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Review Article

Transforming African Education Systems in Science, Technology, Engineering, and Mathematics (STEM) Using ICTs: Challenges and Opportunities

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This paper presents the role of ICTs in transforming Africa's Education Systems (AES) in science, technology, engineering, and mathematics (STEM) subjects/courses. The paper highlights on a positive shift across Africa in using ICT to improve the quality of teaching and learning through activities such as intensive ICT skills training to teachers, increase in ICT equipments and applications in schools, and emergence of living labs (LLs) and innovation spaces/centres (InnoSpace). We first provide some of the challenges of integrating ICTs in education followed by a description of key past and current ICT initiatives supporting the adoption of ICTs in schools using a number of case studies in sub-Saharan Africa. We further present various ICT-based models for education, as a transformational approach towards integrating ICTs in AES. Moreover, we provide various ICT platforms deployed for education service delivery in disadvantaged African society (e.g., rural areas) including LLs and InnoSpace across the continent. Finally, we highlight our main findings and observations in terms of opportunities and future ICT for education research directions in Africa. Our aim is to provide some guidelines and ensure that Africa uniformly meet the 2030 United Nations Sustainable Development Goal number 4, which is to *ensure inclusive and quality education for all and promote lifelong learning*, particularly using ICTs.

1. Introduction

ICTs have become the most basic building block of modern industrial society. Mastering and understanding basic skills and concepts of ICTs are now highly recognized and adopted by many countries in Africa in teaching science, technology, engineering, and mathematics (STEM). In Africa, ICTs have been mainstreamed in instruction design in different teaching courses [1]. The need for ICT-based development is a global resolution that has been and will remain to be a subject of great significance to all mankind for many years.

ICTs can be defined as a shorthand for the computers, software, networks, satellite links, and related systems that allow people to access, analyze, create, exchange, and use data, information, and knowledge in ways that were almost imaginable. The prevalence and rapid development of ICTs have transformed human society from the information age to the knowledge age in almost all sectors (e.g., ICT4agriculture [2–5], education [1, 6], etc.). While that is the case, ICT is at an embryonic stage in the majority of African countries. This is so because, there are competences required by both students and teachers to utilize ICTs in different subjects related to

STEM. These include (1) competence to make personal use of ICTs in instruction, (2) competence to make use of ICTs in instruction as a tool for teaching, and (3) competence in understanding the policy dimensions of ICTs use in instruction for learning.

With ICT integration in the classroom, students would be able to engage themselves in interactive tasks with a wider range of information and knowledge during their learning. At the same time, the teachers' attitudes would influence students to integrate ICT in their teaching practice [1]. Besides ICT skill and knowledge, the attitudes of both teachers and students play a great role in ICT integration in education system. ICTs play a significant role in achieving broad socioeconomic goals in education, healthcare, employment, and social development [1, 6]. ICTs can increase productivity through digital economies, enhancing the delivery of both public and private services in African Education Systems (AES). While that is the case, beyond the rhetoric and of great importance to policy makers in Africa, are basic questions related to the usage of ICTs in education and student outcomes, including retention and learning achievement, affordances that directly change the nature of teaching and learning, delivery mechanisms for teaching and learning, and the foundational ICT-based pedagogy that matters to current and future African students.

African countries continue to adopt ICT policies to underpin growth in a variety of socioeconomic sectors (e.g., education) and help steer development and competition. Indeed, there are new ICT project developments and announcements of initiatives related to ICT for education (ICT4E) on an almost daily basis somewhere on the continent. Yet, for many years, we have noted that the focus of investment has been on making successive waves of new technologies work in resource-poor education environments—an emphasis that tended toward a technocentric approach to ICTs in education. Regardless of a better understanding of ICTs in education today, promotion of integration of ICT4E in AES is a key for transforming African society development through STEM subjects in this knowledge era. Clearly, new strategies and solutions that prioritise teachers to use ICT effectively as an important tool to support instructions and equip learning institutions with the needed IT infrastructures should be the priority and an urgent need for the future of AES.

While ICTs have been introduced in education system in most African countries [1], the expansion and its adoption remain slow due to a lack of effective ICT policies and a long-run supporting ICT infrastructure (e.g., electricity, Internet, software, and hardware devices), teacher capacity, and financial resources. As such, the introduction of ICTs in education and the overall transformation of AES in science, technology, engineering, and mathematics using ICTs especially in a minority of African schools have the potential of widening the digital divide based on several factors (e.g., sex, location, and socioeconomic status). This paper provides a comprehensive survey of the state-of-the-art solutions and ICT-based frameworks with a focus on transforming African education system in STEM using ICTs.

2. Related Work and Open Issues

There are several studies that explore the integration and adoption of ICTs for teaching and learning in the context of Africa. Farrell [7] presented a study of ICTs and education in Africa based on surveys from 53 countries. This report provides a discussion on how ICTs are being used in the education sector in Africa, along with strategies and policies related to this use. Barakabitze [6] presented a critical review on the context of education initiatives, importance, and inhibitors of ICTs towards improving teaching and learning in Tanzania. Sife et al. [8] provided a discussion on new learning and training technologies considering their pedagogical, cost, and technical implications. The authors further discussed challenges for integrating ICTs in Higher Learning Institutions (HLIs) with examples from Tanzania and giving best practice and approaches that address each of the challenges. Hennessy et al. [9] presented an evaluation of both provision of ICT in schools and policy initiatives related to its use in supporting school learning and teacher education in sub-Saharan Africa (SSA) with a particular focus on East Africa. The authors synthesized on the role played by ICTs in improving the quality of learning and teaching in schools with reference to technologies appropriate for this context. In so doing, their review casts new light on the supporting and constraining factors (e.g., pedagogical, social, logistical, and technical issues) that influence ICT integration in education in the region.

Patrick et al. [10] recently assessed classroom ICT integration opportunities and the challenges in relation to Technological Pedagogical Content Knowledge (TPACK) and Substitute, Augmentation, Modification, and Redefinition (SAMR) models. While considering the country's 2020 vision for development, Joly et al. [11] explored issues related to equity and social justice with respect to the introduction of ICTs into school in Rwanda. Professional and practical experiences, challenges, and opportunities of integrating educational technologies at the University of Dar es Salaam, Tanzania, are explored in [12]. The authors further identified gaps that need to be worked upon in order to unleash full potentials brought by educational technologies at the university. The deployment and adoption strategies of cloud computing (CC) [13] for blended learning (BL) (blended learning is a combination of face-to-face (e.g., using video conferencing technologies) delivery with a certain e-learning technology. The combination can be face-to-face delivery with the learning management system where students access learning resources via the system with some selected face-to-face teaching [14]) in HLIs in sub-Saharan Africa are highlighted in [15]. With the aim of ensuring effective delivery of quality education, Jennifer et al. [16] and Kafyulilo [17] explored some of the existing opportunities and challenges in implementing distance learning and e-learning. While the literature above indicates a significant research step of investigating on how ICTs are being integrated in Africa, we note that these works are limited in at least one of the following: (1) they provide limited review and activities related to ICT4E in Africa, (2) no comprehensive descriptions of ongoing ICT4E research projects, SotA efforts and challenges, and concrete future research directions in ICT4E across the continent are given, and (3) with regard to scope, they do not provide important aspects of integrating ICTs in education such as different ICT4E models and frameworks, their implementations, and deployment strategies of ICT4E in rural education settings. This paper is the first step to fill this gap by providing an exhaustive research on integrating ICTs in education with respect to the transformation goals of AES in science, engineering, and mathematics context.

2.1. Scope and Contributions. The major objectives of this paper are to give the reader a fully comprehensive state-of-the-art and updated solutions related to ICT4E integration in Africa. Our contributions are multifold:

(i) We first provide the importance of ICTs in education and present some of the challenges of integrating ICTs in African education systems
(ii) We describe key past and current ICTs initiatives supporting the adoption of ICTs in African learning institutions using a number of case studies in sub-Saharan Africa
(iii) We further present new ICT models and frameworks, as a transformational approach towards integrating ICTs in AES
(iv) Moreover, we provide various ICT platform deployments for service delivery in disadvantaged African society (e.g., rural areas) including living labs and innovation spaces across the continent
(v) Finally, we highlight our main findings and observations in terms of opportunities and future ICT4E research directions in Africa

2.2. Paper Structure and Organization. The rest of this paper is organized as follows: we start our discussion with an introduction to the importance of ICTs and discuss the challenges in education in the context of Africa with vivid examples from selected African countries in Section 3. Section 4 presents the key past and current ICT initiatives that support the adoption of ICTs in schools. Section 5 provides some of ICT4E innovative frameworks that have been proposed as an approach for ICT integration in AES. We further provide various ICT platform deployments for rural education improvement in Section 6. Section 7 presents some of the available opportunities and the future direction of ICT4E research in African education. Finally, we provide our concluding remarks in Section 8.

3. The Importance of ICTs and Challenges of Integrating ICT4E in Africa

3.1. The Importance of ICT in Education. The UNESCO report of 2018 acknowledge that ICTs can be leveraged to accelerate the achievement of the targets of the Education 2030 Agenda, by combining the views of policy makers, academics, and the private sector [18]. ICTs promote student-centred learning and appear to be speeding the rate of educational change in all learning institutions [1, 6]. It is worth noting that students' perceptions change when they are continually exposed to the capabilities of ICTs. Yet, the more they become positive towards ICT use, the more likely that students can develop better skills on ICT use and be encouraged to engage themselves in deeper forms of learning [6]. Over the past years, primary, secondary, and HLIs in Africa are witnessing a paradigm shift brought about by the use of ICTs. As such, learning institutions have seen ICTs as an indispensable tool in the teaching and learning process [1, 15, 19, 20].

It is important to mention that in order to cater to the needs of the twenty-first century, teachers should learn to adopt with the change particularly in the new trends of teaching and learning using ICTs. Maurice et al. [21] indicated that ICTs can facilitate students to search for information and other instructional materials. The use of ICTs in educational delivery and in any other field of endeavor cannot be over emphasized in this era of science and technology. By using ICTs, students are now more frequently engaged in the meaningful use of computers that enable enhanced teaching and learning environments by providing opportunities to practice, analyze, and offer better access to relevant articles and teaching/learning material [17]. Students can develop new understanding in their areas of learning [22]; their creativity can be optimized and may discover new multimedia tools and create some learning materials in the styles readily available to them through game-based learning [23], CDs, or television [24].

Mwalongo in [25, 26] highlighted that ICT use for teaching is likely to motivate teachers and learners/students and help them to clarify difficult concepts, save time, make learners active, and simplify teachers' work. However, it is the ICT use experience that makes teachers see the value of the technology they use [27]. Fu [28] points out that ICTs in education cannot be implemented in isolation but should be applied in combination with diverse teaching methods and approaches, especially constructivists perspective, which is rooted in student-centred learning [29]. ICT can change the role of students they play in the classroom (i.e., from the traditional passive recipients to learning initiators) and can also cope many of the criteria in the teaching and learning process using learner-centred approach [29]. In addition, the roles of teachers also change to facilitator of student learning through contextualizing and monitoring ICT-based learning functions [30]. The International Society for Technology in Education (ISTE) (ISTE provides educational technology resources to support professional learning for educators and education leaders. It also actively advocates for education technology at the local and national levels to advance the global transformation of education through the application of technology to education) also puts emphasis on teachers of today to provide technology-based learning opportunities for their students [31]. However, in order to promote effective implementation and integration of ICTs throughout the curriculum by students/teachers, there is a need to introduce students/teachers to more courses on ICT with needed hand-on experiences [32]. Moreover, there should be an improved ICT infrastructure, good ICT policies, curriculum, and content to support teaching and learning in education so as to enhance the use of ICTs in all educational sectors [1, 6, 33]. While ICTs show a significant importance in education, there are challenges for integrating ICT4E in Africa which are discussed in the next subsection.

3.2. Challenges of Integrating ICT4E in Africa: Case Studies and a Call for Immediate Actions. The majority of Africans (especially in sub-Saharan Africa) as shown in Figure 1 are out of school, mainly due to lack of access to schools or because of various social and economic circumstances.

Despite the adoption of 15 years Sustainable Development Goals (SDGs) [36] in education, which also form the basis of the Education for All (EFA) 2030 Declaration (Incheon Declaration) [37] and emphasizing the importance of vocational and technical training and quality education, the continent is still facing a number of challenges to meet those goals and harness the full integration of ICTs in all levels of education (e.g., preprimary, primary, secondary, and higher learning institutions). Some of the challenges include lack of ICT infrastructure in learning institutions; technology affordability and accessibility; lack of public community facilities; gender and institutional policy on ICT use; corruption, sociocultural, and linguistic factors; economic and political factors; teachers' attitudes, pedagogy, skills, knowledge, and beliefs about ICT; students' ICT literacy; effective leadership and administrative support in learning institutions; lack of government ICT4E Policy awareness; economic and political factors; overdependency on donors' support; and interdisciplinary and lack of innovation skills [6].

3.2.1. Lack of ICT Infrastructure in Learning Institutions. Despite the potential of ICT for teaching and learning, many learning institutions (from primary to HLIs) in Africa are conducting teaching and learning process with limited ICT facilities which include [6, 38] few computer laboratories with few computers and limited electricity supply [39]. Although there are some improvements in the access of telephone networks in most of African countries, still the cost of bandwidth is unaffordable or out of reach of many schools across the continent, mostly in rural and remote areas which are either unserved or underserved [40]. Governments across the continent have established a Universal Service Funds (USF) as their strategy to address the problem of limited coverage of telecommunication services in Africa. However, we note that poor ICT policy formulation limits the implementation of an effective USF model across the continent. In addition, lack of accountability and inadequate ICT stakeholders' engagement, the narrow scope of universal service, and undue political influence all impinge on the ability of USF to achieve their objectives [40].

