Digital Education Index for Developing Countries Framework: Evaluation of the Deployment of Digital Education in Kenya

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The Digital Education Index for Developing Countries (DEIFDC) is a compound index considering nine different variables grouped in three main levers that have been researched relevant to assess the overall state of readiness of Digital Education deployment in a developing country. In the case of Kenya, despite major efforts on introducing Digital Education in public schools since the launch of the DigiSchool program in 2016, the application of the DEIFDC, with a value of 0.576, demonstrates insufficient deployment in all main levers largely due to poor broadband infrastructure, lack of trained teachers and poor literacy and numeracy performance of Kenyan students at early stages of education. Kenya has become an ICT hub for all the African region, with inspiring results in the usage of digitalised services. The experience acquired has also favoured the Education sector that has launched mobile applications and education platforms, especially during the Covid-19 pandemic; however significant social, geographic, and cultural differences arise in the study and bring down the overall performance of Digital Education deployment.

Keywords: digital education, compound index, developing countries, digital economy, social impact

INTRODUCTION

Education is a human right (United Nations, 1948; Lee Dr, 2013) and one of the most potent instruments for development as it contributes to reducing poverty and improving health, equality and peace (Alvarado, 2019). For individuals and societies, education promotes employment, poverty reduction, economic growth and social cohesion (World Bank, 2020). Based on the Incheon Declaration (Ainscow, 2016), adopted at the World Education Forum in 2015, the Agenda 2030 for Sustainable Development Resolution approved by the United Nations General Assembly included the specific development goal number 4 (Boeren, 2019) to ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. Digital Education appears in six out of the ten SDG4 targets (United Nations General Assembly, 2015), especially target 4.4, which is described as substantially increasing the number of youth and adults who have relevant skills, including technical and vocational skills, for employment, decent jobs and entrepreneurship.

Before the pandemic crisis, in low and middle-income countries, 258 million children were out of school, and 53% did not reach a minimum literacy and numeracy level (Rogers et al., 2020); moreover, in

sub-Saharan Africa, the learning poverty rate was as high as 88% (UNESCO, 2017). The school closure originated by the Covid-19 pandemic aggravated the global learning crisis, with 1.6 billion students losing access to their classrooms (UNESCO, 2020), and it has been estimated that as many as 9.7 million children will never return to school (Wagner et al., 2020). National Governments worldwide have tried to promote learning continuity through the usage of online platforms, radio and television; however, the deployment in developing countries was scarce and reliant on families' resources.

In Kenya, the Ministry of Education responded to the Covid-19 lockdown by promoting the usage of digital platforms and media resources (Uwezo, 2020) to be able to keep up with the lessons during the school closure, especially at higher stages of education (Ngari et al., 2020). However, only 25% of the 17 million Kenyan students could follow up with digital learning due to lack of electricity access (Ministry of Energy, 2019), availability of digital devices (Ndung'u, 2019), internet fares expenditure (Al-Samarrai et al., 2020) and lack of personalised content for rural contexts and slow learners (Mariara et al., 2020; Wepukhulu, 2019)

Kenya emerged as an African ICT hub on innovative technologies after the implementation of mobile transfers services in 2007, and new mobile products continuously emerge. Most bills from public and private institutions, from electricity, water, insurance, travel and tax contributions, are paid via mobile phone platforms (Githinji et al., 2014). Following its National Broadband Strategy, Kenya has made tremendous strides in promoting the uptake of ICT services in all industries by ensuring high-speed and reliable broadband networks, local content and regulatory frameworks. For example, mobile cellular subscriptions constantly increase and are above 114 per 100 users. Nevertheless, the digital divide must be addressed if all Kenyans are to participate actively in the knowledge economy. For example, in some parts of the country, people still have to walk more than 2 kilometres to access mobile cellular signals, especially from Turkana to Mandera. In addition, access to Internet services is still a mirage in many parts of Kenya, as fibre optic cables only cover 17% of the land (Ministry of Information, Communications and Technology, 2018). Even with impressive results in terms of mobile penetration, significant efforts need to be undertaken to ensure Kenyan society can fully cope with the demands of digitalisation in all sectors that will bring the advancements lifted by the economy (World Bank, 2018).

As primary school children will enter the labour market in ten years, they will need to have acquired the essential competencies of Digital Literacy: use of computers and digital equipment, ability to use online applications, find and qualify online information and make use of it in their daily life (Internet Society, 2017). Additionally, Digital Education is preparing children for advanced STEM education, increasing the number of children who will later deploy a career in programming, data analysis, cybersecurity or cloud management. Building these skills is crucial for developing countries and should be included in the curricula and assessed in the same manner as other basic competencies like reading, writing and mathematics (Dede, 2010) as its progress is decisive in the conformation of a future workforce.

