
**THE ROLE OF ARTIFICIAL INTELLIGENCE AND
BIG DATA IN ADVANCING SCIENCE
EDUCATION IN AFRICA**

Adeyinka Oluwaseun **KAREEM**

*Department of Science and Technology Education,
Obafemi Awolowo University, Ile-Ife*

Abstract

Science education plays a critical role in improving the socio-economic status of Africa; however, the challenges recorded over the years that inhibit its progressiveness, including a lack of resources, outdated pedagogies, and inadequate teacher training, remain significant. The swift development of Artificial Intelligence (AI) and Big Data technologies offers new prospects for transforming the teaching and learning of science on the continent. In the given paper, the author examines the importance of AI and Big Data to the development of science education in Africa, emphasising their possible impact on the pedagogical innovation, learning customisation, and policy making. The paper also examines the current barriers to adoption and how to adopt it successfully. The paper is based on the frameworks of Technological Pedagogical Content Knowledge (TPACK) and Diffusion of Innovation and suggests that AI and Big Data can close the educational gap in Africa when accompanied by strong institutional capacity, policy frameworks, and contextual pedagogies.

Keywords: *Artificial intelligence, Big data, Science education, Africa, Digital transformation, Educational innovation.*

Introduction

Technological progress, innovation, and long-term national development depend on education in science, which encourages critical thinking, problem-solving, and scientific literacy, all of which are needed in 21st-century economic competitiveness. In Africa, a strong science education plays a crucial role in human capital development, enabling the country to tackle both local and global challenges in across all sectors (United Nations Educational, Scientific and Cultural Organisation, UNESCO, 2022). However, African science education suffers from limited infrastructure, outdated curriculum, inadequate laboratory and digital facilities, and a shortage of trained professionals. About 85% of secondary schools in Sub-Saharan Africa lack proper laboratories, and more than three-quarters of teachers are not trained in either digital or inquiry-based pedagogy, restricting practical learning (World Bank, 2021; UNESCO Institute for Statistics, 2022). These constraints result in low levels of conceptual knowledge, low academic achievement, low participation in science-related courses, with gender gaps, where women are about 30% of science experts (UNESCO, 2022).

Although government institutions are aware of the importance of science education, they have mostly not completely invested in it. Also, teacher education programmes are still at an unmodernised stage of development as policy frameworks rarely adopt new technologies such as Artificial Intelligence (AI) or Big Data analytics. AI and Big Data are transforming the education sector around the globe by making education personalised, more engaging, enabling teacher evaluation, and empowering policymakers to make evidence-based decisions. Learning can be improved via AI student data processing mechanism, understanding weaknesses and personalising resources. Also, adaptive feedback and intelligent tutoring systems seems to boost learner engagement by 30% (World Economic Forum, 2023). Big data may become useful in the examination of attendance, performance and other student-related data so as to monitor performance, identify the students at risk and streamline resource

allocation with noted advantages in many developed regions (OECD, 2022). Also, emerging technologies in Africa has shown encouraging signs in improving science education delivery (UNESCO, 2023; African Union, 2023). Teacher shortage can also be solved using AI-driven solutions, such as intelligent tutoring, simulated laboratories, and early-intervention predictive analytics, and Big Data can be used to effectively allocate resources, improve teacher education and the curriculum, which can help close urban-rural and resource disparities.

The fact that the population of Africa is mostly young is an opportunity and a challenge. The provision of this population with both scientific and digital literacy will be able to stimulate industrial and technological development, decrease the necessity of using the technologies of other countries, and encourage innovations. The use of AI and Big Data falls into the continental agendas like the Continental Education Strategy of Africa (CESA 16-25) and Agenda 2063 where ICTs, knowledge-based economies, and science, technology, and innovation are prioritised (African Union, 2023).

Hence, the incorporation of both AI and Big Data into the domain of African science education has a transformative potential. Infrastructure, digital illiteracy and governance challenges will continue to exist, but strategic implementation of these technologies can rebrand African science education to align with international standards, enhance innovation and provide a new generation of learners with important scientific and technological skills. Hence, this paper assesses how AI and Big Data can promote science education in Africa.

Although there is an increasing appreciation of science education as an enabler of sustainable development, Africa has remained the victim of its challenges, such as conventional teaching approach, lack of sufficient infrastructure, insufficient qualified teachers, and high digital divide. There are also weak policy frameworks, inadequate use of data, and unequal distribution of resources, which further restrict the application of Artificial Intelligence (AI) and Big Data to science education, with rural and low-income areas being especially disadvantaged.