As an example, Figure 2 shows the proportion of primary and secondary schools with computer-assisted instruction (CAI) (computer-assisted instruction is an interactive learning method in which a computer is used by teachers or pupils to present instructional material, perform tasks for learning, and help in selecting and accessing additional pedagogical material) and computer laboratories for ten countries. CAI is not offered in primary schools in Madagascar and is rare in Sao Tome and Principe and Zambia, where it is offered in 3% and 5% of primary schools, respectively. In contrast, it is offered in 78% of primary schools in Botswana. In Mauritius, CAI is universally offered in all primary schools. Secondary schools are more likely to offer CAI, and this is particularly true in Sao Tome and Principe where 71% of secondary schools offer some form of CAI. Yet, despite the greater proportions of secondary schools offering CAI, fewer than 10% offer it in Comoros and Madagascar.

3.2.2. Teachers' Attitudes, Pedagogy, Skills, Knowledge, and Beliefs about ICT. Major predictors of the use and integration of ICT in teaching and learning are teachers' attitudes and their beliefs. However, the lack of ICT-related skills and knowledge of teachers is one of the main inhibitors to students' learning and their ICT-related goals. While Ndibalema in [41] investigated the attitude of teachers towards using ICT as pedagogical tool, results indicate that teachers are not aware of the potentials of ICT in their teaching. In addition, previous studies by Apiola et al. in [42, 43] find that the preference of teacher-centric instruction, memorizing as a mode of self-study, and discouragement of critical thinking are quite typical attitudes among new IT students/teachers in Tanzania. It is worth mentioning that effective leadership is a key element of success in any innovation and integration of ICT in education, especially in the African region. The lack of appropriate leadership and administrative support on guidelines, training on the pedagogy of ICT in Tanzania, has been among the challenge for facilitating teaching and learning in Africa. Although some of the countries have ICT policies and plans in place, still there is limited strategic leadership to pioneer and champion activities related to ICT4E. Yet, the implementation efforts are largely uncoordinated and piecemeal [44].

3.2.3. Lack of ICT in Education Policy, Plans, and National Curricula. The early integration of ICT into primary and secondary curricula through formal recommendations is an important lever to ensure children and adults will develop digital literacy. As such, this is not only important for general life and work skills but also empowers youth in their ongoing education throughout secondary, postsecondary, and tertiary education levels. However, the integration of ICT for example in sub-Saharan Africa, is a low priority when compared to other objectives, including increasing enrollment rates, decreasing the proportion of out-of-school children, and ensuring an adequate number of trained teachers. Furthermore, the integration of ICT in education is occurring relatively slowly in many countries due to a number of factors, including a lack of formal policy, financial resources, basic infrastructure, and teachers with appropriate skills [45].

According to the UNESCO Institute for Statistics (UIS) report, several countries in Africa have no an active policy or plan to implement ICT into the education system (Figure 3).

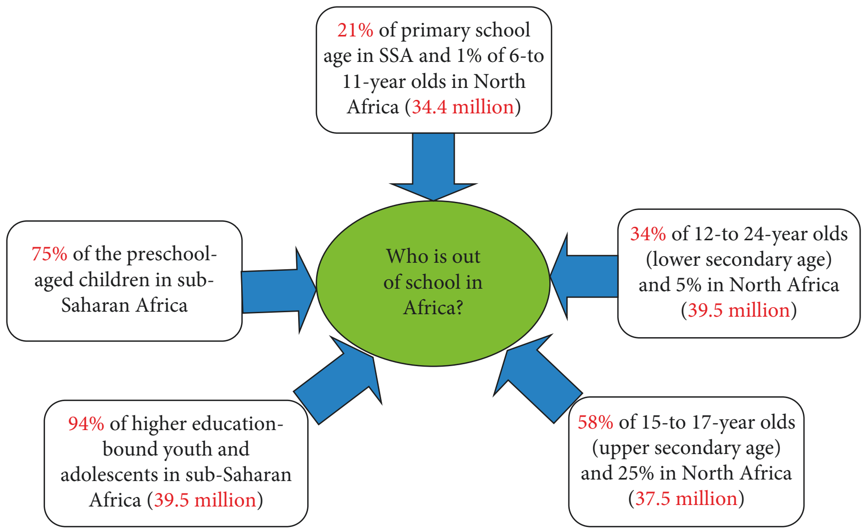

Figure 1: Percentage of children who are out of school in Africa (adapted from [34]).

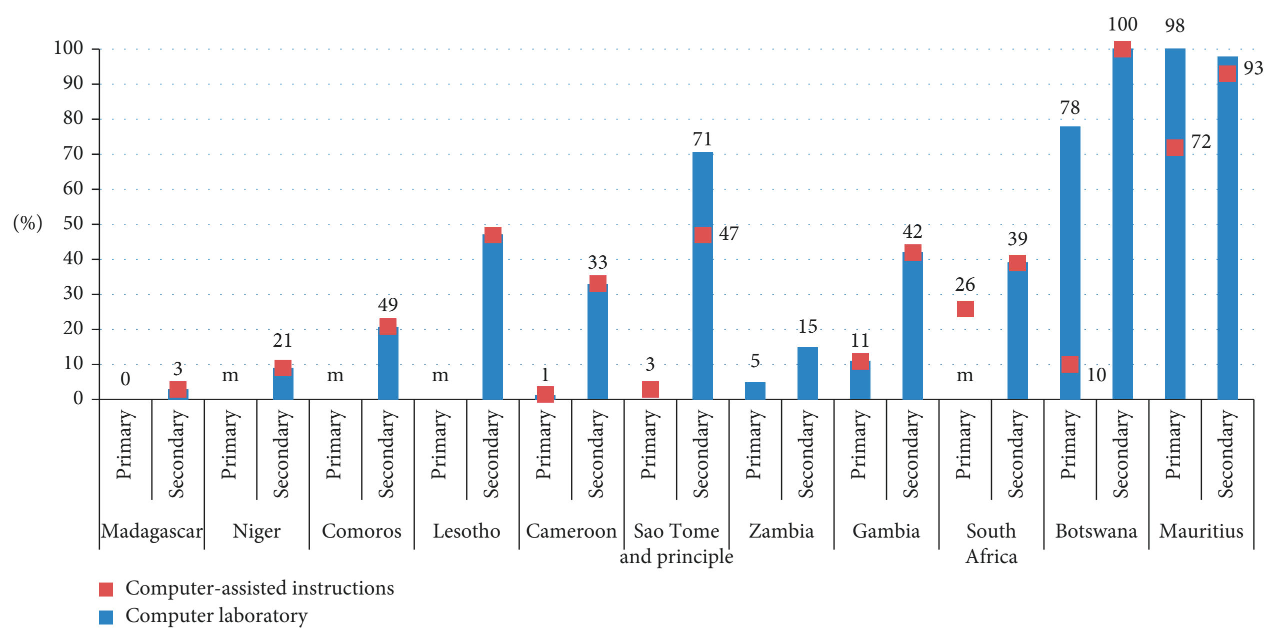

Figure 2: Computer-assisted instruction and laboratories in primary and secondary education (adapted from [35], under the creative commons attribution license/public domain).

Country has an ICT in education policy	Only for upper secondary school	No ICT in education policy	No information collected
Angola, Botswana, Ivory Cost, Eritrea, Gambia, Sao Tome and Principe, Mauritius, Rwanda, South Africa, Tanzania, Kenya, Zambia, Uganda, Tunisia, Morocco, Egypt			
Country has national plan on ICT in education policy			
Angola, Botswana, Ivory Cost, Eritrea, Gambia, Sao Tome and Principe, Mauritius, Rwanda, South Africa, Tanzania, Kenya, Zambia, Uganda, Tunisia, Morocco,Egypt	Ethiopia, Djibouti, and Togo	Cameroon, Comoros, Democratic Republic of the Congo, Guinea, Lesotho, Madagascar	Burundi, Benin, Central African Republic (CAR), Chad, Zimbabwe, Equatorial Guinea, Gabon, Guinea-Bissau, Malawi, Namibia, Mali, Nigeria, Niger, Senegal, Somalia

Figure 3: Policy and national plan on ICT in education in African countries (adapted from [35], under the creative commons attribution license/public domain).

The report further finds that many African countries including Burkina Faso, Comoros, Guinea, Madagascar, and Niger do not have objectives or offer courses on basic computer skills or computing in primary or secondary curricula. In other countries, regardless of whether or not it is achievable in all schools, courses are first recommended in upper secondary.

4. Key Past and Current ICT Initiatives Supporting the Adoption of ICT in Schools in Sub-Saharan African Countries

This section presents a comprehensive review of some of the initiatives and projects that support the integration and adoption of ICTs in schools in sub-Saharan African (SSA) countries. More generally, we present lessons learned and issues raised by the wider ICT4Development initiatives implemented in some African countries. It is worth mentioning that these initiatives are done at both local level as well as at the national level, and the main aim has been to improve education provision and delivery in all learning institutions (primary schools, secondary schools, teacher training colleges, vocational education colleges, and higher learning institutions) [9].

4.1. ICT Initiatives in Eastern Africa. Through the ICT National Master Plan 2017 and *Vision 2030*, Kenya recognizes the importance of ICT4E which is manifested through the promulgation of the national ICT strategy in education and training. A previous series of ICT initiatives identified by Farrell [7] in the *survey of ICT and Education in Africa: Kenya Country Report* include the following:

(i) Learning resource centre establishment that provides integration of ICT and training in educational management for school managers, lecturers, and students at the Kenya Technical Teachers College.

(ii) Development of learning content focusing on digitization of curriculum content for schools at the Kenya Institute of Education.

(iii) Establishment of central and regional ICT support centres to provide immediate solutions on ICT issues to schools via telephone or online inquiries

(iv) School broadcasting using WorldSpace technology to broadcast educational content to 11 million students. Free software licenses were also initiated to provide free access to Microsoft Corporation's operating software for schools and higher education institutions.

(v) An MoE project "ICT equipment for schools" established as the ICT in education strategy reforms.

To date, there are a wide range of ICT Initiatives and projects ongoing in Kenya focused on e-infrastructure (e.g., Konza City, County Connectivity projects, National Fibre Optic Broadband Infrastructure, and Digital Migration), e-learning and skills development (the Laptop Programme, Digital Learning Programme, and Presidential Digital Talent Programme), digital Inclusion (Pasha Centres/Digital Villages), business process outsourcing, local content programme (Tandaa Digital Content Grants and Open Data Portal), information security, and other initiatives (zero-rated taxes on imported ICT hardware and eGovernment).

The Tanzania Development Vision 2025 highlights the importance of leveraging ICT alongside the necessary skills and capabilities to realize a well-educated and learning society and a strong, competitive economy capable of sustainable growth and shared benefits. ICT Initiatives are currently ongoing at national level in the areas of e-infrastructure and Education (Science, Technology and Higher Education Program, Tanzania National Research and Education Network, e-libraries, Education and Management Information System), Information Society and Entrepreneurship (TANZICT project, Dar Teknohama Business ICT Incubator, Binu Innovation Hub), and the Tanzania ICT Technology Park.

The Tanzania Education and Research Network (TERNET) is the National Education and Research Network (NREN) for Tanzania. TERNET provides research facilities and an electronic network that connects all HLIs in the country as well as TTCs [39]. TERNET also provides network infrastructure that facilitates Education Management Information Systems (EMIS), support for e-libraries and electronic information access, research databases, and enhancement of e-learning capacity [39]. The Science Technology and Higher Education Program (STHEP) is a World Bank funded project to the Government of Tanzania, implemented through the MoEVT with support from the Ministry of Communication Science and Technology (MCST). STHEP had four program components: Component 1A: investments in priority discipline for economic growth; Component 1B: expanded capacity for teachers' preparation and for graduate studies in education; Component 2A: strengthening key higher education agencies and institutions; Component 2B: investments in ICT-based higher education systems. STHEP Component 2B was focused on four (4) major areas being National Research and Education Network (NREN), Education Management Information system (EMIS), e-library, and e-learning. Shared mechanisms to support the implementation of Component 2B of STHEP have been established between all 128 HERIs under this program [46].

The Government of Uganda has recognized the critical importance of ICT in national development through the National Science, Technology, and Innovation Plan 2012/2013–2017/2018. As such, Uganda's ICT sector is one of the most vibrant and fastest growing sectors since its liberalization in 2010, supported by a good ICT legal and regulatory framework. The support from donor agencies in the area of ICT for development has translated into a myriad of ICT projects being implemented in various sectors of Ugandan society, most notably in rural infrastructure, education, livelihoods, and health. A wide range of Internet points of presence, Internet cafes, training centres, telecentres, ICT labs in schools and higher education institutions has been implemented by the Rural Communications Development Fund (RCDF). As of today, Uganda is currently implementing ICT-related initiatives in the areas of e-infrastructure (Research and Education Network Uganda, Broadband Services ERT Programme, National Backbone, Migration from Analogue to Digital Broadcasting Project, and eNetwork project) and eGovernment (Electronic Government Infrastructure and ICT4Democracy in East Africa project).