More developed economies have defined digital education indexes to measure a country's ability to upscale its workforce (Beblavý et al., 2019), focusing on the application of Digital Education on lifelong learning opportunities. At the same time, systematic research has been developed to provide trend analysis and country comparisons of their digital performance (Foley et al., 2018). However, there is a lack of information on the deployment of Digital Education at the early stages of schooling; hence the purpose of this research is to contribute to closing this knowledge gap by defining a framework with related educational variables required in developing countries' schools to provide the necessary conditions that enable the acquisition of Digital Age skills.

Thus, the following research questions were formulated and will be answered throughout the paper:

RQ1. *What are the main metrics that affect implementing a Digital Education program in a developing country?*

RQ2. *What is the state of readiness of Digital Education in Kenya, so students acquire sufficient 21st-century skills?*

The methodology used proposes the definition of a Digital Education Index for Developing Countries (DEIFDC) as a geometric mean of nine different variables (school net enrolment, persistence to the last grade of primary, literacy and numeracy skills, digitally teaching practices, digital learning resources, personal and adaptive learning, electricity access, broadband coverage and LMS availability) that have been grouped into three levers (students' readiness, pedagogical capabilities and IT infrastructure development) and assigned a different weight based on the perceived importance to assess Digital Education deployment in a developing country provided by educational experts. Additionally, the ultimate goal of this research was to build and present a tool that might be used in the future for policymakers, Ministries of Education and international agencies working in developing countries to identify major areas of improvement in the deployment of Digital Education.

In the application of the DEIFDC for the Kenyan case, an overall score of 0.576 situates Kenya in the countries with insufficient deployment. Therefore, significant reforms need to be undertaken to plan the introduction of Digital Education in schools properly. The DEIFDC application is also under study in additional developing countries, for example, preliminary results leave Kenya with a lower score on digital education deployment than Peru and India.

The rest of the article is organized as follows; the first part reviews the literature approaching Digital Education from an instrumental point of view, focusing on the advantages that different digital tools bring to the learning process. In the second part, there is a detailed description of the methodology and research procedure to depict the levers and variables that compose the index. In the third part, the Kenyan context is introduced in terms of social, cultural, economic and educational characteristics, as well as the digital programs deployed and results obtained in the application of the index. Lastly, the final section includes a summary of the results, encountered limitations and lines of future research.

RESEARCH CONTEXT

Literature Review

Digital Technologies have been progressively introduced in most Education Systems, even if traditional textbooks and chalk and board lessons were also used. Nowadays, and due to the workarounds originated due to the school closures during the Covid-19 pandemic (Arora et al., 2020), many education world leaders agree that technology is no longer a supplementary tool (Gianini, 2020) and that it should be fully integrated into all Education Systems. In 2021 most schools in developing countries were still closed due to restrictions imposed by the pandemic that started in 2020 (Selim, 2020; Lennox et al., 2021). As a result, 1,6 billion children and youngsters were displaced from school in 190 countries with diverse consequences regarding their learning progress, nutrition support and subsequent enrolment continuity (UNESCO, 2020). Moreover, in vulnerable environments, the current digital divide (World Bank, 2020) has made evident that those with less technical resources have greater challenges to follow up with online lessons as more than two-thirds of children aged 3 to 17 years lack internet access at home (UNICEF, 2020).

For this research, we have reviewed the index construction based on the potential use of Digital Education tools to improve learning practices in low and middle-income countries (Trucano, 2017). On the one hand, individual learning tools are principally based on the usage of educational resources on computers, tablets or mobile phones to speed up the learning process by giving each student access to different content available on the internet or previously downloaded and made available offline. This way of working is singular for three reasons:

1) Knowledge boundaries: Digital Education extends the boundaries of knowledge of traditional textbooks, especially if the children can connect to the internet and explore further than what is written in the books just with a device. This process can be similar to having access to an infinite library where thousands of books are available, and children can conduct their own research (Mitra, 2014).
2) Adaptive learning: Digital Education enables learning personalisation and the ability of the educational resources to adapt to the current capacities, abilities, achievements and misconceptions depending on the student's level (Luckin et al., 2016).

3) Evaluation and assessment: Digital Education facilitates evaluation and assessment as different types of tests and questionnaires can be applied to verify students' levels at different stages of the learning process. At the same time, it simplifies the individual certification or warranty of proficiency in particular subjects or matters than can be used to access higher education or specialised jobs (Beblavý et al., 2019).