Moreover, there is a lack of context-specific empirical studies that restrict the successful implementation and generalisation. As a result, the education of science in Africa has not fully benefited in terms of AI and Big Data, although they can contribute to the improvement of access, quality, equity, and evidence-based decision-making. This study hence, seeks to explain the current situation in science education while providing insight into strategies and methods of effective application and incorporation of AI and Big Data in science education in Nigeria.

Conceptual Clarifications and Theoretical Framework

Artificial Intelligence (AI) and Big Data are transforming the education process in various ways to enhance the efficiency and effectiveness of the instruction process and student education. Evidence-based science education is supported with the assistance of Big Data, which is produced through the application of digital learning and management systems and related to aspects like real-time performance tracking, timely feedback, and the identification of struggling learners (Daniel, 2019). Pilot projects in Africa demonstrate that data-driven systems can improve the accuracy of assessment and policy responsiveness in the face of infrastructural and capacity issues (UNESCO, 2023). Along with Big Data, AI supports continental aspirations in science learning but its implementation will be context-dependent, relying on teacher preparation and ethical management of data.

Technological Pedagogical Content Knowledge (TPACK) Framework.

TPACK model describes the successful technology integration of content, pedagogy and technology knowledge into educational practices (Mishra and Koehler, 2006). It emphasises the significance of teacher professional development and context sensitivity in the use of AI tools, especially simulations, virtual labs, and adaptive tests, in African science education. Research indicates that educators who have TPACK are apt to embrace innovative technology and attain improved learning outcomes as constant change in AI and data systems necessitate constant

development of skills (Koehler et al., 2013). TPACK offers a micro-level perspective of teacher capacity, curriculum alignment and pedagogical effect of AI and Big Data in science classrooms in this study.

The Diffusion of Innovation Theory

The Diffusion of Innovation (DOI) theory describes the process of adoption of educational technologies in phases of awareness, decision, implementation and confirmation depending on the relative advantage, compatibility, and complexity (Rogers, 2003). African science education, African infrastructural, cultural, and training limitations influence AI and Big Data diffusion, whereas it has been demonstrated that early university adoption and donor-funded programmes are beneficial (UNESCO, 2023). DOI used in this study is a complement to TPACK that places classroom-level teacher competence in wider processes that happen within the institution and system, which can help explain the scalability, impact of policies, and the diffusion of AI-based innovations in science education.

The State of Science Education in Africa

Africa education and science is in a critical crossroad despite being at the center of socio-economic development, health-innovation, and global competition. major challenges centres around underinvestment, inappropriate laboratories and information technology, unreliable electricity, crammed class rooms and narrowly teacher-focused, test-based pedagogies which restrict inquiry, experimentation and problem solving (NASAC, 2022; Ogunleye, 2011). This limits the student's exposure in practical science, diminish their capacity to reason scientifically, and lead to low scientific literacy and general unreadiness to pursue STEM-linked professions.

Gender differences in STEM are added to pedagogical constraints that include the lack of qualified science teachers, gaps in teacher content knowledge, poor pre- and in-service professional development, lack of student interest, and gender

differences in STEM participation (Ogunleye, 2011; Okoronka, 2014; Jackson, 2022). Nevertheless, as much as most nations have embraced reforms in curriculum, which are based on STEM or competencies, in reality, it may be compromised by a lack of resources and the failure to align curriculum plans, assessment and classroom practices (NASAC, 2022; Okoronka, 2014). These disadvantages support the socio-economic and spatial disparity in having access to quality science education, limiting the ability of nations to innovate (Adebayo, 2025).

The new technologies like Artificial Intelligence (AI) and Big Data can provide a way to fill these structural and pedagogical gaps with the help of virtual laboratories, adaptive learning systems, and data-driven decision-making. Nevertheless, they require parallel investment in infrastructure, capacity building of the teachers, curriculum alignment, regulation of data, and context-sensitive and inclusive implementation. In the absence of these conditions, technological solutions will strengthen the status quo instead of changing science education on a scale.

Applications of Artificial Intelligence in Science Education

Science education is being radically changed by Artificial Intelligence (AI) through opportunities to customise learning, increase access to laboratory experiences, assessments through artificial intelligence, and enhanced student engagement. In African countries with infrastructural deficiencies and education inequality, AI offers an opportunity to scale and reduce costs to change the learning outcomes.