The Government of Uganda has also been implementing the technology-enhanced learning. A number of projects were initiated over the past decade to support the education system including the Connect-ED project to put computers and Internet points of presence in teacher colleges (commenced in 2000 with support from USAID). The CurriculumNet Project (https://www.idrc.ca/en/article/casting-curriculumnet-wider?PublicationID=716) prepared an ICT-based curriculum materials in mathematics and geography for primary schools and mathematics and science for secondary schools. Along with the above, the VSAT project and SchoolNet Uganda project; Content Development project at National Teacher Colleges; Connecting Classrooms project; UConnect (http://www.uconnect.org/) supporting connectivity and training in schools; and iNetwork (http://www.i-network.or.ug/) Project were initiated to support connectivity and training in schools, improve learning outcomes through ICT, and help teachers use ICT for teaching. Other projects include the Microsoft Innovation Centre, ITELE for ICT project, the Huawei Initiative to address the challenges for local content, and the NUFFIC-ICT (https://maksweden.mak.ac.ug/?p=919) projects.

Moving to Rwanda, the country's Vision 2020 places ICTs at the heart of the transformation across all sectors. Aligned with the Smart Rwanda Master Plan, the Education Sector Strategic Plan (ESSP), and the Draft ICT in Education Policy, the ICT in Education Master Plan [47] is seen as a strategic lever for achieving this transformational vision. The Rwandan government views ICT as a key tool for transforming the economy, with the education sector playing an important role in developing the necessary human resources. As such, the education sector in Rwanda has been enjoying a considerable political will in terms of designing and implementing programmes for mainstreaming ICTs in education. To a large extent, the Ministry of Education has overseen an expansion of ICT infrastructure in primary and secondary schools. Since 2000, there has been a big push to introduce computers into schools in Rwanda and integrate ICT into the education curriculum through a range of initiatives including the following [11]:

(i) Partnership for Africa's development (NEPAD) e-schools initiative; this project involved equipping six secondary schools in Rwanda with ICTs equipments. It is important to note that this was part of a broader project that involved 20 African countries with the aim of building capacity in ICT use in African countries.

(ii) Ministry of Education initiative that supplied 10 computers per secondary school both private and public owned schools. 400 out of about 500 secondary schools in Rwanda had received these computers by the end of 2006.

(iii) ICT training in basic skills for 3,000 secondary school teachers carried out in partnership with Microsoft Partners in Learning (PIL) using a trainer-of-trainers model [9].

(iv) One laptop Per Child (OLPC) project that was officially launched in October 2008 and since then has supplied over 5000 laptops to primary schools in three districts. The overall aim of OLPC is to equip every child at primary school level with a laptop so as to make them computer literate.

(v) UNESCO-KFIT Project [48] launched in 2015 with the aim of increasing the access and quality of basic education through innovative ICT solutions in three African countries (Mozambique, Rwanda, and Zimbabwe). The project also intends to strengthen higher education systems through Open and Distance Learning (ODL), facilitate the development of national ICT in education policies, master plans, and knowledge sharing, including supporting the Information for All Programme (IFAP).

South Africa (SA) is currently one of the countries in southern Africa where ICT has made a significant impact to the society. The e-education vision is to provide ICT platforms for learning where learners and teachers increase their computer literacy and skills for full participation in a knowledge society [49]. Some of the past and current ICT Initiatives that are at the national level include [50] *Teacher Laptop project*, *Sentech Ltd.* and Telkom Internet Project that was initiated to establish Supercentres (with computers, software, Internet connections, monthly subscriptions, and rent-free telephone lines) in more than 1,300 schools. The *Mindset Network* and *Thutong portal* were initiated to provide digital content resources via satellite television. The SchoolNet, SA's primary educator ICT development programme, was launched to enable serving teachers feel confident and competent to teach using ICT within the curriculum [51]. Moreover, the *Intel Teach to the Future* (http://www.schoolnet.org.za/ttf/index.htm) and the Microsoft Partners in Learning initiatives were launched to offer training programmes to teachers including basic ICT skills and ICT integration, peer coaching, and ICT leadership for education managers. In addition, ICT initiatives such as Khanya project and *GautengOnline* were established by the government in collaborations with the private sector to provide ICT-based resources in specific provinces. To date, ongoing projects at national level include the development of strategies emanating from the integrated ICT policy review process, the implementation of the South African National Research Network and Tertiary Education and Research Network, the Digital Terrestrial Television Migration process, and SA Connect Broadband infrastructure rollout [46]. Table 1 summarizes key past and current projects in other countries from southern African. Based on this ICT in education initiatives, we provide the lesson learned in the next subsection.

Table 1: A summary of ICT in education platforms, projects, and implementations in southern African countries.

Country	ICT initiative	Objective/functionality
Botswana	Kitsong Centres, Thuto Net, Botswana Innovation Hub, Connecting Communities Programme, and Pan African e-Network Project	To link all secondary schools to the Internet. As such, all secondary schools in Botswana have computer laboratories comprising about 15–20 computers
Burundi	Burundi Education and Research Network (BENET)	
Ethiopia	EthERNet (Ethiopian Education and Research Network), SchoolNet, ICT Business Incubation Centre, Entrepreneurship, and e-Education	SchoolNet provides Internet connectivity as well as TV-broadcast educational content to secondary schools across Ethiopia. As such, it provides students in rural schools with access to equal learning opportunities to those in urban schools. EthERNet was launched to build and deliver highly interconnected and high-performance networks for universities and other educational and research institutions while EthioICT-Village is to establish Ethiopia as the premier IT hub of Africa [46]
Namibia	eEducation (TECH/NA! ICT in Education Initiative, XNet, eLearning Centre (eLC), and ICT Centre of Excellence)	To equip, educate, and empower administrators, staff, teachers, and learners in ICT literacy and ICT integration skills to help bridge the digital divide with communities and meet the goals of Vision 2030 to fulfil Namibia's ambition
Malawi	MAREN, Education and eLearning (Computers for African Schools Malawi, Pan African eNetwork, Digital Repositories, Malawi Library and Information Consortium, National Digital Repository)	To provide ICT training to teachers, provide computers and printers to schools, and develop the ICT curriculum for schools [52]
Mozambique	Mobile ICT Unit, Provincial Digital Resource Centres (CPRDs)	To provide training courses in districts isolated from ICT facilities to address the problem of ICT skilled human resources across the country. CPRDs concentrate ICT infrastructure, skills, and investment by providing a single-entry point for ICT deployment and activity in the provinces
Mauritius	Universal ICT Education and Digital Youth Engagement Programme, Public Internet Access Points (PIAPs), and Learning Corners	Training the internationally acknowledged internet and computing core certification (IC3) course to students, employees, nonemployees, and the population at large with a view of making it the benchmark for digital literacy/proficiency in Mauritius

MAREN = Malawi Research and Education Network.

4.2. Summary and Lessons Learned. It is evident that there is considerable interest in delivering educational ICT initiatives at the national level through projects such as Intel Teach to the Future, SchoolNet, African Research Agenda, and One Laptop per Child that span in many countries across Africa. As pointed out by Hennessy et al. [9], the majority of these projects to develop ICT use in African schools in fact operate in isolation, with limited participation and coordination from each ICT initiative.

It is worth mentioning that African governments are eager to use ICTs so that they are at the forefront of technological change. The state of the art indicates that the international agencies and other donors are eager to provide ICT resources to help "*Bridge the Digital Divide*." The private sector is also keen to invest where companies see potential ICT in education market growth possibilities in the future. Nevertheless, as we show in later sections, academics are interested in sharing the results of their research on the agenda of integrating ICT in education across Africa. Moreover, civil society organizations are willing to help facilitate the integration of ICT in education and delivery of resources on the ground. However, this multiplicity of interest means that there is frequent duplication of efforts, lessons from the projects are not sufficiently learnt and shared, and there is a wasteful lack of coordination in the activities that actually take place across Africa. Generally speaking, there are many examples of small-scale ICT initiatives, which are embarked on with the best will in the world, but that only benefit a few people for a short while in most African countries. It is worth mentioning that if all those involved would truly work together for the interests of the poor and marginalised in Africa, rather than primarily for their own agendas and targets, it would be possible to achieve very much more than has been achieved so far [9].

5. Innovative Framework for Integrating ICTs in African Education System: A Transformational Approach

5.1. Dimensions of ICT in Education. For many years, as noted by Isaacs [53], the focus of investment in Africa has been on making successive waves of new technologies work in resource-poor education environments. Such emphasis

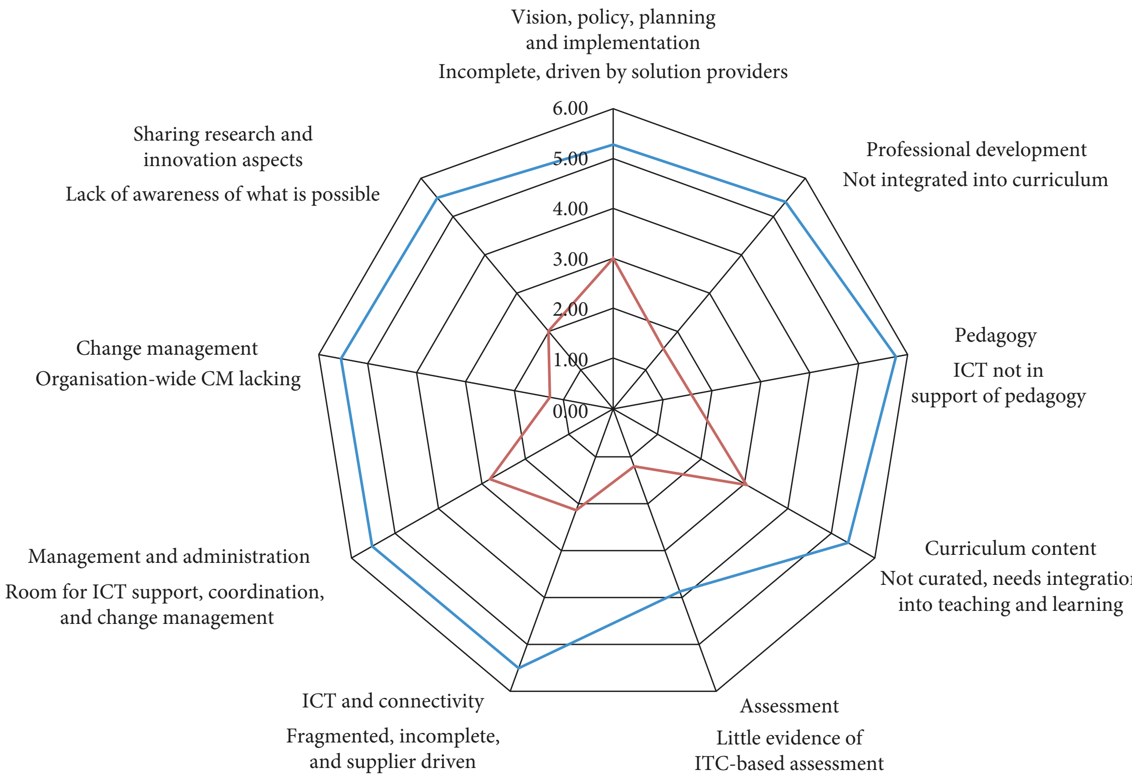

Figure 4: Dimensions of ICT in education and the associated constraints.

tends toward a technocentric approach to ICT in education. Clearly, a consistent strategy that prioritizes sound pedagogy, training teachers to use ICT effectively to support instruction, and building the overall ICT-capable capacity is more appropriate for the African education system to move forward. The implementation and integration of ICT4E should go along with clear guidelines and dimensions of ICT in education as well as integrative strategies. The guidelines and dimensions of ICT in education defines useful exercise and clarify the various focus areas of ICT studies and the role of different players (teachers, learners, policy makers, etc.) in integrating ICTs in education.

We discuss next the dimensions of ICT in education (DICTE) in the context of Africa. DICTE defines nine focus area of integrating ICT in education, namely, (1) ICT vision, policy, planning, and implementation; (2) ICT curriculum and content; (3) ICT assessment; (4) ICT pedagogy; (5) ICT change management and leadership; (6) ICT and connectivity; (7) ICT management and administration; (8) ICT professional development; and (9) ICT sharing research and innovative practices. The analysis presented in this paper draws and maps some of the approaches from different initiatives such as the ICT in e-Education white paper [54], ICT for Rural Education Development (ICT4RED) initiative [55], and the UNESCO ICT Competency Framework for Teachers (ICT-CFT) [56]. Figure 4 shows the dimensions aspects of ICT in education and the associated constraints. The description of each aspect is as follows.

5.1.1. Vision, Policy, Planning, and Implementation. For each African country, there should be a national ICT policy with a clear and defined vision and strategy that creates an enabling system for the advancement of ICT research, development, and innovation (RDI) within the context of education. The implementation roadmap should be put in place as the means by which the ICT national RDI strategy is put into a coherent set of actionable plans. The roadmap should provide the required strategic direction to guide countries in planning, coordinating, and managing ICT4E investments.

5.1.2. Teacher Professional Development (TPD). There are should be strategies and models of TPD with an emphasis on programs designed to prepare in-service teachers to integrate ICT into their classrooms [57]. It is important to note that effective TPD has various attributes that are common across various subjects (e.g., science or math education) that mainly focus on content and engaging teachers in lifelong learning. However, as shown in Table 2 there are key issues and strategies related to ICT for effective professional development.