On the other hand, collective learning digital tools bring a new way of working with soft skills, allowing teachers to introduce complementary forms of student interaction. It changes the way of interaction in a classroom from a teacher-centered approach to a student-centered approach (Ruhl, 2018). These tools can be interactive whiteboards (IWB) or projectors, but also more advanced systems such as Virtual Learning Environments (VLE) or Learning Management Systems (LMS) deployed either locally or connected to the internet (Light, 2016). Among others, they enable:

1) Teamwork and collaboration: The students can be grouped in smaller clusters to develop different subjects, research together or complete tasks that involve thinking out of the ordinary (Scheuer et al., 2010).
2) Peer evaluation: The software deployed on tablets or computers allows the students to assess the work of their peers and help them create a cooperative environment where everyone learns from both producing and reviewing the work of others (Gueldenzoph et al., 2002).
3) Gamification: It helps to motivate the students to create avatars and game-related content that can be used to study a specific matter deeply. The children will get higher scores depending on how they dominate the subjects and how they perform compared to others (Freitas, 2011).

Digital Education is critical as it prepares children to acquire the digital competencies indispensable in a 21st-century workforce, like digital literacy and computational thinking (World Economic Forum, 2020). Nonetheless, these skills cannot be considered isolated. It is necessary to use a holistic approach in which the new ways of teaching and learning will also help them to acquire a series of soft skills that have been analysed in several forms, such as the four C's (Ruhl, 2015): critical thinking, creativity, communication and collaboration; the ABCs (Wilson-Body, 2020): adapt, be resilient and communicate or the four Pillars of Education (UNESCO, 2015): learn to know, learn to do, learn to live and learn to be. On the other hand, the ISTE framework proposes the following standards for students: Creativity and Innovation, Communication and Collaboration, Research and Information Fluency, Critical Thinking, Problem Solving and Decision Making, Digital Citizenship and Technology Operations and Competencies (International Society for Technology in Education, 2007).

As stated by the Reimagine Education program (UNICEF, 2020), the availability and potential of technology mean that digital learning should be part of a basic basket of essential services for every child to build and accredit basic skills. These skills include reading and writing, maths, problem-solving, creativity and critical thinking needed for work, starting a business and engaging productively in their communities.

Recent studies (Ganimian et al., 2020) suggest four different ways to realise the potential of Digital Education to accelerate student learning and focus on potential uses of technology: scaling up quality instruction, facilitating differentiated tutoring, expanding opportunities to practice and increasing learner engagement through videos and games.

It has also been considered that providing the required basics to schools in terms of technological resources like electricity, internet connectivity, and learning digital resources is insufficient. Therefore, it is even more relevant that educators (Béteille et al., 2018) are prepared to teach and learn based on new innovative methodologies (Light, 2016) and able to translate this knowledge to students.

International experiences show that Digital Education is related to increased school attendance, decrease in dropout rates, content creation, improvements in educational management and teachers' training (Marcone, 2010). However, in Kenya, recent research has shown that providing internet access in schools increased students' participation in digital education programmes but did not help improve basic metrics like school attendance (Okyere, 2020). The current effects of Digital Education will be part of future evaluations of basic competencies and how Digital Technologies are enhancing the effectiveness of learning (Qureshi et al., 2021).

As crucial as Digital Education has been revealed during the pandemic crisis (Monirujjaman et al., 2021). Empirical findings (Riviello, 2020; Olszewski et al., 2020) demonstrate it should not be considered as a backup instrument to respond in case of school closure but as a means to prepare children at early stages of education to acquire the competencies that will be needed in a new Digital Economy (UNICEF, 2020).

Globally, it has been demonstrated that there is a 9% increase in hourly earnings for one extra year of schooling (Psacharopoulos et al., 2018). Still, universal education should be accompanied by universal digital literacy. Moreover, in developing countries, Digital Education is even more relevant because it can not only improve the teaching and learning processes but also introduce the approach necessary for producing a technologically proficient workforce (Kalolo, 2018) that might change in the next 10-15 years the composition of the labour market (Kask, 2021).

In a new Digital Economy, developing countries must aim to become not only countries of manufacturing outsourcing but also move into services with customer call centres, data entry facilities and higher-skilled professional jobs ranging from engineering to artificial intelligence (Lieberman, 2004). Likewise, it has been demonstrated through recent research that inequalities in education may limit the positive economic outcomes and benefits derived from the use of ICT (Billon et al., 2017).