The most important uses are Intelligent Tutoring Systems (ITS), which simulate learner behaviour and provide adaptive instruction. It has also been found that ITS enhances the performance and conceptual knowledge of students in STEM fields, as both postsecondary and primary settings report positive consequences (Steenbergen-Hu and Cooper, 2013; 2014; Xu et al., 2019). The lack of physical laboratories is also a widespread problem tackled by virtual laboratories and simulations, which

allow safe and flexible experimentation. The research in Tanzania and South Africa shows that virtual laboratories help to improve conceptual knowledge and supplement the lack of equipment, yet their application is usually restrained by poor internet connectivity (Nkwande et al., 2024; Shambare and Jita, 2025; Juandi et al., 2023).

Robotic assessment systems also facilitate learning of science by providing feedback in time and decreasing the number of teachers working. It has been argued that when applied effectively, automated scoring can be as reliable as human scorer and can also drive better learning results in African universities (He, Hui and Quan, 2009; Orim et al., 2025). Equally, chatbots and conversational tutors that are powered by AI have been shown to help facilitate independent learning, as seen in the Kwame for Science program throughout West Africa, but proper supervision and context customisation are both necessary (Boateng et al., 2023).

In addition to classroom training, AI, Big Data, and learning analytics can be used to monitor performance of learners at a large scale, identify vulnerable learners, and implement targeted interventions in STEM-based education (Holmes et al., 2021; Mtebe and Raphael, 2022). Nevertheless, there are still serious issues such as a lack of connectivity, insufficient digital literacy, risk of losing information privacy, algorithmic bias, and a risk of increasing existing disparities in case the use of AI remains uneven (Miao et al., 2021; UNESCO, 2023; Holmes et al., 2025).

As a result, the international and regional bodies focus on the fact that AI implementation in African science education should be human-centred, equitable, transparent, and culturally responsive and should be backed by proper policy alignment, teacher training, and infrastructure development (UNESCO, 2023; NEPAD, 2022; African Union, 2023). Well-applied AI-driven tutoring systems, virtual laboratories, automated evaluation, and analytics can greatly improve inquiry-based, inclusive, and high-quality science education in Africa.

The Role of Big Data in Science Education

Big Data is also changing the field of science education, as it is possible to analyse in detail the students' learning, the performance of institutions, and the inefficiencies of the system, and thus help to make evidence-based decisions. Learning analytics can help close learning gaps, diagnose the causes of these gaps and anticipate which students are likely to perform poorly or drop out through data on learning management systems, assessments, and administrative records, hence, providing quick intervene. These methods prove particularly useful in blended and distance learning. On the policy and institutional level, Big Data may assist in planning and monitoring via dashboards and management information systems to help mitigate the issues of quality, equity, and resource distributions in the fast-growing African education systems. It is believed that data-driven approaches may reveal regional differences in science engagement and laboratory access and make more effective investments.

Nonetheless, the successful application of Big Data to African science education is hindered by poor test quality of data collection, disconnected systems, insufficient infrastructure, low analysis ability, and severe ethical issues associated with privacy and data security. Regular national learning assessments are not used in many countries either, so this hinders longitudinal analysis.

In order to achieve its potential, Africa needs to enhance data systems at the base level, invest in interoperable platforms of MIS and LMS, develop data literacy in educators, test predictive analytics to create precise support, and develop robust governance and ethical frameworks. On these grounds, Big Data can be used to transform the science curriculum to a system that is more responsive, equitable, and focused on learning.

Planning sustainable, inclusive integration of artificial intelligence and big data in African science education

To render AI and Big Data sustainable in African science education, an investment in effective infrastructure, data safety mechanisms,

and collaboration with the corporations that would not rely on the immediate donor funding, and develop an interoperable platform, specifically, in the under-served locations, will be required (NASAC, 2022; NEPAD, 2022; African Union, 2023). The concept of teacher professional development is addressed, and AI is not an alternative to teaching, testing, and differentiation, but an assistant to them, and AI literacy and data-driven teaching are introduced into the national systems of teacher competency (Miao et al., 2021; Holmes et al., 2021; African Union, 2023). The efficient implementation also requires a high level of governance and ethical values, such as data protection, transparency, and responsible use of generative AI that can be implemented in line with continental and national policies (UNESCO, 2023; Holmes et al., 2025; African Union, 2024). The promotion of local EdTech ecosystems and the inclusion design of the cultural applicability of the available AI-enhanced science resources, as well as the establishment of equitable access, gender equality, and effective cooperation, should be encouraged (NASAC, 2022; Adebayo, 2025; Jackson, 2022; Miao et al., 2021).