5.1.3. ICT Pedagogy. Training and awareness are required to ensure that ICTs are integrated in support of pedagogy, in a phased manner. In that aspect, a clear goal must be established, and teachers and learners must be guided to use ICTs in support of teaching and learning. As narrated by Jung in [58], there are a variety of approaches in ICT-pedagogy integration in teacher training. Figure 5 shows these approaches using a four-cell matrix. It is worth mentioning

Table 2: A summary of key issues and strategies related to ICT for effective professional development.

Key issues	Strategy
Learning designs	Design programs based on what we know about how ICT can support learning
Opportunities for reflection	Design activities that encourage participants to use ICT and reflect on their practice
Collaborative efforts	Encourage the use of ICT for collaboration among all stakeholders in the design, implementation, and evaluation of programs
Ongoing support	Use ICT and online technologies to provide ongoing support
Informal learning	Provide opportunities for informal learning and support
Systemic effort	Coordinate TPD with broader ICT and school improvement efforts
Leadership	Foster leadership which nurtures innovation, change, and the creation of schools as learning organizations
Authentic engagement within teachers' contexts	Situate programs in teachers' context so that activities are authentic

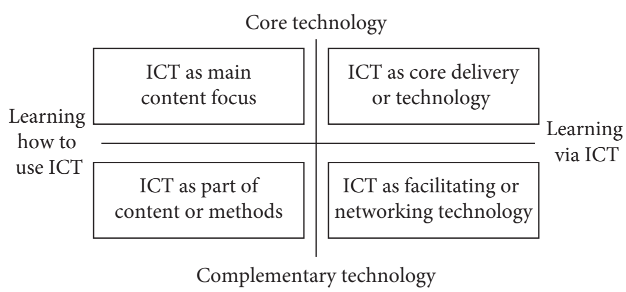

Figure 5: ICT-pedagogy integration in teacher training.

that a majority of the countries in the world have provided ICT teacher training in a variety of forms and degrees after having recognized the importance of ICT in teaching and learning.

As shown in Figure 5, ICT teacher training can take many forms, for example, teachers can be trained to learn how to use ICT or teachers can be trained via ICT. On the perspective of being used as a tool, ICT can be used as a core or a complementary means to the teacher training process [58]. ICT as a core technology for delivering teacher training can be used as the major way of providing the learning experience of teacher training. In that aspect, the content of this approach does not necessarily focus on ICT skill itself but rather covers a variety of ICT applications. One example of this approach is the Virtual High School (VHS) (http://vhslearning.org/) in the USA that provides the Internet-based ICT teacher training. In Morocco and Namibia, the Computer-Assisted Teacher Training (CATT) project developed computer-assisted teacher training courses and constructed communications network that facilitate interaction among teacher trainers, teacher trainees, and inspectors [59].

5.1.4. ICT Curriculum Content. The ICT curriculum planning and development should provide appropriate curricula with meticulous attention to the new transformational trend in Africa. The CT curriculum should state the role of ICT in educational domain. It should further provide an integrating and blending programmed approach for ICT teachers and students such that it prepares a field in which the potential of individual capabilities of students and their own and personal experiences could be increased [60].

5.1.5. ICT Assessment. As ICT adoption in African education systems matures, the use of ICT in assessment needs to be included as an objective and incorporated into teacher development.

5.1.6. ICT and Connectivity. The introduction of ICT tools (e.g., hardware devices) by solution providers needs to be aligned with education standards and ICT policies. Connectivity needs to be seen as a very important resource and an integrative strategy in ICT4E. However, user commitment in schools is required to optimize its use from a technology and content perspective. There should be ongoing support in terms of training and device replacement.

5.1.7. ICT Management and Administration. During ICT in education integration, new and ongoing initiatives/projects need to be supported adequately and consistently, to ensure uptake. Appropriate monitoring and evaluation mechanisms should be undertaken in order to justify the return or output of the investment.

5.1.8. Change Management. Change management should be a key enabler across all levels of the education system. A change management focus is required that permeates all levels of the hierarchy and should be aligned to a common goal that adopts holistic change management practices, beyond training.

5.1.9. Sharing Research and Innovative Practices. There are should be a significant room to define, undertake, and share good educational research that informs policy makers in regards to what happens in the classroom or any other learning environments. It is worth noting that continuous ICT4E research that explores what happens inside a classroom and provides innovative practice what the system needs is required at the university level. Furthermore, a forum is required where the nature of good ICT4E research is shared.

5.2. Models of Technology in Education. In order to transform African educational system, ICT integration in teaching and learning is necessary, since it is instrumental in defining a clear objective, and, as such, in guiding strategy, tactics, and implementation from primary to tertiary level. To archive this goal, an efficient ICT4E model have to be developed with an intended learning outcome aligned with the teaching activities, course development, and the assessment and learner support [61, 62]. The model should also provide context for effective learning and teaching and reviewing the overall performance of an education system in Africa on a regular basis.

A significant body of literature emphasizes that ICTs need to be used in support of teaching and learning [1, 6, 8, 52, 63]. Generally, different ICT models of teaching and learning have been proposed, for example the TPACK or the UNESCO ICT-based models. It is important to note that each model describes different interpretations of how learners are able to familiarize themselves with, adopt, and utilize new knowledge and skills using ICTs. In essence, each of these describes a progression from familiarization with new knowledge to competence in the use and application of ICTs thereof. The models outlined below reflect different perspectives on this support role of ICTs. A brief overview is given of the intent of each model. Common to most of the models is their reflection of education as a progression through which learners develop increasingly advanced skills.

5.2.1. Bloom's Taxonomy for Educational Learning. The Blooms taxonomy [64] was first published in 1956 aimed at classifying educational objectives also known as *taxonomy of educational objectives* The BT framework has been applied by generations of K-12 teachers and college instructors in their teaching.

The revised version of the BT as shown in Figure 6 consists of six major categories, namely, (1) remembering; (2) understanding; (3) applying; (4) analyzing; (5) evaluating; and (6) creating to form the basis of learning, from which the other levels are derived [65]. The BT model is commonly applied to structure curricular activities, and it defines a progression from assimilation of information, to using information to create new knowledge. Using a variation of Bloom's revised taxonomy, Caroline et al. [66] developed an assessment model that includes a content component and a cognitive component, namely, knowledge, routine procedures, complex procedures, and problem solving, currently used in the South African curriculum documents. The authors investigated, in particular, various taxonomies, including those used in international assessments and in mathematics education research, for constructs that teachers of mathematics might find meaningful.

5.2.2. Technological Pedagogical Content Knowledge (TPACK) Model. The TPACK model [67, 68] shown in Figure 7 was introduced to the educational research field as a theoretical framework for understanding teachers' knowledge required for effective technology integration. It intuitively measures preservice teachers' self-assessment of their technological pedagogical content and knowledge.

The TPACK framework emphasizes the role of the context where teaching and learning occurs. It is imperative to note that teachers with developed TPACK use technology to design learning experiences tailored for specific pedagogies, crafted for specific content, and instantiated in specific learning contexts [69]. We describe next, each of the components of the TPACK framework and, most importantly, their interactions with each other [69, 70].

As summarized in Table 3, the academia, researchers, and ICT policy makers across the continent have received these models as the major step towards improving teaching and learning in Africa. As an example, the TPACK has been used in South Africa [77–79], Ghana [80], and Tanzania [10, 81] as a framework for preservice teachers' professional development to integrate technology in mathematics and science teaching, respectively. Leendertz et al. in [77] indicated that TPACK of mathematics teachers contributes towards more effective Grade 8 mathematics teaching in South African schools. Chigona [79] applied the TPACK model to understand why, given the deployment of ICTs for teaching and learning in teacher education, the new teachers remain underprepared to teach with ICTs. Moreover, Janet and Oludayo [78] addressed the nature and context of Computer Application Technology (CAT) and teachers' procedural, functional, and pedagogical content knowledge (PrFPACK) in an ICT-enhanced classroom at 11 government Further Education and Training (FET) colleges in South Africa.

(1) *Technological Knowledge (TK)* refers to the knowledge about various technologies, ranging from low-technologies to digital technologies used in educational contexts such as the Internet, digital video, interactive whiteboards, and software programs. Most importantly, TK covers the ability to adapt to and learn new technologies [73].

(2) *Content Knowledge (CK)* refers to the knowledge or specific nature of a discipline or subject matter. This varies greatly between different educational contexts (e.g., the differences between the content of primary school math and graduate school math). Teachers are expected to have knowledge and master the actual subject matter that is to be learned or taught.

(3) *Pedagogical Knowledge (PK)* refers to the methods and processes of teaching and includes knowledge in classroom management activities, assessment, lesson planning development, and the role of student learning and motivation [74].

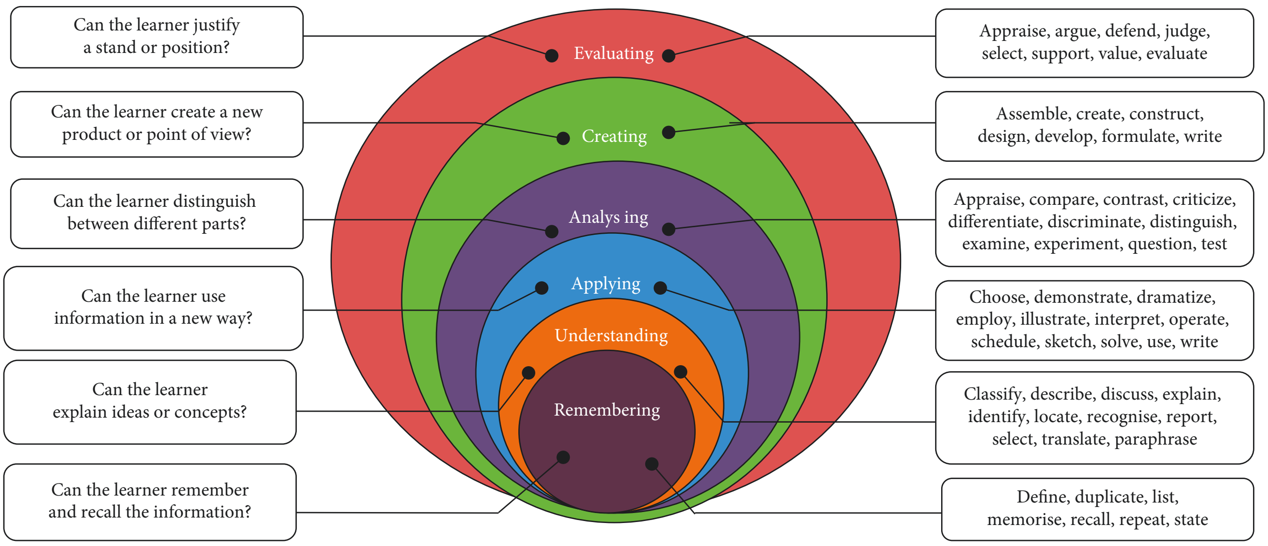

Figure 6: The revised Bloom's taxonomy for educational learning.

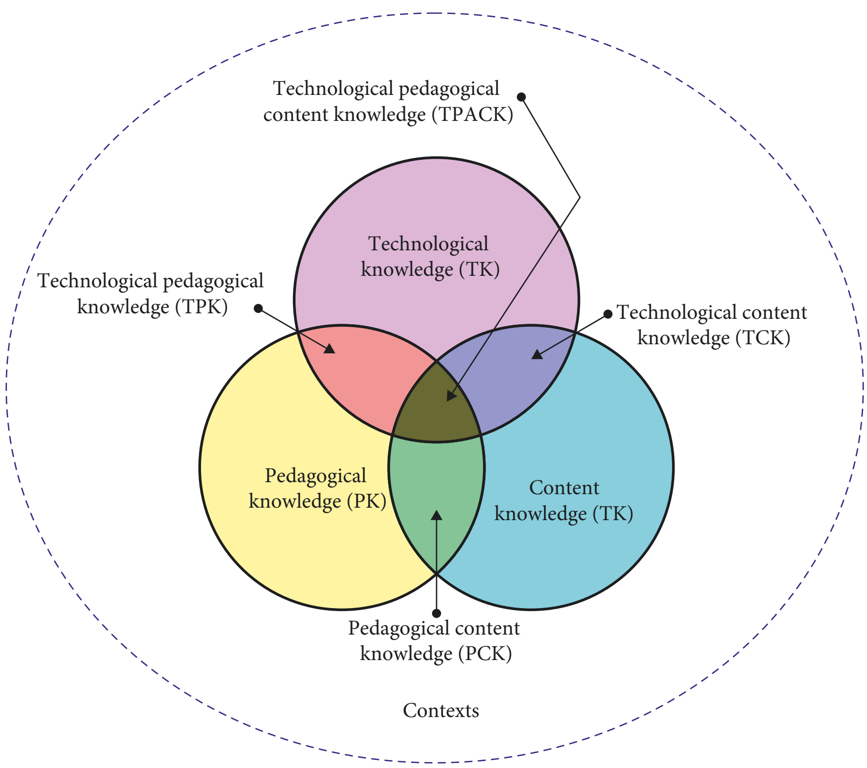

Figure 7: The components of the TPACK framework.

(4) *Pedagogical Content Knowledge (PCK)* refers to the content knowledge that deals with the teaching process [75] and is different for various content areas, as it blends both content and pedagogy with the goal being to develop better teaching practices in the content areas. For example, the teaching of a graduate level art appreciation seminar is different from teaching speaking skills for a foreign language where student-centred activities are required to engage students in meaningful and authentic communicative tasks [67].