The recent pandemic crisis had shown that only those with jobs adapted to the current digital economy could introduce massively home working. Furthermore, lower-income economies had a lower share of jobs that could be done at home (Dingel et al., 2020). Likewise, at a micro-level, workers from developing regions and lower wages had a more challenging time continuing to work during the pandemic, increased overall economic vulnerability and worsened inequality in lower-income households (López-Calva, 2020). Therefore, it is relevant for developing economies to ensure economic growth and build a more resilient and inclusive society.

Kenyan Background

The Republic of Kenya is one of the most developed East African countries bordering Ethiopia, Somalia, South Sudan, Tanzania, Uganda and the Indian Ocean. Kenya is the 48th largest country in the world and the 27th most inhabited country, with a population of 53.77 million (United Nations, 2020). Most of the population lives in rural areas; 27.8 % of the urban population is mainly distributed between the capital city of Nairobi, the coastal city of Mombasa and Kisumu City, the inland port of Lake Victoria and around 56% of this urban population live in informal settlements or slums. In addition, 43% of the Kenyan population are children, and one in four children under the age of 5 are stunted, with the highest rates of stunting in rural and remote areas (Masibo et al., 2012).

Kenya is divided into 47 counties that establish an administrative division for management and election (Ministry of Devolution and Planning, 2016); however, the diverse ethnic groups (Kikuyu, Luhya, Kalenjin, Luo, Kamba, Somalis, Kisii, Mijikenda, Meru, Maasai and Turkana among others) extend their influence independently of the administrative borders. Although English and Kiswahili are the official languages, the ethnic groups use their mother tongue within their communities while they tend to be multilingual, mainly in the major cities. In addition, skirmishes often occur among diverse ethnic groups due to land assignation for agriculture and farming, political conflicts and availability of natural resources (Veit, 2019).

After gaining independence from the British empire in 1963, Kenya has undergone significant reforms, especially during the establishment of the new 2010 constitution that marked the beginning of modern democracy. The long-term Vision 2030 (Ministry of Planning and National Development, 2007) aims to develop the major areas of concern: economic improvement, universal healthcare, affordable housing and food security (World Bank, 2021). Climate change (Kenya Food Security Steering Group, 2012) is also a key concern due to Kenya's varied landscape of plateaus and high mountains that create great contrasts in humidity and temperature, affecting the primary sector production and the nutrition stability of a high percentage of the population (Mohajan, 2014).

Kenya is one of the countries with the highest number of refugees and asylum seekers due to the conflicts of neighboring Somalia, South Sudan and the Democratic Republic of Congo. The two major

camps are in Dadaab and Kakuma, although there is also a minority residing in urban areas (Hyndman et al., 1998).

Kenya's GDP has steadily grown at 5.4 percent over the last years based on agriculture, fishing, mining, manufacturing, energy, tourism and services (International Monetary Fund, 2018). GDP growth reduced extreme poverty from 46.8 percent in 2003 to 36.5 percent in 2016. Still, Kenya ranks 143 in the Human Development Index with an IDH of 0.601 (United Nations Development Program, 2020), which places the country in the medium human development category. In addition, 38.7 percent of the population are multidimensionally poor, while an additional 34.9 percent are classified as vulnerable to multidimensional poverty. Moreover, the effects on the economy of the COVID-19 pandemic (contraction of domestic demand, exports decline, and tourism dropping out) have widened the goal of eradicating extreme poverty by 2030 (International Bank for Reconstruction and Development, 2020).

Kenya has the potential to become an example for the rest of the African countries in terms of social development, sustainable economic growth and improved services infrastructure. In this scenery, counting on a youthful skilled workforce is indispensable to lead the necessary change (World Bank, 2021); and it is within this context that the importance of digital education at the early stages of schooling has been analysed.

Education in colonial times was reserved for a small, privileged group, giving access to only 31% of Africans to secondary school (Eshiwani, 1993). However, since gaining independence, the Kenyan government has appointed several education commissions to introduce access to basic education, eliminate social and gender inequalities, provide further opportunities for post-secondary education and update curriculum content (Lelei et al., 2012).

Under the Kenyan Constitution, articles 43(f) and 53(1) provide the right to free and compulsory education managed through the national and county governments. At the national level, four central state departments (Early Learning and Basic Education, Vocational Education, University and Skills Development) develop standards, policies, curriculum guidelines, examinations and access to universities, whereas the county governments oversee pre-primary schools, vocational training and home craft centers (Ministry of Education, 2019).