Case Studies from Countries on the Diagnosis of Science Education in Africa

Nigeria

Poor infrastructure, such as underfunding, poor and deteriorating laboratories, high classroom size, unreliable ICT and electricity, and lack of skilled science teachers, specifically in rural schools, hamper science education in Nigeria (NASAC, 2022; ADEA, 2024; UNESCO, 2021; World Bank, 2020). Such circumstances restrict the teaching of science based on practice and inquiries and are one of the reasons why students perform poorly (Nwangwu, 2014; Ogunleye, 2011). The pedagogy is mostly teacher-centred and exam-oriented, supported by the lack of content knowledge of teachers, poor professional development, and inability to engage in inquiry-based instruction and use technology (Ogunleye, 2011; Okoronka, 2014; Okebukola, 2019; Ogunkola and Olatoye 2015).

The use of different AI-enabled tools is becoming more popular, although their adoption is not widespread due to underdeveloped digital infrastructure, teacher digital illiteracy, and ineffective policy execution (Okunade, 2024; Ukala & Ukala, 2024; NASAC, 2022). In Nigeria, the policies regarding STEM and digital education exist, but the implementation of the curriculum and its evaluation are, to a large extent, based on rote learning, which is hampered by the lack of funds and effective monitoring tools (Federal Ministry of Education, 2020; World Bank, 2020). Most existing AI and Big Data projects are small, privately-led, and in a nascent national learning analytics and integrated data system, with more robust data governance, investment into infrastructure, and capacity building required by educators to facilitate successful integration in science education (Prinsloo, 2022; World Bank, 2025).

Kenya

Kenya boasts of competency-structured and ICT-oriented education policies, such as the Digital Learning Programme that promotes STEM in primary schools (UN DESA, 2020; ADEA, 2024). Nevertheless, rural schools continue to experience unstable electricity, lack of devices, and inadequate teacher preparation to facilitate learning through inquiry and learner-centred teaching (UN DESA, 2020; ADEA, 2024). Even though Kenya as an up-and-coming AI and EdTech centre has seen little introduction of AI into standard science classrooms, the potential expansion of inequalities through favouring schools that have access to AI resources continues (State of AI in Africa Report, 2023; van der Meer et al., 2025; Malik & Undheim, 2025). The overall picture is that the teachers are open to ICT but need additional training to employ digital tools to provide students with hands-on science education (Wambugu and Changeiywo, 2008). Aside from the digital education strategies and influx of investments in data and cloud computing, to succeed and be equitable in implementing AI, it must be sustained, be connected in rural areas, be consistent in curricula, and be robust in

protecting data privacy (Ministry of Education, Kenya, 2019; Reuters, 2024).

South Africa

The system of science education in South Africa is characterised by such a high level of inequality, where well-resourced former Model C and independent schools and under-resourced township and rural schools stand in stark opposition, an aspect that is evident in TIMSS outcomes, and gaps in science participation and achievement (Jansen, 2019; Mullis et al., 2020; NASAC, 2022; ADEA, 2024). Although AI-assisted inquiry learning, virtual lab, and analytics have demonstrated positive impacts on engagement and critical thinking in well-realised cases, they are currently beneficial to schools with more resources, which increases the risk of increased differences in case of high attendance in large classes, teacher capacity, and access to connectivity and machines (Mokoena & Seeleste, 2025; Mtebe and Raphael, 2022; Dlamini, 2025; Malik & Undheim, 2025). Even though AI in education and learning analytics are being policy and research-driven, successful and just implementation is limited by structural inequalities and the digital divide (Department of Basic Education, 2018; Prinsloo, 2022; Cross & Feldman, 2025; Jere, 2025).

Ghana

The policy on science education in Ghana focuses on STEM as a source of industrialisation, but the lack of proper laboratories, materials, and other qualified science teachers, especially in the rural regions, as well as inconsistent learner-centred pedagogy and gender inequities, remain (NASAC, 2022; ADEA, 2024; Maringe, 2024). There is also teacher preparedness and imbalanced in-service training that also restricts effective delivery of competency-based science curricula (Arthur & Obeng, 2023; MoE Ghana, 2019). Although the EdTech and AI industry in Ghana has been on the rise, the application of AI in school science is still in the prerogative of better-resourced institutions, but research indicates that it can be used to aid focused interventions should it be reinforced with national STEM reforms (State of AI in

Africa Report, 2023; van der Meer et al., 2025; Dlamini, 2025). The implementation of AI in science education will necessitate offline-enabled tools, long-term teacher professional growth, and effective data governance systems (UNICEF Innocenti, 2025; Prinsloo, 2022).