(5) *Technological Content Knowledge (TCK)* refers to the knowledge of how technology can create new representations for specific content. It suggests that teachers understand that, by using a specific technology, they can change the way learners practice and understand concepts in a specific content area. For example, today, visual programming software

Table 3: Models for integrating ICTs for teaching and learning in education system.

Model	Focus area	Elements/objectives/dimensions
Bloom's taxonomy	Classifies educational objectives structure and curricular activities	A progression from recalling facts to producing new and original work
TPACK framework	Emphasizes key knowledge elements required for teaching and learning with technology	Technological pedagogical content knowledge: the TPACK describes what teachers need to know to effectively integrate technology into their teaching practice
NIMB framework [71]	Describes the ways in which ICTs can be used in teaching and learning, based on integration of a number of models	The effect of notions of learning, ICT in Education, and models of learning design on the progression of learning as described by Bloom's taxonomy
UNESCO framework	Uses ICT and online technologies to provide ongoing support for teachers	Design programs based on what we know about how ICT can support learning
SAMR model [20, 72]	Redefining how teaching and learning should be carried out using ICTs to perform tasks that cannot be accomplished without technology	Presenting a guide when moving from substitution to redefinition of learning tasks and to switch from enhancement to transformation while exploring the massive opportunities ICTs have on teaching and learning

NIMB = notions of learning, ICT in education, model for learning design, and Bloom's modified taxonomy framework; SAMR = substitute, augmentation, modification, and redefinition.

now allows even primary school students to pick up programming by designing and creating digital game.

(6) *Pedagogical Knowledge (TPK)* identifies the knowledge that makes teachers to understand what technology can do for certain pedagogic goals and enable them to select the most appropriate tool for the specific pedagogical approach [67].

(7) *Technological Pedagogical Content Knowledge (TPACK)* refers to the knowledge of each of the bodies described above, required by teachers for integrating ICTs into their teaching in any content area. Alone, each of the constituent bodies of knowledge that comprise TPACK represents a necessary and an important aspect that should be integrated for teaching and teaching. However, effective teaching is much more than each of the pieces (TK, PK, and CK). It is worth mentioning that for the teacher with TPACK, knowledge of technology, pedagogy, and content is synthesized and put to use for the design of learning experiences for students [76].

Ayoub [82] investigated the role of activity-based learning using TPACK among preservice science and mathematics teachers at the Dar es Salaam University College of Education (DUCE), Tanzania. Ayoub et al. further adopted the TPACK model in [81] to investigate on how ICTs can be used in science and mathematics teacher education in Tanzania. In relation to TPACK and SAMR models, Patrick et al. [10] assessed the impacts of TPACK and SAMR model characteristics related to the technology use planning, classroom ICTs integration, and redesign of learning tasks. However, based on the identified challenges such as lack of competencies on pedagogical ICT applications, the authors recommend that African governments should work on a harmonized ICT in education integration framework that considers the existing opportunities and challenges facing teacher training systems.

5.2.3. UNESCO ICT Competency Framework Standards for Teachers (ICT-CST). The UNESCO framework shown in Figure 8 covers 15 skill areas for teachers in five educational domains and 3 progressive levels, namely, technology literacy, knowledge deepening, and knowledge creation. It also promotes a teacher development model for effective ICT integration and improved teaching across six education system domains [39, 83], namely, *Policy and vision, Curriculum and Assessment, Pedagogy, ICT, Organization and Administration*, *and Teacher Professional Development* The intent of the ICT-CST is to provide education policy makers with tools that they can use to craft ICT-based education reform and teacher professional development to support economic and social development goals. Generally, the objectives of the ICT-CST are (1) to extend teachers' professional development so as to advance their skills in pedagogy, collaboration, leadership, and innovative school development using ICT, (2) to provide a basic set of qualifications that allow teachers to integrate ICT into their teaching and learning, to advance student learning, and to improve other professional duties, and (3) to harmonize different views and vocabulary regarding the uses of ICT in teacher education [83].

Looking at Kenya and Tanzania as a case study, the ICT professional development strategies and various programmes describe, in broad terms, national and local efforts for building teacher ICT capability, from basic literacy skills to ICT use in management and administration and to content development and pedagogical integration of ICT in practice [84]. In 2013, the Global e-Schools and Communities Initiative (GeSCI) [85], in partnership with the MasterCard Foundation and in collaboration with the Kenya and the Tanzania Ministries of Education, introduced officially the globally benchmarked UNESCO ICT-CFT into the partnership teacher development project mainly for Strengthening Innovation and Practice in Secondary Schools (SIPSE) in Kenya and Tanzania.

The SIPSE project was conceptualized to enhance teacher capacity in ICT competencies and skills to teach

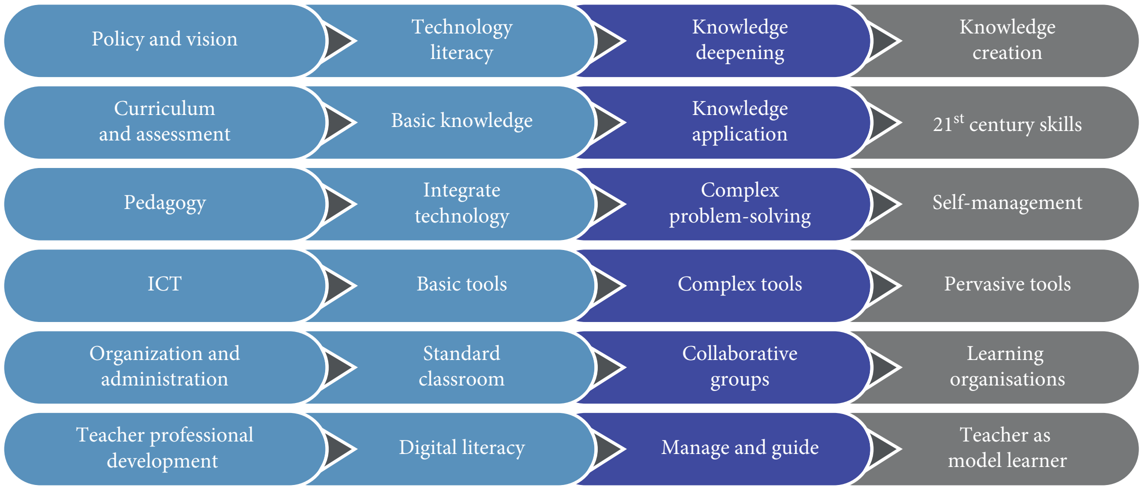

Figure 8: UNESCO ICT competency standards for teachers.

Table 4: A summary of benefits of an ICT competency framework for teachers in Africa.

Competency level	Advantage/benefits
Innovation at systemic level	A competency framework in the SIPSE can focus ICT integration on transformative practices at the systemic level in education. This will lead to changes in the organisational and structural features of ICT course provision in both preservice and in-service
Innovation at classroom level	A competency framework in the SIPSE can focus ICT integration on innovative and transformative practices at the classroom level of STEM teaching and learning where technology integration changes content as well as pedagogy (e.g., what students learn as well as how they learn)
Confidence in course materials	The Ministry, partners, and course stakeholders can be confident in course development and materials that are aligned to agreed and transparent ICT teacher competency standards
Policy awareness and transformative teachers	The framework embed school, district, and national policy in ICT integration by applying it in their daily work and engaging with students in innovative and exemplary practice Standards

STEM subjects in secondary schools for twenty-first century context, and to increase access to, and quality of the teaching and learning materials. It is worth mentioning that the adoption of the UNESCO ICT-CFT in SIPSE presented a number of advantages for promoting the innovative and transformative practices that underpin the SIPSE project [84] as shown in Table 4.

As a follow-on activity, the ICT-enhanced teacher standards for Africa (ICTeTSA) was conceptualized and initiated by UNESCO International Institute for Capacity Building in Africa (IICBA) in 2009 as one of the strategies of building the capacities for strengthening teacher development in Africa. Again, the ICTeTSA expects teachers to have and demonstrate the knowledge, skills, and attitudes composed of subject matter, pedagogy, and technology in order to help their students learn better in a given subject area in the twenty-first century across the continent.

Different from the above ICT models developed by international bodies or organizations, there has been a tremendous effort from ICT researchers across the continent to develop models for integrating ICT into teaching and learning. Asabere et al. [62] proposed an Awareness Incentives Demand and Support (AIDS) model in Technical University Education in Ghana. The AIDS model depicts how different ICTs can be integrated in tertiary education for effective teaching, learning, and research. Gyamfi [86] developed a technology acceptance model as an approach for Ghanaian preservice teachers' readiness for computer use. Benjamin et al. [87], introduced a large-scale instructional technology in Kenya as a way of changing instructional practice and developing accountability in a national education system. A model for evaluating and measuring the impacts of e-learning systems on students' achievement and quality of education in higher learning institutions in developing countries is proposed by Hadullo [88] and Kisanjara et al. [19].

5.3. Summary and Lessons Learned. As summarized in Table 3, it is evident that there is a holistic and comprehensive effort to include ICT infrastructure enhancement, development of innovative models/frameworks for ICT use, and integration in schools and large-scale professional development within and across African countries. It is worth noting that the continent is pushing forward an effective integration of ICTs into teaching and learning using contemporary ICT pedagogical approaches and the utilization of the appropriate technological tools at appropriate learning environments. This could enhance a process that creates value in the learner's ICT-based education, such as remembering, understanding, applying, evaluating, and creating as well as facilitate/inspire student learning, innovation, and creativity as envisaged in the ICT-enhanced teacher standards for Africa and the UNESCO ICT-CFT. The key message from these models is that ICT is relevant within education as a means of supporting a progression of learning and is best employed in support of transforming and value creation process in teaching and learning in STEM subjects. However, a random provision of access to ICTs within the classroom will not necessarily make a difference. It is therefore important to define and measure the progress of the use of ICTs in the educational process in each instance where technology is deployed.

6. ICT Platform Deployment for Service Delivery in Rural Areas

6.1. ICT4E Living Labs and Innovation Spaces in Africa. ICTs have power to connect or provide access to poor people in remote rural villages [89]. In African context, living labs (LLs) (living lab is defined as an open innovation environments in real-life settings, in which user-driven innovation is fully integrated within the cocreation process of new services, products, and societal infrastructures) paradigm has emerged primarily to act as a catalyst to address complex challenges in education whilst working towards developing the socioeconomic and research vision of the African Science, Technology, and ICT Innovation (STI) landscape. As pointed out in [90], LL is a power to create an innovation platform where academia, industry, students, and other stakeholders can cocreate new ideas and concepts that can support their teaching and learning, as well as improve their ICT skills in a quest to address challenges [91, 92]. The LL is aimed at creating interdisciplinary spaces where learners or students can cocreate and prototype solutions to challenges (for example those related to ICT4E) and incorporate ICT research and development, with a core focus on human-computer interaction [91].

One of the key dimensions of LLs in African context is the rural community to leverage methodologies and networks to test new products and services, educational technologies, processes, business models, or ideas customized for their developments. The importance of LLs as catalysts of innovation was explored in the Second Action Plan (2011–2013) of the 8th Africa-EU Strategic Partnership (Science, Information Society, and Space) which identified a number of priority areas for public sector, private sector, and research community collaboration between Africa and Europe to complement investments in ICT infrastructure deployment by exploiting synergies between the EU 2020 Digital Agenda and the African Union (AU) ICT development frameworks [90]. Following this strategy of ICT innovation in Africa, various groups such as the AU Commission, IST-Africa national partners, World Bank, EU Commission, Living Lab Network in Southern Africa (LLiSA) [93], and European Network of Living Labs (ENoLL) [94] have been supporting the establishment of more LLs to address Africa's socioeconomic and developmental needs in STEM [95] subjects. The main objective is to provide full support in STI and ICT capacity-building initiatives for mass diffusion of ICTs and related services, as key enablers for poverty reduction, economic growth, social development, and regional integration [90] through education transformation. Again, sustainable LL networks across Africa are to remain as a tool that will enhance ICT research cooperation, local innovation, entrepreneurship, and wider socioeconomic and community development in STEM.

6.1.1. The Living Lab Model for Effective Engagement of ICT in Rural Education. The LL model is an ecosystem and a platform that enables community members in collaboration with other stakeholders in society (e.g., researchers/academia, public, and private sectors) to explore and cocreate new technologies for social and economic advancement [96, 97]. As stated by Mosuoe-Tsietsi et al. [98], the integrated LL model becomes favourable for collaborative relationships between the different sectors in society (researchers) in their efforts to initiate or support the development and sustainable engagement of ICT in development activities in rural areas. The role of researchers from academia is to design and create innovative ICT applications and services in close collaboration with the target users. As such, the model can be applied to all areas of science, engineering, and technology education to spur the social-economic development of the continent [90].