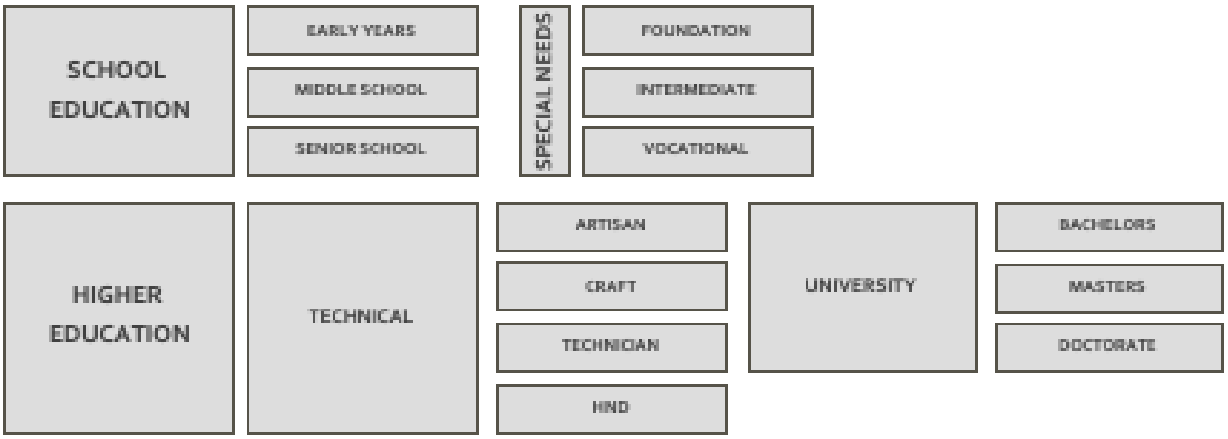
Before the Covid-19 pandemic broke out, there were 496,801 teachers in Kenya (Ministry of Education, 2019), 92,359 teachers in pre-primary learning centers, 287,532 teachers in primary schools and 116,910 teachers in secondary schools, with public schools accounting for 90% of the teachers. On enrolment, there were 2.7 million learners in pre-primary centers, 10.1 million pupils in primary schools and 3.26 million in secondary education. One of the main achievements in public schools has been the reduction in the students per teacher ratios, with 39 pupils per teacher in primary schools and 29 in secondary schools (Koc et al., 2015).

The student-per-textbook ratio in primary schools has also improved to reach 0.96 books per student due to the centralized procurement and distribution of Mathematics, English and Kiswahili books by the central government (Ministry of Education, 2019).

Current education reforms are based on the 2018-2022 National Education Sector Strategic Plan (NESSP), which establishes an all-inclusive plan to enhance access and equity, provide quality and competency-based education, strengthen management, governance and accountability and improve relevance and capacities for science, technology and innovation (Ministry of Education, 2018).

Figure 1 summarises the renovated Kenyan Education System routes to create a high-quality, competent workforce for sustainable economic, social and environmental development (Technical and Vocational Education and Training Authority, 2018). The Ministry of Education, Science and Technology tries to guarantee a strong link between skills learnt and the needs of the labour market by producing graduates with superior employability through education provided in National Polytechnics, Technical Training Institutes, Vocational Training Centres and Technical Trainer Colleges.

FIGURE 1
KENYAN EDUCATION SYSTEM

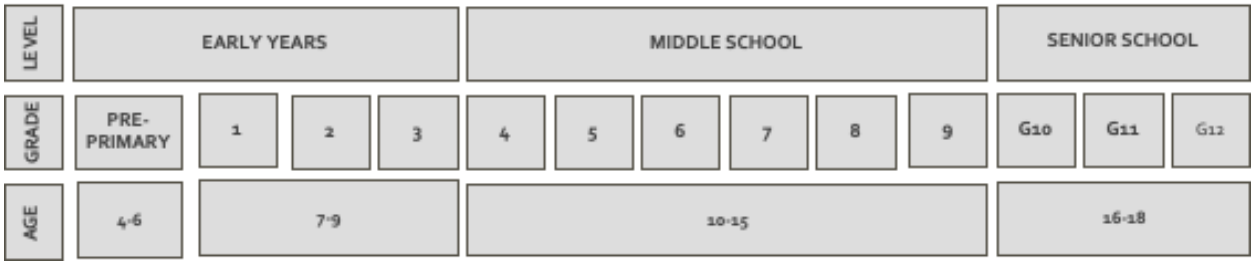


Source: Authors' elaboration with data from the national education sector strategic plan (ministry of education, 2018)

As we can see in Figure 2, at a school level, the old 8-4-4 summative examination-oriented system has been replaced by a 2-3-6-3 competency-based system where the emphasis is on communication and collaboration, critical thinking and problem-solving, creativity and citizenship through the adoption of new methodologies that change the teachers and learners' mindset: learning to learn, self-efficacy and digital literacy (Kenya Institute of Curriculum Development, 2017). This new formative assessment has continuous feedback measurement, hands-on experience, and interactive learning to prepare children with relevant competencies to prosper in a rapidly changing world.