Ethiopia

In most schools in rural Ethiopia, lack of laboratories, internet service providers, and electricity persists (UNESCO, 2021). The growth of digital infrastructure is continuous yet not uniform (World Bank, 2022). Special education Teacher training on STEM and inquiry-based science is evolving, although remaining erratic, particularly in rural areas (Semela, 2019). Also, digital education and STEM enhancement are national priorities, yet the lack of capacity and funding for implementation are major concerns (Ministry of Education Ethiopia, 2020). These issues have the potential to affect the effective adoption of AI and big data in science education.

Ethiopia's newly articulated Digital Education Strategy and Implementation Plan (2023-2028) delineates a policy framework for the integration of digital technologies, encompassing AI and analytics, into educational institutions and teacher training. It also outlines the creation of centralised, privacy-sensitive data systems to facilitate learning analytics and strategic planning at regional and national levels, with a focus on improving the use of virtual laboratories and functional adaptive learning systems (Ministry of Education Ethiopia, 2023).

Egypt

Egypt boasts of better STEM infrastructure than most of its African counterparts, but there remains inconsistency in access to laboratories by type and region (World Bank, 2020). The model schools of STEM have reinforced inquiry-based science, yet the application of the model to mainstream schools remains low (Nagdi & Roehrig, 2020). The education reform (Education 2.0) of Egypt has both ambitious targets in STEM and digital sectors, but

the sustainability will require long-term investment and alignment between schools and training institutions (MoE Egypt, 2018). This increases the potential of adoption of AI and big data in this country.

Egypt has articulated a national AI strategy emphasising educational initiatives (AI awareness, curriculum integration, and human capacity development) and is building a national AI research and development ecosystem. This positions the country favourably to implement curriculum-aligned AI tools, ensuring multilingual capabilities where required while safeguarding student data, and fostering local content and model development. (Egypt's National AI Strategy, 2025; UNESCO readiness evaluation)

Rwanda

The national vision and Smart Education Master Plan of Rwanda prioritise STEM and ICT as the central means of its transformation into a knowledge-based economy, and massively invest in connectivity, school networking, and digital content (UN DESA, 2020; ADEA, 2024). Science curriculum is designed on a competence-based approach, although studies note that there are still problems with laboratory resources and teacher capacity to deliver inquiry-based, hands-on science in many ordinary schools (Nsengimana, 2025; NASAC, 2022). Rwanda is commonly mentioned as a country that experimented with AI-enabled solutions to digital skills, teacher assistance, and individualised learning paths, which are often backed by international collaborations (van der Meer et al., 2025). Simultaneously, AI in African education is critically reviewed in terms of the importance of well-established data protection mechanisms and rural-urban and language disparities, considering such systems on a large scale (van der Meer et al., 2025; Dlamini, 2025).

Uganda

The secondary science education in Uganda has a lack of and frequently obsolete laboratory equipment, excessive student

numbers in classes, and insufficient access to ICT, which limits the possibilities of regular practical work and hands-on experimentation (UN DESA, 2020; ADEA, 2024). According to the teachers, there are infrequent instances of professional development in the modern practice of science and technology integration, as well as sustained professional development in modern science teaching, which causes teachers to still rely on chalkboard and note-copying as teaching methods (UN DESA, 2020).

There are limited studies concerning AI and Big Data in use in basic education in Uganda; the majority of the efforts emphasised e-learning and broadcast media, and only pilot-scale use of adaptive platforms and analytics has been reported within certain projects and higher education institutions (van der Meer et al., 2025; Bervell et al., 2025). Surveys of AI adoption in education in Sub-Saharan Africa emphasise that with less robust investment in infrastructures, digital capabilities and systems, countries such as Uganda will continue to lag behind early adopters in terms of using AI to teach and learn science, as well as assessment (Bervell et al., 2025; Dlamini, 2025).

Implications from Different Countries

The most directly influential AI/Big Data in science education in each of the countries is (a) adaptive formative learning to close latent underlying foundational gaps, (b) virtual laboratories/simulations to replace the limited physical labs,, (c) teacher support and (d) learning analytics to plan systems - so long as they are implemented with offline or low-bandwidth modes and with robust data governance. The risks of equity are not imaginary: in the absence of offline modes, intentional focus on under-resourced schools and effective privacy/ethics frameworks, AI may only increase the urban-rural and public-private divide.