Figure 9 shows an integrated LL model for effective engagement of ICT in rural education in Africa. The model is primarily aligned with and driven by the strategic ICT4E research focus and mission of every African country. As indicated in the figure, based on the ICT4E research mission, each LL has to focus on specific objectives such as socio-technical feasibility or investigating the impact of ICT on emerging economies and user-focused design and development in science and engineering education [99]. It is imperative to mention that each LL has to continuously evaluate itself to ensure that it is still aligned to the main LL definition with its four dimensions (e.g., user-centred, open innovation, real environment, and multistakeholder components) [93]. Based on the defined ICT4E research context and appropriate ICT application area (e.g., teaching or

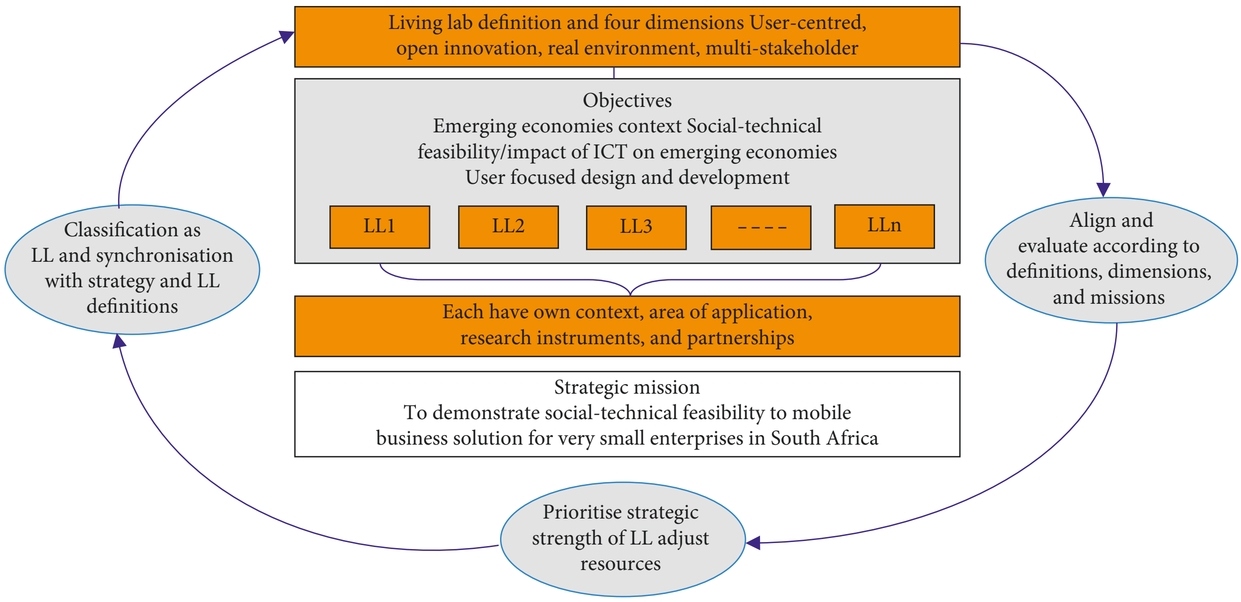

Figure 9: An integrated LL model for effective engagement of ICT in rural education in Africa.

learning), the different stakeholders that interact in particular environment have to be identified. As such, their roles need also to be defined within the ICT4E research context.

The associated ICT4E research instruments have to be designed in order to achieve and assess the goals of a particular LL in every African country. The generic model can be used to facilitate both the classification and synchronization of the various LLs. It further enables individual LLs to create their uniqueness given the context of ICT4E or ICT4D research needs. Coetzee et al. [93] narrated that such a cyclic approach should be followed where the LLs align and evaluate themselves but also to (bottom of Figure 9) prioritize the ICT4E strategic strengths of each LL and allocate resources to support the development and cocreation activities within their working ecosystem. This then feeds back (left hand side of Figure 9) to the LL definition. That way, synchronizing the LLs with the ICT4E or ICT4D strategy and definition is a constant cycle to ensure that all LLs do address important STEM issues within and across the continent [98, 100]. We present some examples of LLs from some of selected countries from eastern and southern part of Africa (Tanzania, South Africa, Mozambique, and Mauritius). We summarize a number of LLs and InnoSpaces across the continent in Figure 10. It is important to note that most of LLs and their network across the continent are introduced based on the model depicted in Figure 9.

6.1.2. Living Labs in East Africa. In Tanzania, the LLs emerged as a result of the IST-Africa LLs Workshops and IST-Africa Week 2012 that was supported by the TANZICT Programme. Some of the existing LLs in Tanzania include the Arusha Living Lab (EcoLab) (https://arushalivinglab.wordpress.com/), Elimu Living Lab [101] (Sengerema, Mwanza), Mbeya Living Lab (https://mbeyalivinglabb.wordpress.com/), Kigamboni Community Centre, (Dar es Salaam), RLabs Iringa, and Tanzania Youth ICON (TAYI) Living Lab (Zanzibar) [100]. In partnership with the Nelson Mandela African Institute of Science and Technology, the EcoLab is strongly focused in innovation and entrepreneurship as well supporting local primary schools and small and medium enterprises (SMEs). The Elimu LL is primarily focused on supporting education and vocational skills development, with a view to creating employment opportunities and capacity building. There is a strong focus also on continuing education, ICT skills, and social entrepreneurship for youth and women. While the Mbeya LL provides training focusing on leadership, entrepreneurship, ICT skills, and social media, the TAYI and Rlabs are focusing on youth empowerment, capacity building, creation of employment opportunities, ICT training, and outreach activities [100].

6.1.3. Living Labs in Southern Africa. This section describes some of the LLs in South Africa, Mozambique, and Mauritius as case studies of countries from the southern part of the continent. LLs in South Africa that have now been successfully running for several years include Siyakhula LL [96], Limpopo LL, Reconstructed (RLabs) [102], and Siyadala LL. The Siyakhula LL is primarily focused on ICT4D and action research activities. As such it acts as the field site from which the Telkom Centres of Excellence in ICT4D and distributed multimedia derive their research projects. Activities currently supported include computer training, a low-maintenance service-oriented telecoms infrastructure, e-service development for mobile devices, and establishment of an ICT solution provider to commercialize software prototypes developed [103]. The RLabs LL on the other hand utilizes a value-based model to develop and train people in disadvantaged communities in the use of ICT and social media (e.g. Facebook, Twitter, and others), focusing on using innovative ICT solutions to address social problems in communities [104]. The Siyadala is also focused on ICT4D,

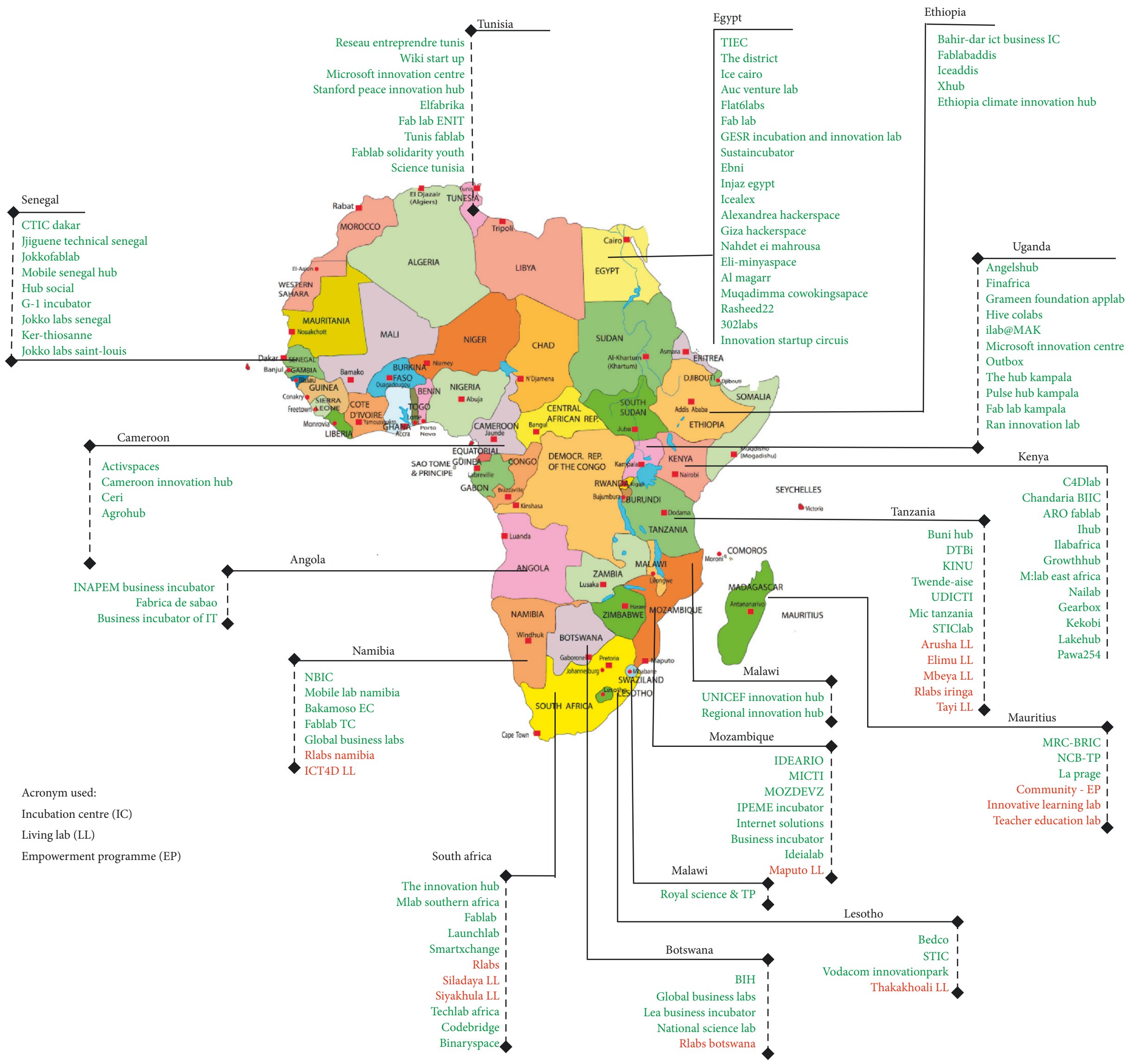

Figure 10: The landscape of living labs and innovation spaces in Africa.

capacity building, skills, and leadership development; thematic areas addressed include education and healthcare. Using LL methodologies as part of community engagement activities, a number of education-related mobile applications to date have been developed and tested based on local needs.

In Mozambique, the Maputo Living Lab [105] which was established in 2011 is mainly focused on building capacity by carrying out specialised ICT courses to students from universities of Mozambique and young professionals through summer schools, implementing research, and developing ICT projects that address local needs and supporting ICT enterprises. It is worth mentioning that the objectives and activities were linked and inspired by the government of Mozambique's strategic priorities in the areas of STEM education using ICTs. Similar to other countries, Mauritius is using LL approach within its Community Empowerment Programme (CEP) to build an ICT-capable society by enabling and sharing ICT knowledge and skills for community development and promoting development of local content. As of today, 270 regional computer clubs and a number of Public Internet Access Points (PIAPs) have been established to facilitate wider adoption of education materials via e-contents. The Innovative Learning and Teacher Education Living Lab (ILTELL) of the University of Mauritius (UoM) is primarily focused on improving and refinement of teaching techniques and the application of ICT tools in day-to-day practice. In collaboration with the Microsoft through its Partners in Learning (PiL) (the PiL Program provides government and education leaders with the local resources to deliver ICT skills training and curriculum leadership to primary and secondary teachers, school leaders, and students.) programme, the ILTELL promotes the integration and the use of ICTs in the classroom, with the main focus on primary and secondary education sectors.

6.2. ICT Tech Hubs and Innovation Spaces in Africa. The continued growth in mobile and Internet subscriptions in Africa is a clear indication that the Internet penetration will continue to rise to offer more competitive innovative products and services that cater for the needs of the growing population in the continent [106]. It is imperative to mention that, many of such innovation are happening in the ICT-based tech hubs and innovation spaces (InnoSpace) [107]. InnoSpace can be defined as physical or virtual environments that support, encourage, and spur innovation by transforming the ideas of the graduates and young entrepreneurs into real products. InnoSpace can include *Pre-incubators, Incubators, Innovation Centres, Entrepreneurship Centres, Accelerators, Science Parks, Research and Innovation Parks*, and to some extent, even relatively undifferentiated *Coworking Spaces* [104]. InnoSpace have increasingly been at the centre stage of economic development. This is notably through rapid technological advancement, facilitating speedy access of ideas and experiences, financial aid for students, collaborations among researchers, and prompt exchange of information.

ICT tech hubs or innovation hubs can be defined as organizations that aimed at encouraging development of mobile-focused ICT innovation: acting as startup creators, developing individual skills, and building networks of stakeholders within the ecosystem [108, 109]. An assessment done by infoDev [110], a World Bank program focused on innovation and entrepreneurship highlighted the importance of ICT tech hubs including providing strategies that align with the national ICT4E goals and drive policy makers to have a good understanding of the benefits derived from the innovation ecosystem for teaching and learning ICTs in all levels of education.

6.3. Summary and Lessons Learned. It is evident that there is a positive development and a clear commitment across African countries within different public sectors to establish InnoSpace and LLs as the necessary infrastructure in place that leverage ICT4E to support socioeconomic development, complimented by the priority given to STEM education in the continent. We note that the growth in the establishment of new LLs is significantly slower than for InnoSpace. From the sustainability perspective, it is obviously advantageous to colocate LLs and InnoSpace with research institutes and higher education institutions or innovation-oriented government agencies. Doing that way will facilitates the reuse of existing ICT infrastructure, equipment, personnel, and access to competent ICT mentors. Again, academic institutions can facilitate links between innovation practitioners and other networks within the wider ecosystem, including students and academics, as well as providing a unique source of funding to the hub organization or its incubatees.