As of the end of 2019, all pre-primary and primary schools had migrated to the new Competency-Based Curriculum, although the Covid-19 pandemic closure has slowed down the implementation and evaluation process of the new program.

FIGURE 2
SCHOOL EDUCATION



Source: Authors' elaboration with data from the national education sector strategic plan (ministry of education, 2018)

As part of their Vision 2030 program, the Kenyan Government launched the Digital Literacy Program in 2013, intending to enable teachers and students in public primary schools to incorporate digital technology into the learning process (Ministry of Information, Communications and Technology, 2021). The program publicly known as DigiSchool has been developed based on three priorities:

1) Infrastructure and technology: It ensures the schools are provided with all necessary facilities to introduce Digital Education within the classrooms, mainly a stable power connection (solar power or the national grid), internet connectivity, storage and servers, devices for teachers and students, and digital content. An initial assessment ensures the classrooms are e-ready, free of dust desks, secured storage cabinets and charging points. The DigiSchool components (teacher

laptop, student tablet, projector, content servers and router) have been assembled locally in a consortium created by the Jomo Kenyatta University of Agriculture and Technology (JKUAT) and the Ministry of Industrialization and Enterprise Development (MoI&ED) (Ministry of Information, Communications and Technology, 2021).

2) Teacher capacity: A specific training program has been rolled out to ensure at least three teachers per primary school have the necessary digital skills to enhance the student's learning process. As of November 2021, 80,980 teachers have completed the training module (Teachers Service Commission, 2021)
3) Digital Content: The Kenya Institute of Curriculum Development (KICD) has been in charge of developing a content creation framework to ensure it can be consumed independently of the platform. The Digital Learning Program devices are preloaded with Kiswahili, English, Mathematics, Science and Social Sciences resources available in text, audio and video formats. In addition, the Kenya Education Cloud portal contains Open Educational Resources for all grades of Primary and Secondary Education as well as online materials for teacher training on ICT integration, competency-based curriculum and health and financial literacy content. These resources are also preloaded in the teachers' laptops deployed in public schools and are available without the need for an internet connection (Kenya Institute of Curriculum Development, 2018).

Several private and NGO digital education programs have been operating at a country or regional level in public and private schools (Atambo, 2020), providing an experimentation ground to introduce the mobile innovations already succeeding in the banking industry:

- M-shule: A knowledge-building platform that relies on SMS to reach the 80% of the Kenyan population that does not have smartphones or access to the internet. The students get personalized training and micro-courses in a self-paced, interactive and personalized manner using artificial intelligence to evaluate performance and assess progress through quizzes and tests (Ojino et al., 2018).
- e-Limu: With 500,000 users in 2019, e-Limu is one of Africa's most awarded online platforms and is widely used in East Africa. It offers digital education resources in a gamified manner to improve learning outcomes and out-of-school support. In addition, the content is adapted to the local context with videos, images, animations and local stories to improve reading and writing in for early years (Masago et al., 2020).
- Kytabu: It deploys a mobile-based information management system for learning institutions and a mobile-first learning management system with digital content for students specially created for the African context. It is based on the fact that 87% percent of schools' administrators and 68% percent of students have access to a smartphone daily, whereas access to desktop or laptop computers is limited to 30% and 6%, respectively. The Kytabu digital ecosystem includes several applications like Super School for school management purposes, Kibanda for teachers' training and Somanasi with learning content for students in textbooks, audiobooks, assessments and courses for rent on an hourly, daily or weekly basis (Wepukhulu, 2019).
- iMlango: It is a public and private collaboration programme that provides high-speed satellite broadband connectivity to schools, maths and literacy digital content, ICT training for teachers and electronic attendance monitoring with conditional payments to ensure families send their daughters to school. It aims to improve maths and literacy skills by integrating technology into the learning processes at the same time as they help children that do not regularly attend school due to environmental, economic and social issues. iMlango is currently working with 180,000 students (including 70,000 marginalized girls) in 240 schools in Kajiado, Kilifi, Makueni and Uasin Gishu (Ndiku et al., 2016).
- Ubongo: It delivers African educational entertainment through radio, tv and multimedia platforms. It provides children with an amusing and interactive way to understand maths, science and literacy principles. Also, it promotes team and collaboration skills and citizenship

behaviors through original stories and songs. In addition, children can interact with the characters through short assessments on their mobile phones. It is available in English and Kiswahili, reaching around 6 million households weekly (Watson et al., 2021).