Conclusion

AI and Big Data can significantly revolutionise science education in Africa in terms of personalisation, assessment, and evidence-based teaching, but only if adapted to the context. The success of these depends greatly on teacher readiness, enabling infrastructure, ethical leadership and correlations to the curricular and continental education priorities. Sound pedagogical and diffusion frameworks, have the potential of making valuable contribution to quality, inclusive and sustainable science education.

Suggestions

Investment into digital and data infrastructure, long-term teacher professional learning, and explicit ethical and policy frameworks regarding the application of AI in science education should be made by the African governments and stakeholders in the education sector. The emphasis should be on locally applicable AI solutions, access to underserved learners, and regional sharing of knowledge. It is also suggested to monitor and research continuously to assess the effect and plan the scalable implementation.

References

- Adebayo T. (2025). Indigenizing modern STEM for the public: uncovering a new form of knowledge reproduction in Africa. *Africa*, 95(1),80-105. doi:10.1017/S0001972025000166
- African Development Bank. (2023). *African economic outlook 2023: Mobilizing private sector financing for climate and green growth*. African Development Bank.
- African Union. (2016). *Continental education strategy for Africa 2016–2025 (CESA 16–25)*. African Union. <https://au.int/en/documents/cesa-2016-2025>
- African Union. (2023). *Continental Education Strategy for Africa (CESA 16–25): Implementation status report*. African Union Commission.

- Arthur, S. E., & Obeng, P. K. (2023). *Ghanaian teachers' perception on their readiness in implementing the standard-based curriculum*. *West African Journal of Educational Sciences and Practice*, 2(1), 21–32.
- Association for the Development of Education in Africa. (2024). *The status of STEM education in secondary school level in Africa*. ADEA & African Development Bank Group (AfDB).
- Bervell, B., Mireku, D. O., Dzamesi, P. D., Nimo, E. B., Andoh, R. P. K., & Segbenya, M. (2025). AI acceptance and usage in Sub-Saharan African education: A systematic review of literature. *Journal of Advocacy, Research and Education*, 12(1), 82–106. <https://doi.org/10.13187/jare.2025.1.82>
- Boateng, G., John, S., Boateng, S., Badu, P., & Agyeman-Budu, P. (2023). *Real-world deployment and evaluation of Kwame for science: An AI teaching assistant for science education in West Africa*. *Computing and Language*, arXiv.
- Centre for Intellectual Property and Information Technology Law. (2023). *State of AI in Africa report*. Strathmore University.
- Cross, S., & Feldman, J. (2025). Artificial intelligence in education: Considerations for South African schooling. *Journal of Education*, 98, 27–41. <https://doi.org/10.17159/2520-9868/i98a02>
- Daniel, B. (2019). Big Data and learning analytics in higher education: Current theory and practice. *Journal of Educational Technology Systems*, 47(1), 5–17.
- Dlamini, R., Simuja, C., Feldman, J., & van Wyk, M. (Eds.). (2025). AI in education: Challenges, opportunities, and possibilities (Special issue). *Journal of Education* (98). University of KwaZulu Natal.
- Egypt National Artificial Intelligence Strategy Second Edition (2025-2030). *National Council for Artificial Intelligence*. <https://ai.gov.eg/SynchedFiles/en/Resources/AIstrategy%20English%2016-1-2025-1.pdf>
- El Nagdi, M., & Roehrig, G. (2020). Identity evolution of STEM teachers in Egyptian STEM schools in a time of transition: A

- case study. *International Journal of STEM Education*, 7(41). <https://doi.org/10.1186/s40594-020-00235-2>
- Federal Ministry of Education (2020). *Federal Ministry of Education E-Learning*. <https://ignite.education.gov.ng/>
- He, Y., Hui, S.-C., & Quan, T.-T. (2009). Automatic summary assessment for intelligent tutoring systems. *Computers & Education*, 53(3), 890–899.
- Holmes, W. (2025). AI, education, and children’s rights. *Frontiers in Education*, 10. <https://doi.org/10.3389/feduc.2025.1656736>
- Holmes, W., Porayska-Pomsta, K., Holstein, K., & Baker, R. S. J. d. (2022). Ethics of AI in education: Towards a community-wide framework. *International Journal of Artificial Intelligence in Education*, 32(2), 504–526. <https://doi.org/10.1007/s40593-021-00239-1>
- Jackson, C. (2021). Democratizing the Development of Evidence. *Educational Researcher*, 51(3), 209-215. <https://doi.org/10.3102/0013189X211060357>
- Jansen, J. (2019). Inequality in education: What is to be done? In N. Spaul & J. Jansen (Eds.), *South African schooling: The enigma of inequality* (pp. 355–372). Springer Nature.
- Jere, T. (2025). Systems Dynamics Solutions for Inclusive. *Inclusion and Accessibility: The New Challenge of Cultural Routes*, 31..
- uandi, T., Kaniawati, I., Samsudin, A., & Riza, L. S. (2023). Virtual laboratory and artificial intelligence in science education: A bibliometric analysis. *Journal of Advanced Research in Applied Sciences and Engineering Technology*, 59(3), 129–149.
- Koehler, M. J., Mishra, P., & Cain, W. (2013). What is technological pedagogical content knowledge (TPACK)?. *Journal of education*, 193(3), 13-19.
- Malik, M. Q., & Undheim, T. A. (2025). AI infrastructure for trust and learning in education: The emergence of the ‘learning provenance’ concept. *NEAIS 2025 Proceedings*, 2
- Maringe, F. (2025). The Green University Economy and

