpful to learners and teachers. Many AI tools and applications have been developed for use in the field of mathematics education. 2025). There are many AI and Mlm tools developed for mathematics education pedagogy. They may be generative or pedagogical. Generative AI creates new content like text or images, while pedagogical AI tools are designed to specifically support teaching and learning**,** often utilizing generative AI to assist educators with tasks like lesson planning or assessment creation. The key difference is purpose**:** generative AI's is content creation, whereas pedagogical AI's is educational process improvement and student support (Noroozi et al., 2024; Timayi et al., 2024). Table 1 is a list of some AI tools developed for mathematics education pedagogy.

Table 1:

Some AI tools for mathematics pedagogy

Generative AI tools	Pedagogical AI tools
ChatGPT, Bard, Photomath, Gemini**,** Wolfram, Alpha**,** Mathway**,** Julius AI	Khan Academy, MathE, Snatchbot , Zapper, HP Reveal, Vuforia, GeoGebra AR (augmented reality), GeoGebra, ENTiTi Creator, Vlab, 3D minigames, CalcVR, Eclipse VR (Virtual reality), NeoTrieVR, Forum Graph, Squirrel, cleARmaths

Source: Compiled from Walkington et al. (2023) and Awang et al. (2025)

With AI tools in Table 1 and others being developed continuously, mathematics education is being transformed daily where the tools are applied. Although the AI is seen to be advantageous generally, Opesemowo (2025) argued that:

> AI has emerged as a transformative force in various fields, including education. AI technologies provide a wide range of possible improvements in mathematics education (including personalize learning, adaptive assessment, and real-time feedback) and glitches (i.e., lack of creativity and problem-solving skills, absence of emotional intelligence, and data privacy and security concern, etc.) pg 18.

The statement above raises some concerns about the disadvantages of using AI. Timayi et al. (2024) submitted that even in the face of the challenges that comes with the usage of AI as reported in literature such as Opesemowo (2025) the possibilities, potentials and applications of the AI and MLm in mathematics education is endless and increasing.

Virtual and Online Laboratories in the Artificial Intelligence Era

The virtual and online laboratories refer to internet-accessible learning environments that use software simulations or remotely controlled real equipment to allow users to conduct experiments and develop practical skills without needing physical access to a traditional lab. Moreover, a virtual lab typically uses software to simulate a lab environment and its experiments, while a remote lab uses the internet to control real instruments at a separate physical location. Both offer anytime, anywhere access, unlimited repetitions, and safe exploration of potentially hazardous experiments (Safaeipour et al., 2025). Virtual or online laboratories are increasingly gaining popularity in the field of education. Studies such as Oladipo and Ebabhi (2020), Ndunagu et al. (2023), Akinwumi and Clement (2024) and Adeyemi et al. (2025) were carried out on virtual laboratories in Nigeria in STEM related subjects such as Physics and Chemistry.

The relevance of virtual and online laboratories in the AI era is incredibly high, moving beyond simple simulation to become intelligent, adaptive, and integral tools for both education and advanced scientific discovery. AI is transforming virtual labs from static exercises into dynamic, personalized environments that enhance learning, democratize access, and accelerate research (Druitt, 2025). The virtual labs in the AI era are observed to have certain advantages (Druitt, 2025). These include enhancing Accelerated Discovery, Human-AI collaboration, Digital twins **(**a faithful computational representation of a real-world entity, process, or even a human-machine interaction**)** and Automation and robotics.

With laudable gains of the AI-driven virtual labs are challenges which includes bridging digital and physical, ethical considerations **(**intellectual property ownership, data privacy, and algorithm bias), infrastructure and access and evolving research questions such as the need for standardized software platforms and creation of opportunities for AI researchers and domain scientists to collaborate more effectively (Klami et al., 2024).

Virtual and Online Laboratories for mathematics education

Virtual Mathematics laboratories represent digital environments where students can explore mathematical concepts through simulations, visualizations, and hand-on experimentations (Balacheff & kaput, 2017; Orobor & Orobor, 2020). When integrated with AI technologies, these platforms can provide personalized learning experiences, adaptive feedback, and robust tutoring system that responds to the individual student needs and learning patterns (Orobor & Orobor, 2020). There are many virtual laboratories for mathematics used worldwide depending on the need. Many more are being developed due to the possibilities that the AI provides. These laboratories offer interactive simulations, statistical analysis tools, and adaptive learning environments to explore mathematical concepts like fractions, geometry, and probability. These tools allow students to manipulate variables, visualize complex problems, and conduct experiments remotely, fostering deeper understanding and engagement with mathematics. Table 1 presents some of the popularly used virtual laboratories for mathematics education. Also, Table 2 is the virtual laboratories Nigerian researchers have reported to have used in their studies.

Table 2:

Some popular Virtual laboratories for mathematics education

SN	Lab name	Description
1	PhET Interactive Simulations	research-based, interactive simulations for math and science, allowing students to explore abstract concepts in a fun and engaging way.
2	Lab4Physics	transforms a smartphone into a scientific laboratory, using its sensors to facilitate real-world experiments and explorations that can be

		designed and shared by teachers and students.
3	Intellectus Statistics	An online tool that provides a user-friendly environment for performing various statistical analyses, often used in conjunction with virtual lab experiences.
4	Virtual Labs (India)	A comprehensive platform that provides a virtual laboratory experience with various tools, including simulations, video lectures, and self-evaluation components, across many disciplines including mathematics.
5	ALEKS	An AI-driven platform that offers personalized learning pathways and adaptive feedback, guiding students through math topics at their own pace
6	EdReady	A non-profit online platform that provides personalized learning paths, helping students prepare for college-level math and improve their skills.