METHODOLOGY

Research Model and Procedure

The research approach was mixed since it combined a descriptive study based on the application of semi-structured interviews, a questionnaire to establish a weight for the digital education variables selected, the definition of a compound index as well as the introduction of available data from international resources to apply and define an overall score:

TABLE 1
RESEARCH MODEL AND PROCEDURE

Phase	Methodology	Description
I	Theoretical and contextual frameworks	Overview of supporting literature: professional journals, expert think-pieces, case studies, interviews, systematic reviews, comparative studies and policy statements.
II	Qualitative study	Semi-structured interviews with recognized experts in Digital Education to define drivers and variables.
III	Quantitative study	Detailed survey to educational experts world-wide, including senior public officials from international organizations, NGOs leaders working on developing countries and EdTech executives to support weighting of variables.
IV	Index definition	Definition of the index as a geometric mean of nine different variables that have been grouped into levers and assigned a different weight based on the implications to deploy Digital Education in primary schools of Developing Countries
V	Global application	Application and evaluation of the results obtained

Source: authors' elaboration

Qualitative Study

The qualitative study was designed to complement desk research information obtained through literature analysis, information from international organizations and educational congresses participations. The conversations provided valuable insights into the opportunities and challenges related to Digital Education across developing countries.

The interview design was based on the methodological approach of qualitative interviewing as a flexible tool to capture the opinion of Digital Education experts (Guion et al., 2001; Klimova et al., 2021; Kvale, 2012; Rabionet, 2011). The respondents were chosen based on their expertise on Digital Education on three different profiles: academia, international educational institutions, and NGOs active in developing countries.

The research was conducted between January and April of 2021 after most educational systems were recovering from the pandemic and students returned to school. The data was collected through online semi-structured interviews where the participants were invited to discuss their insights on the relevance of Digital Education deployment for developing countries.

The interview was designed to create a natural environment for conversation, with the researcher encouraging more detailed responses. Moreover, to inspire their contribution, the participants of the study were asked the following open-ended questions:

A. What would be the main factors affecting Digital Education deployment? Is there any difference between developing countries and more developed economies?
B. What would be your top recommendations for governments at a national level in developing countries regarding Digital Education?
C. What level of relevance has Digital Education in each level of education? Primary vs. Secondary schools in developing countries?
D. How did you think the Covid-19 pandemic affected digital education deployment? Are the changes to stay?
E. What are the top solutions/app/platforms that you recommend for developing countries? Should they be based on basic literacy and numeracy or work on computational thinking, stem, mathematics, etc.?
F. What relevance will have Digital Education in the preparation with 21st century skills of a future work force in developing countries?
G. What are the key roles of different agents and institutions in the development of Digital Education in developing countries?
H. Is there any other aspect regarding Digital Education deployment in developing countries you would like to discuss?

All these questions were presented to the participants in a verbal format at the beginning of the interview, that is, to facilitate the transcription of all the answers provided; the researcher asked each question and then there was sufficient time for the interviewee to express his opinion or relate the discussion to previous questions already responded. All participants were free to express their opinion independently of the organization they were working for but determined to show the experience acquired before, during and after the pandemic crisis for research purposes.

Given the variety of responses obtained, the results have been grouped into clusters to facilitate the analysis and define the levers and variables that integrate the DEIFDC framework:

TABLE 2
CLUSTERS' SELECTION ON QUALITATIVE STUDY

Cluster	Topic
I	Relevance of Digital Education in a new Digital Economy driven society
II	Main variables affecting deployment in developing countries
III	Covid-19 pandemic crisis as a turning point in digital education