- Sustainable Development in Education: Linking Research to Globally Significant Imperatives. *Journal of Educational Studies*, 24(1), 3-8.
- Miao, F., Holmes, W., Huang, R., & Zhang, H. (2021). *AI and education: Guidance for policymakers*. UNESCO Publishing.
- Ministry of Education, Ethiopia (2020). Education Sector Development Plan. 2020-2025. Ethiopia
- Ministry of Education, Ghana (2019). Medium Term Expenditure Framework (MTEF), 2019-2022
- Ministry of Education, Kenya, (2019). National Curriculum Framework for Basic Education (NCFBE)
- Mishra, P., & Koehler, M. J. (2006). Technological Pedagogical Content Knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Mokoena, O. P., & Seeletse, S. M. (2025). *AI in rural classrooms: Challenges and perspectives from South African educators*. *International Journal of Current Educational Studies*. <https://doi.org/10.46328/ijces.199>;
- Mtebe, J. S., & Raphael, C. (2018). Key factors in learners' satisfaction with the e-learning system at the University of Dar es Salaam, Tanzania. *Australasian Journal of Educational Technology*, 34(4). <https://doi.org/10.14742/ajet.2993>
- Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., & Fishbein, B. (2020). TIMSS 2019 international results in mathematics and science. TIMSS & PIRLS International Study Center, Boston College. <https://www.iea.nl/sites/default/files/2020-12/TIMSS%202019-International-Results-in-Mathematics-and-Science.pdf>
- NEPAD. (2022). *2022 annual report: Strengthening education systems and harnessing innovation for Africa's development*. African Union Development Agency – NEPAD. <https://africanlii.org/akn/aa-au/doc/report/2022-12-31/auda-nepad-2022-annual-report/eng@2022-12-31/source.pdf>
- Network of African Science Academies. (2022). *The state of science*

education in Africa: NASAC Science Education Programme (SEP) survey report. <https://nasaonline.org/resource/the-state-of-science-education-in-africa-nasac-science-education-programme-sep-survey-report/>

- Nkwande, M. J., Mwisomba, C., Karawa, C., & Salawa, J. S. (2024). Design of a Virtual Laboratory for Secondary Schools. *East African Journal of Information Technology*, 7(1), 394–399.
- Nsengimana, T., Mugabo, L. R., Hiroaki, O., & Nkundabakura, P. (2024). Reflection on science competence-based curriculum implementation in Sub-Saharan African countries. *International Journal of Science Education*, 47 (8), 1071-1084. <https://doi.org/10.1080/09500693.2024.2356971>
- Nwangwu, R. (2014). Teachers for Technology: Basic Principles of School Technology Report. PATT 3 Conference, 2, Liverpool John Moores University, 487 – 493.
- Ogunkola, B. J., & Olatoye, R. A. (2015). Strategies for improving participation and performance of girls in secondary school science in Nigeria: Science teachers' opinions. *Gender and Behaviour*, 3(1), 453-464.
- Ogunleye, B. O. (2011). Trends and patterns of Nigerian students' WASSCE entry and performance in physics, chemistry and biology (2000–2009). *African Journal of Historical Sciences*, 7(2), 331–334
- Okebukola, P.A. (2019). What is culture-techno-contextual approach (CTCA)? Retrieved from <http://ctcapproach.com/index.php/about-ctca/> on 23rdDecember, 2019
- Okoronka, O.N. (2014). Effect of emotional pictures on students, concept attainment in primary Science. *Journal of Primary and Teachers' Education Association of Nigeria*, 9(2) 56-62.
- Okunade, A. I. (2024). The role of artificial intelligence in teaching science education in secondary schools in Nigeria. *European Journal of Computer Science and Information Technology*, 12(1), 57–67,
- Organisation for Economic Co-operation and Development.