While there are some positives based on the explanations above, common challenges still exist whether the location is urban, rural, or deep rural and whatever the relative level of socioeconomic development of the country. Some of the challenges that could be eliminated by the above deployment of LLs and InnoSpace include high level of youth unemployment [111] and significant educational gaps in some countries. In particular, with all existing LLs and InnoSpace, there is still a lack of access to appropriate entrepreneurship and ICT skill training to a large extent. In the case of InnoSpace, there are limited levels of differentiation and relatively high dependency on grants and funding by international donors. It is noticeable that while most LLs in African countries have a strong focus on transforming the STEM education using ICTs, such efforts tend to be more well tuned to local differences [104]. Generally, we note that the overall level of ICT4E and innovation related to STEM education activities across the continent have increased dramatically in recent years.

6.4. Mobile and e-Learning Platforms for HLIs in Africa. Mobile device ownership in Africa has increased rapidly in recent years [112]. This increased access makes mobile learning a useful way to reach a broader segment of learners who may have the capacity and desire to learn but are limited and have unequal access to classroom education. Mobile communications in Africa enable teachers, parents, and learners to share knowledge and develop stronger educational frameworks [113]. Throughout the world, HLIs are increasingly turning to e-learning to support and enhance their learning and teaching activities.

There are several mobile and e-learning platforms for HLIs in Africa. Figure 11, shows a framework for mobile learning based on 4 core challenges. For instance *Samaskull* e-learning platform in Senegal provides interactive massive open online courses (MOOCs) and small private online courses (SPOCs) for those who prefer one-on-one private lessons and enable users to access database of unlimited educational materials. The educational platform in Kenya, *Eneza* (http://enezaeducation.com/), enables virtual tutor and teachers to track and assess students' knowledge using common form of technology like the mobile phone. In this platform, students access unlimited education contents through learning, interacting, playing, and exploring. The *OkpaBac* platform delivers high-school students with tremendous educational resources to prepare for the Baccalaureate exams. The tests are crucial as it determines university admission for thousands of students in Togo and across the western Francophone coast of Africa. Praised as one of the Africa's top coding schools, *Moringa School* (https://moringaschool.com/) is an immersive coding school in Nairobi, Kenya. At Moringa, students go through an accelerator programme to improve their technical skills, learning different programming languages such as Javascript, HTML, CSS, Ruby on Rails, Android L, and User Interface and UX Design. *Ubongo* significantly improves school readiness and learning outcomes for kids and also promotes social and behavioural change for kids, caregivers, and educators in Tanzania. *Daptio* (https://dapt.io/) and a Nigerian platform *sterio.me* that enable students to access material and lessons they listen outside the classroom are among other mobile platforms used in Africa. *Daptio* uses artificial intelligence to help students, mentors, and teachers to understand the proficiency level of each student. The goal is to

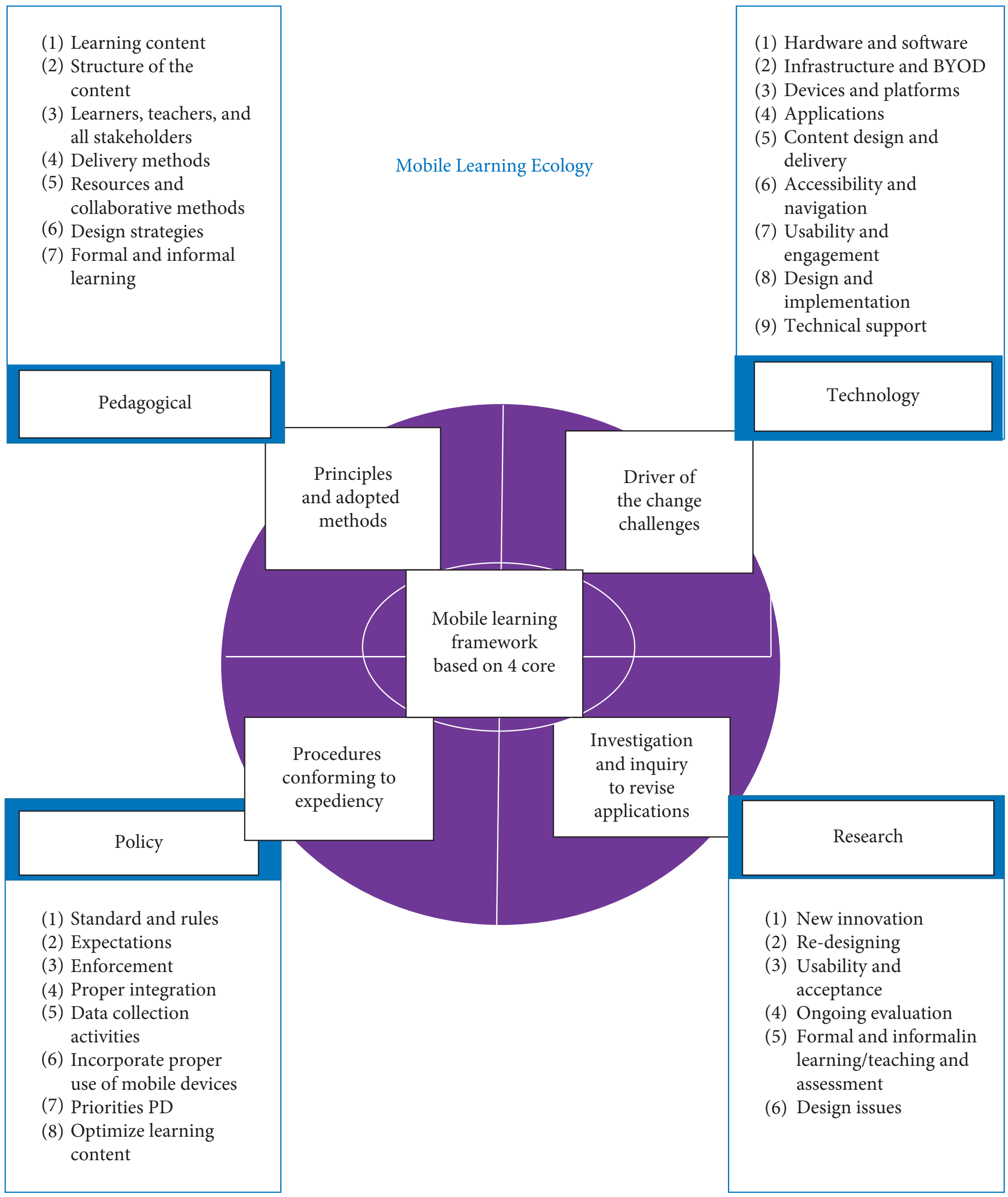

Figure 11: A framework for mobile learning based on 4 core challenges.

find a model that allows students to receive the right content, leading to a more tailored education and higher grades.

The use of mobile devices outside the classroom for learning in Africa is presented in [113] where teachers use cameras, videos, YouTube, and maps to acquire or disseminate knowledge. The authors in [114] assessed the potential and versatility of m-learning for mobile education in institutions of higher learning in South Africa. Using a policy analysis perspective, Baldreck et al. [115] explored the applicability of mobile-centric services in teaching and learning. Haji et al. [116] discussed some of the opportunities and challenges in using mobile phones as learning tools for higher learning students in developing countries. The identified opportunities include (a) student-centred learning encouragement as students can access resources according to their needs rather than their teachers or other peoples' involvement and (b) mobility and increased engagement and motivation of learning behaviour. Tumisho et al. [117] discussed the development of a mathematical computer-assisted learning mobile application that integrates a text-to-speech synthesis module for South African low-resourced languages. It is worth noting that most of the m-learning approaches highlighted above follow the framework shown in Figure 11.

7. Opportunities and Future Direction of ICT4E Research in Africa

This section presents opportunities and future direction of ICT4E across Africa. Despite the current move in African education system and existing challenges, there are still a lot of opportunities that the government, learning institutions, teachers, and students can still employ for integrating ICTs in education across the continent, especially using some of recent advancements of educational technologies such as the augmented or virtual reality or mobile computing for education paradigms.

7.1. National ICT Research Capacity and Priorities for Education. While there is a significant improvement in some areas of ICT4E, it would be of importance if African countries can explore more in the following research areas: e-infrastructures, Cloud Computing/High-Performance Computing for Education (CC4E) [118], Mobile Computing for Education (MC4E) [119], ICT for Creativity and Learning, Ubiquitous Learning of Education, Education via Social Media and Innovative teaching strategy (e.g., Gaming4education [120]), and Flipped teaching and classroom. For CC and high-performance computing (HPC) for education, intensive research is needed so as to improve the industrial development and education service delivery possibly using data analysis, business intelligence, data mining, and warehousing. To this end, we recommend all HLIs in Africa to participate in the overall prioritization of national ICT research regarding education provisioning across the continent. A comprehensive research regarding to MC4E is also needed for supporting student and lecturer collaboration and providing distant communication, increased student participation and engagement, facilitating authentic learning and reflective practice, and fostering learning communities.

More research on ubiquitous learning of education and education via social media (Facebook, Twitter, and Instagram) where most of university and secondary school students use on a daily basis is needed. As such, innovative teaching strategies that employ digital technology via social media such as Facebook are needed to enhance team-based learning outside the classroom and complement face-to-face lessons [121]. Yet, novel approaches of ICT that encourage creativity and learning provide lifelong learning, and the creation of a knowledge society and knowledge economy are needed across the continent. While MC4E research and CC4E research are very important, we believe that, game-based learning [122] and social media are innovative and effective tools in a student-centred learning environment that can enrich students' *educational experiences*, increase the relevance of the subject matter, and encourage students to collaborate effectively with their peers in the classroom/faculty context.

7.2. Emerging Technologies in Education in the Era of Big Data for Africa. Nowadays, the trend of education and technology development is changing on a huge scale, especially, on the next big research topics including *Internet of Things (IoT), Information Centric Networking (ICN)* [123, 124] *for universal Internet access and education* [125], *big data, ubiquitous learning, Flipped teaching and classroom, emerging technology (e.g., Artificial Intelligence (AI), Augmented/Virtual Reality (A/VR), and Mixed Reality (MR)), Wireless sensor networks and education* [126–130], *Blended education with HiTech, Game-Based Learning* [131], and *social media*. IoT and big data are two big things that many countries are working hard to develop for their economy and industry as well education. Education is the foundation of a country's economic progress. Therefore, emerging technologies such as AI, A/VR (virtual reality is a model of reality with which a human can interact, getting information from the model by ordinary human senses such as sight, sound, and touch and/or controlling the model using ordinary human actions such as position [132]), and strategies in education in the big data era have to be pioneered for the new era of education provision in Africa. Except ubiquitous learning and social media as discussed above, until now relative few studies explore these things especially in educational research discipline in Africa. Technology-assisted teaching and learning have been gradually paid much attention and their effectiveness has been empirically verified for student outcomes in educational research or teaching practice [9, 133]. Applying the above big things into technology-assisted teaching and learning should be the future hot topics for educational research in Africa.

For example, several studies indicate that VR provides students with an enriched learning and training experiences to study [134, 135]. Key advantages of VR as reported in the UNESCO report of VR for education in Africa include [136] to allow (a) the user to interact with the learning material in a more natural way, (b) the learner to build a comprehensive and natural "mental model" of the subject matter [137], (c) the user to navigate easily through the information space, (d) learners to overcome literacy barriers and facilitate a "*look-see-do*" mode of learning [138], and (e) active participation within the virtual world as well as motivating students to learn. VR can lower the cost of infrastructures in Africa when used as a substitute of school laboratories [139].

It is worth noting that the multimedia-based new learning environments which are essential in developed countries are even more needed in the developing world particularly in Africa. It is therefore important that these learning cutting-edge technologies should not be imported but should be locally produced in order to address the wide range of learning needs of Africa's excluded majority and disadvantaged society, whilst taking full account of local literacy, language, and cultural issues in the education settings. However, despite the potential benefits that can be derived from the application of A/VR in African learning, there are a number of challenges that still need to be overcome. Such challenges include issues related to equity and access to ICT facilities but also to the cost of developing content for the African learning environment.