Source: compiled by Researcher (2025)

Table 3:
Popular Virtual laboratories for Mathematics Education in Nigerian Research

SN	Lab name	Description
1	GeoGebra	an effective virtual laboratory for geometry education. It allows students to create and manipulate interactive graphics to explore mathematical concepts in algebra, geometry, and calculus.
2	Photomath	A mobile app that can solve mathematical equations by scanning them with a camera. Nigerian research suggests it can be used as a virtual laboratory strategy to improve students' performance in algebra and other areas by providing step-by-step solutions.
3	Mathway	A web-based application is a problem-solving tool that provides solutions and explanations across a wide range of mathematical topics, including algebra, calculus, and trigonometry. Nigerian studies identify it as a tool that can boost student achievement and interest.
4	Imisi 3D	This Nigerian company has pioneered the use of VR for education. In a 2019 pilot program, the company provided virtual reality headsets to students in a Lagos public school to learn mathematics, providing an immersive, 3D learning experience.
5	Labster and PhET Interactive Simulations	These international AI-powered virtual lab platforms are available and accessible in Nigeria via computers or smartphones. While covering broader STEM topics, these resources can be applied to mathematics concepts by simulating real-world scenarios and experiments.

Source: compiled by Researcher (2025)

Looking at Table 1 and 2, Nigeria needs to develop more of the virtual laboratories specifically for mathematics education across all levels of education. Apart from Imisi 3D, there are no indigenous virtual laboratories for mathematics education.

The virtual laboratories for mathematics can enhance students' interest and potential in the subject.

Best Practices for Integrating Virtual and Online Laboratories in Math Education

The Virtual laboratories have emerged as transformative tools in modern education, offering immersive, interactive, and cost-effective learning experiences (Chattopadhyay, 2025). The integration of virtual mathematics laboratories into teaching and learning of the subject can bridge the gap between theoretical knowledge and practical application. This is because virtual mathematics laboratories platforms simulate real-world experiments that enable students to conduct complex procedures in a risk-free, controlled environment.

The following are best practices for integrating virtual mathematics laboratories into mathematics education pedagogy (Chattopadhyay, 2025):

1. **Align with the curriculum**: The virtual mathematics laboratories activities and experiments should directly align with and support specific learning objectives in the mathematics curriculum. This ensures that the labs are not just a supplement but a core part of the lesson.
2. **Visualize abstract concepts**: Use virtual labs to demonstrate and visualize complex mathematical ideas, like geometry, algebra, or calculus, in a dynamic way. This helps bridge the gap between abstract theory and practical application.
3. **Provide teacher training and support**: Mathematics teachers should be given the necessary requisite training on how to use virtual laboratories effectively. Training should cover both the technical aspects of the platform and strategies for integrating labs into lesson plans.
4. **Ensure access and infrastructure**: There should be reliable internet access and a suitable device to access the laboratories. Institutions should evaluate their technical infrastructure and consider providing equipment or offline alternatives for students with limited connectivity.
5. **Prioritize a user-centric design**: The platform should be intuitive and easy to navigate for students of all tech-literacy levels. A well-designed user interface (UI) and user experience (UX) prevent students from getting frustrated with the tool instead of focusing on the math concepts.
6. **Promote experiential and inquiry-based learning**: Move beyond rote memorization by encouraging students to experiment with variables and test hypotheses in a risk-free digital space. Teachers can create inquiry-based activities that lead students to discover mathematical concepts on their own.

7. **Emphasize real-world applications**: Use labs that connect mathematical concepts to realistic scenarios from fields like engineering, finance, or data analysis. Showing how math is used in everyday life increases student motivation and understanding.
8. **Use multimodal instruction**: Incorporate a variety of instructional methods to address different learning styles. Virtual labs can use visual elements, animations, and interactive simulations to complement traditional methods.
9. **Facilitate collaboration**: Use the labs for group projects and problem-solving tasks. Many platforms include tools like virtual whiteboards and shared documents to enable peer-to-peer interaction and teamwork.

Conclusion

The advent of AI has impacted the educational sector and has brought transformation in many aspects including mathematics education. One of the fundamental areas in mathematics pedagogy is the use of laboratories which were physical or hands-on. The mathematics laboratory offers practical insights into concepts and broadens their understanding with a view to developing skills among students and teachers. The invasion of AI led to the development of virtual or online laboratories which is gaining ground worldwide. The virtual mathematics laboratories have transformed mathematics educational pedagogy through the application of virtual and online AI-driven applications and websites. It is of utmost importance to compliment the traditional mathematics laboratories in our institutions with the virtual and online laboratories for mathematics education teaching and learning to keep pace with the trend for the future. Nigeria has already keyed into the use of these virtual and online laboratory applications but more needs to be done to provide for indigenous and specific cases. There is a need to explore the best practice and keep abreast of the global trend in virtual and online laboratories. This will help Nigeria achieve her STEM and STEAM ambitions. The integration of AI in mathematics education holds immense promise, with ongoing advancements and ample scope for scholarly inquiry.

Suggestion of the Study

Based on the discussions forgone, the following recommendations are made:

1. All tiers of Government and Heads of institution should consider designing virtual and online laboratories that integrate AI and mathematics education in their institutions to enhance learning of mathematics.
2. Institutions should train mathematics educators on the use of virtual and online laboratories.

3. Institutions should upgrade their remote laboratories by complimenting them with virtual and online laboratories to transform mathematics pedagogy.
4. Best global practices should be imbibed in integrating virtual laboratories in schools and institutions.
5. More researchers should be taken in virtual laboratories and AI in mathematics education. This is needed to understand the impact of virtual mathematics laboratories on student learning outcomes.

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