- (2022). *Artificial intelligence in education: Challenges and opportunities*. OECD Publishing.
- Orim, F. S., Ofem, U. J., & Edam-Agbor, I. B. (2025). Implementation of automated classroom assessment in higher education using the technology acceptance model. *Discover Education*, 4, Article 87.
- Okunade, A. I. (2024). The role of artificial intelligence in teaching science education in secondary schools in Nigeria. *European Journal of Computer Science and Information Technology*, 12(1), 57–67.
- Prinsloo, P., Slade, S., & Khalil, M. (2022). The answer is (not only) technological: Considering student data privacy in learning analytics. *British Journal of Educational Technology*, 53(4), 1125–1140. <https://doi.org/10.1111/bjet.13216>
- Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). Free Press. <https://books.google.com/books?id=9U1K5LjUOwEC>
- Russell, S., & Norvig, P. (2021). *Artificial intelligence: A modern approach* (4th ed.). Pearson.
- Semela, T., & Cochrane, L. (2019). Education–migration nexus: Understanding youth migration in southern Ethiopia. *Education Sciences*, 9(2), Article 77. <https://doi.org/10.3390/educsci9020077>
- Sghir, N., Ben Ammar, M., Bouhleb, S., & Kacem, A. (2022). Recent advances in predictive learning analytics. *Frontiers in Education*, 7, Article 904167. <https://doi.org/10.3389/educ.2022.904167>
- Shambare, B., & Jita, T. (2025). Factors Influencing Virtual Lab Adoption in Marginalized Rural Schools: Insights from South Africa. *Smart Learning Environments*, 12(11).
- Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2), 4–14. <https://doi.org/10.3102/0013189X015002004>
- Steenbergen-Hu, S., & Cooper, H. (2013). A meta-analysis of the effectiveness of intelligent tutoring systems on K-12 students'

- mathematical learning. *Journal of Educational Psychology*, 105(4), 970–987.
- Steenbergen-Hu, S., & Cooper, H. (2014). A meta-analysis of the effectiveness of Intelligent Tutoring Systems on College Students' academic learning. *Journal of Educational Psychology*, 106(2), 331–347.
- Ukala, C. C., & Ukala, A. N. (2024). Charting a strategic path: Artificial intelligence in Nigerian Education and implications for policy. *International Journal of Scientific Research in Education*, 17(4), 496-504.
- UNESCO Institute for Statistics. (2022). *Global education monitoring report: Data for SDG 4*. Montreal: UNESCO Institute for Statistics. <https://uis.unesco.org/en/topic/global-education-monitoring-report>
- UNESCO. (2022). *Science, technology and innovation in Africa: Policy review and trends*. Paris: United Nations Educational, Scientific and Cultural Organisation. <https://unesdoc.unesco.org/ark:/48223/pf0000380210>
- UNESCO. (2023). *Global Education Monitoring Report 2023: Technology in education — A tool on whose terms?* UNESCO. hapsc.org
- UNESCO. (2023). *Reimagining education for Africa's future: Digital learning and AI integration report*. Paris: United Nations Educational, Scientific and Cultural Organization. <https://unesdoc.unesco.org/ark:/48223/pf0000387423>
- van der Meer, J. (2022). The Importance of an increased focus on developing the “Whole Student” during and beyond their time at Higher Education, with a Particular Focus on First-Year Students. *Open Journal of Social Sciences*, 10(07), 297–316. <https://doi.org/10.4236/jss.2022.107025>
- Wambugu, P. W., & Changeiywo, J. M. (2008). Effects of Mastery Learning Approach on Secondary School Students' Physics Achievement. *Eurasia Journal of Mathematics, Science and Technology Education*, 4(3), 293–302. <https://doi.org/10.12973/ejmste/75352>

- World Bank. (2021). *Innovation in Education: Improving Learning Outcomes through ICT and Technology* (Background paper). World Bank Publications. *World Bank*
- World Bank. (2021). *World development report 2021: Data for better lives*. The World Bank. <https://www.worldbank.org/en/publication/wdr2021>
- World Economic Forum. (2023). *The future of learning: How artificial intelligence is transforming education systems*. World Economic Forum.
- Xu, Z., Wijekumar, K. K., Ramirez, G., Hu, X., & Irey, R. (2019). The Effectiveness of Intelligent Tutoring Systems on K-12 Students' Reading Comprehension: A Meta-Analysis. *British Journal of Educational Technology*, 50(6), 3119–3137.