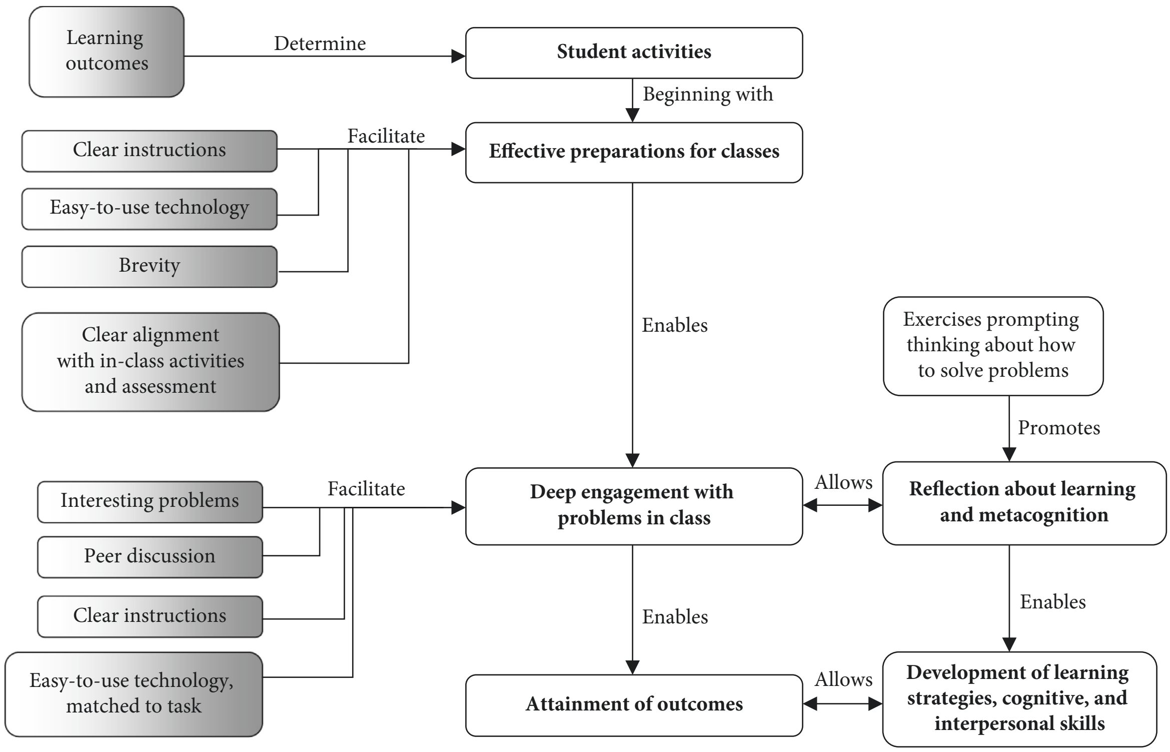

Figure 12: A concept map of flipped learning and classroom (adapted from [141]). *Note.* Student behaviour is shown in bold; instructor behaviour is shown in italics.

7.3. Flipped Learning, Ubiquitous Learning, and IoT-Based Education in Africa. Flipped learning (FL) has emerged as a unique approach which reverses the role of homework and classroom activities. FL is a pedagogical approach in which direct instruction moves from the group learning space to the individual learning space, and the resulting group space is transformed into a dynamic, interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter [140, 141]. In the traditional classroom teaching, the teacher delivers new learning to the students face-to-face. As such, students listen, interact, take notes, and then consolidate new knowledge during homework or follow-up tasks. In FL, the students acquire knowledge at home (via watching videos made by the teacher) and practice the skills in class where the teacher can easily monitor and correct the student. This approach provides a dynamic and interactive learning environment where the educator guides students as they apply concepts and engage creatively in the subject matter [140]. In another way, a flipped classroom [141] is an instructional strategy and a type of blended learning that reverses the traditional learning environment by delivering instructional content, often online, outside of the classroom.

It is the time for African countries to adapt this approach that enables instructors to incorporate a variety of teaching strategies and learning activities while engaging students more frequently and more deeply than traditional lectures [141]. As shown in Figure 12, the flipped classroom approach creates a more learner-centred environment that increases student engagement, encourages critical thinking, and improves student attitudes [142]. It also presumes a thoughtful approach to selecting learning content and designing learning environments that support knowledge construction by students. It is imperative to mention that when students prepare before class by watching the instructor's videos, they can learn at their own pace because they are able to pause, rewind, and replay the videos at their will. Again, repeated exposure to the learning materials and resources strengthens and deepens the students' understanding of the material in Africa.

The knowledge can then be applied in a richer scope during in-class activities. As stated by Hamdan et al. in [143], FL frees instructional time, consequently allowing for more dynamic and interactive classroom learning experiences, deep engagement with problems in class, reflection about learning and meta-cognition, development of learning strategies, cognitive and interpersonal skills, and effective preparation for classes as illustrated in Figure 12 and by the four components of the four pillars of F-L-I-P model (e.g., flexible environment, learning culture, intentional content, and professional educator) [140, 144]. In the context of Africa, Tanner and Scott [142] employ a flipped classroom approach to teach system analysis, design, and implementation at university level. The overall observations from this study is that the flipped classroom approach had a positive impact on students' attitude to learning, level of understanding, ability to apply concepts and engagement. However, the limitation of this approach is in-line with a reluctance to take charge of their own learning and inability to engage in group discussions. In [145, 146], a multimodal learning is used that incorporates self-designed multimedia study material within a flipped classroom approach for specific nutrition and accounting courses in South African context.

The Internet of Things (IoT) on the other hand is promoting changes in higher education, such as in teaching, learning, management, experiment, and training as well as school campuses [147]. With the development of IoT, the prospective application in higher education lies in the three aspects, namely, (a) students' progressive evaluation, (b) integration of current teaching platforms, and (c) development of educational middleware [148]. This change provides increased convenience for students and makes the teaching process more effective for instructors and university professors. The flow in connected devices and technology means that instructors and professors can focus on the actual learning that is more useful to the students rather than perform the routine task [149]. In addition, IoT has the ability to increase the learning experience by providing for real-time and actionable insights into student performance. Nowadays, students particularly in university are gradually moving away from textbooks to new technologies such as tablets and laptops. The advanced e-learning applications allow students to learn at their own pace and have an identical learning experience in classrooms and homes [150], which rises progression and satisfaction rates, and instructors can deliver one-to-one instruction and persistent student assessments [151]. Moreover, through IoT technology, professors can collect data about students' performance and then determine which ones need more care and attention. This data analysis also helps instructors accurately change plans and methods for future classes. Additionally, connected devices can allow instructors to do dynamic classroom.

For Africa, the adoption and implementation of IoT would allow better operational efficiency in all learning environments especially in rural areas. IoT can support classroom instruction by improving learning setting, enhance learning resources, improve methods and techniques of learning, raise management efficiency, and save costs. IoT also has many opportunities for STEM subjects, such as computer programming. It is therefore easy for policy makers and researchers across Africa to foresee how IoT capabilities can be used in STEM disciplines, such as robotics, computer science courses, etc. This is all in the potential of the IoT.

Although main IoT technologies are so far unclear, the point certainly is that a lot of contents are the outcome of new development phase. Considering the demand of more professional research, setting the IoT major is relatively easy and applicable for graduate students in Africa. Different colleges and universities across Africa have to explore the appropriate approach to start using IoT in teaching and learning process according to their own characteristics. The system approach and courses content need to be progressively established and improved in all African education environments. Since IoT is achieving the unity of the virtual world and that of the physical world, many new training methods and cross-cutting areas will be generated in the future [152]. Moreover, the future IoT-based education provision in Africa can be shaped by experts and leaders in higher education sector and by educating the students across the continent [23]. That way, the development within higher education systems will visualize, improve, and lead to new innovative ways of teaching and learning in Africa. Therefore, we feel that higher education sectors in Africa must work with business and industrial sectors to shape and build the future of an IoT-based education and the overall continent economy. Furthermore, higher education sector, especially universities across Africa, has the opportunity to lead the future of IoT technologies by designing courses for technical and business leaders and by facilitating students and researchers work to build new business methods that leverage IoT technologies in a multidisciplinary way.

7.4. Education Provision through Virtual and Remote Labs. For Africa, laboratory experimentation would play an essential role in STEM education. Virtual and remote labs reduce the costs associated with conventional hands-on labs due to their required equipment, space, and maintenance staff [153]. Furthermore, they provide additional benefits such as supporting distance learning, availability, improving lab accessibility to handicapped people, and increasing safety for dangerous experimentation [154]. A remote lab offers the user (student/teacher/worker) the opportunity of conducting a real experiment using the Internet as the communication channel [155]. That is, the eyes and the hands of the user will be the Internet and the interface. So, the user can access the experiment from everywhere at every time; he needs only an Internet connection to perform the experiment. Instead of going to the university to program a robot (hands-on lab or classical lab), the student could access the remote lab to write the program in the web and to see the behaviour of the robot using a webcam. Today, Go-Lab-Africa is deploying and contextually engaging digital STEM educative content in Africa by adapting the proven Go-Lab ecosystem to local needs [155]. The Go-Lab (https://cordis.europa.eu/project/rcn/213186_en.html) as developed in the FP7 Go-Lab project and implemented in Europe in the ongoing 2020 Next-Lab project is to adapt and implement the learning ecosystem in Europe and first piloting in 3 African countries and then scaling up to more users and more countries. The Go-Lab-Africa will offer students rich, challenging, and socially embedded experiences that shape their skills and knowledge in STEM subjects.

7.5. Summary and Recommendations. Based on the state of the art, the usage of ICT4E models in the majority of African counties has proved to be an organic approach that can provide school-based training that would support the evolution of each teacher's classroom, school, and region, as well as the training of the ICT teacher trainers. Such training can be provided largely on a face-to-face basis for teachers in a sequence of three modules: (a) teachers' own professional use of ICT; (b) management skills relating to use of ICT directly with pupils when teaching; and (c) evaluating the impact of ICT on learning. On top of that, there could be an additional module (d) that enables recommended teachers to become trainers.

We further note that the fundamental issues that need to be addressed across the continent for a coherent and effective ICT integration in education include (a) the duplication of effort and the lack of integration as well as coordination in many ongoing ICT activities and (b) national ICT strategies that have been led primarily by telecommunications interests and not paid sufficiently detailed attention to the real potential for ICT to deliver on development agendas and to transform the processes of teaching and learning using ICTs in Africa. While some countries have had a good progress for the past 10 years, indeed there remains considerable misunderstanding across the continent about the potential of ICTs in transforming the education systems. Generally speaking, infrastructure provision and delivery mechanisms for both initial and in-service teacher education vary across Africa, and these are the major hindrance of ICT integration in AES. It is therefore worth stressing that local solutions are needed, thanks to the recent establishments of LLs and InnoSpace in African countries. In order to achieve a transformation in AES, this paper recommends the following to ICT policy makers and the African governments.

7.5.1. Shaping the Implementation of ICT Strategies within the Context of Infrastructure Provision. African governments should invest more in ICT resources in all levels of education systems, primary to HLIs. As such blended solutions for the use of ICT in teacher training need to be thought carefully in specific national contexts so that teachers and students can have access and use cutting-edge ICT resources for their training in different media (e.g., video, computers, the Internet, MC4E, and more traditional forms of classroom-based learning) depending on the infrastructure available in schools/universities [9].

7.5.2. Strategic Leadership, Management, and Integration with Overall National ICT4E Strategies. As pointed out by Barakabitze [6], ICT training programmes for students/teachers and curriculum development need to be owned at a national level by African governments as a whole and led by the relevant Ministry of Education and ICTs.

7.5.3. Project Ownership and Involvement of Relevant ICT4E Stakeholders and Potential Partners at an Early Stage of Projects/Programmes. We contemplate that it would be good if representatives of ICT teachers themselves (e.g., from Teaching Unions) and those involved directly in teacher education, HLIs, providers of hardware and software, and ICT curriculum developers are involved in ICT4E projects.

7.5.4. Continuous Preservice and In-Service Training. Blended solutions and consistent preservice and in-service training are seen as the best approach to support teachers, with elements of the use of ICTs. As such, the use of new ICTs should build on local practices and experiences particularly through the use of multimedia computers, mobile learning, and the Internet at large which are envisaged as being particularly important in the delivery of African in-service teacher training programmes today.

7.5.5. Sustainability through Community-Led Agendas and Awareness Raising Workshop. African Governments should provide hands-on experience workshops on the use of new ICTs. This is crucial at an early stage in the development of strategies for the use of ICT in teacher training. That way, it would allow government officials and teachers, administrators, heads of teacher training colleges, and HLIs to grasp the true significance of the AES transformations using ICTs. Effective and sustainable incorporation of new ICTs in teacher education in Africa will become possible with support from the local community. As argued by Unwin, this complements the existing commitment of the governments and civil society organizations and private sector at a macroscale in global initiatives, to ensure that ICT4E initiatives are appropriately designed, implemented, maintained, and resourced in African countries.

8. Conclusion

This paper highlights ongoing initiatives and positive shift across Africa in using ICT to improve the quality of teaching and learning through activities such as intensive ICT skills training to teachers, increase in ICT equipments and applications in schools, and emergence of living labs and innovation centres. Even with such improvements, there is still enormous work to be done in Africa's education system to ensure that all countries uniformly meet the 2030 United Nations Sustainable Development Goal number 4, which is to "*Ensure inclusive and quality education for all and promote lifelong learning.*" As the world undergoes a fast pace of technological advancement, we believe that Africa must be flexible enough to leverage the opportunities that emerge with the dynamism of technology. The future of ICT4E in Africa hinges on embracing new technologies that will (a) improve motivation and enhance student engagement, (b) promote self-regulated and collaborated learning, and (c) enforce challenge-driven and human-centred learning.

As such, we first provide some of the challenges of integrating ICTs in Africa education systems. We describe key past and current ICT initiatives supporting the adoption of ICTs in schools using a number of case studies in sub-Saharan Africa. We further present new various ICT for education models, as a transformational approach towards integrating ICTs in AES. Moreover, we provide various ICT platforms deployed for education service delivery in disadvantaged African society (e.g., rural areas) including living labs (LLs) and innovation spaces (InnoSpace) across the continent. Finally, we highlight our main findings and observations in terms of opportunities and future ICT for education research directions in Africa. As our final remarks, we recommend to ICT policy makers and the overall governments of Africa on five major areas including (a) shaping the implementation of ICT strategies within the context of infrastructure provision; (b) strategic leadership, management, and integration with overall national ICT4E strategies; (c) project ownership and involvement of relevant ICT4E stakeholders and potential partners at an early stage of projects/programmes; (d) continuous preservice and in-service training for ICT teachers; and (e) sustainability through community-led agendas and awareness raising workshop.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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