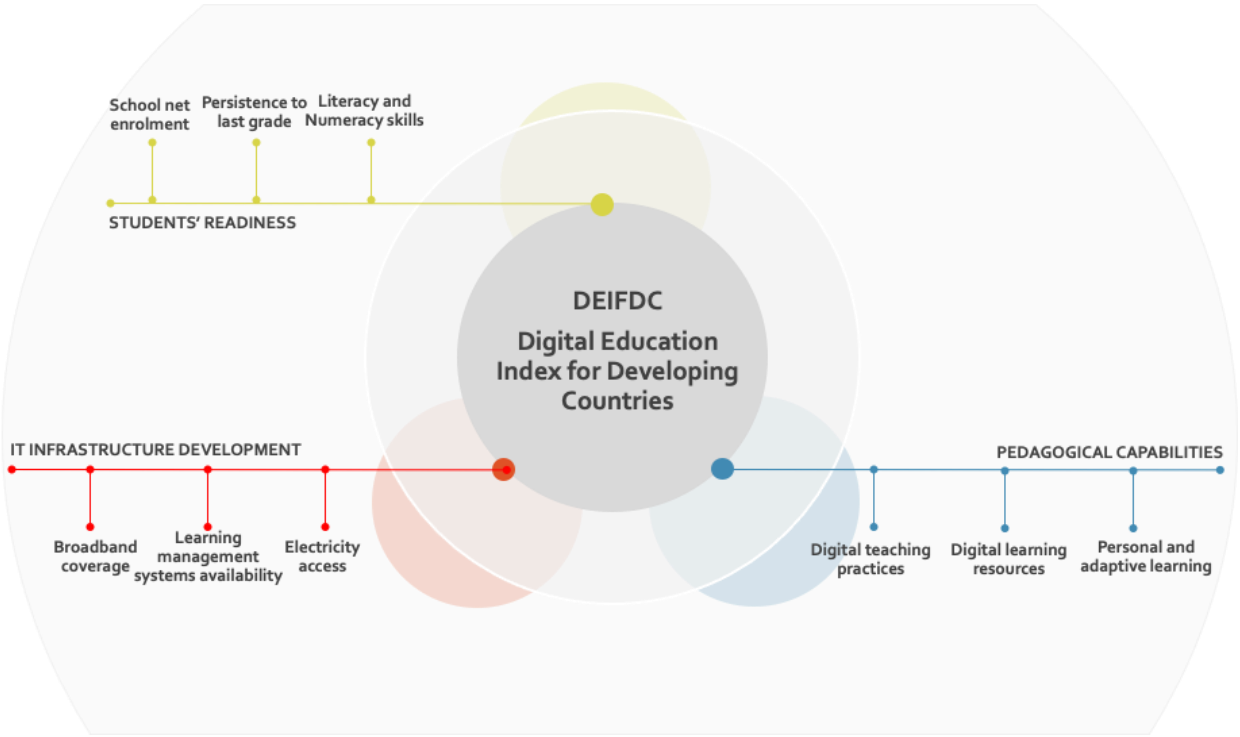
Source: Authors' elaboration

Quantitative Study

The Digital Education Index for Developing Countries (DEIFDC) is a geometric mean of nine different variables that have been grouped into levers and assigned a different weight based on the implications to deploy Digital Education in primary schools of Developing Countries. The selection of levers has been carried out based on the qualitative study.

Two main digital indices have supported the framework: the Index of Readiness for Digital Lifelong Learning (Beblavý et al., 2019) and the International Digital Economy and Society Index (Foley et al., 2018).

FIGURE 3
DIGITAL EDUCATION INDEX FOR DEVELOPING COUNTRIES



Source: Authors' elaboration

As exposed in figure 3, the qualitative study constructed the main levers to assess Digital Education deployment in developing countries are: Students' Readiness (L_1), Pedagogical Capabilities (L_2) and IT Infrastructure Development (L_3). To support the weights of variables within each lever, a quantitative survey was launched to educational experts worldwide, including senior public officials from international organizations, NGOs leaders working in developing countries and EdTech executives. The survey has served to gain insight on the importance they assign to the variables on a 1-4 scale:

TABLE 3
VARIABLES' METRIC DISTRIBUTION

Relevance	Description	Metric
Irrelevant	The variable has no relevance in the deployment of Digital Education	1
Important	The variable is essential in the deployment of Digital Education	2
Decisive	The deployment of Digital Education is largely affected by this variable	3
Critical	No Digital Education deployment will be possible without the adequate placement of this variable	4

Source: Authors' elaboration

As suggested by the central limit theorem (Kwak et al., 2017), the objective was to count at least thirty responses. From the thirty-three responses obtained, the following equations were applied, where $\boldsymbol{GM}(\boldsymbol{V_{i,j}})$ is the geometric mean of all the responses obtained and $\boldsymbol{W_{i,j}}$ is the calculated weight for each variable:

$$\boldsymbol{GM(V_{i,j})} = \sqrt[n]{\prod_{k=1}^{n} A_{i,j}^{k}} \quad (1)$$

where n is the number of responses obtained and $A_{i,j}^{k}$ are the responses obtained for the variable $\boldsymbol{V_{i,j}}$

$$\boldsymbol{W_{i,j}} = \frac{100 \times \boldsymbol{GM(V_{i,j})}}{\sum_{j=1}^{3} \boldsymbol{GM(V_{i,j})}} \quad (2)$$

The equations defined to calculate the DEIFDC are as follows, where each variable has been given a 0-1 scale:

$$\boldsymbol{L_i} = \sum_{j=1}^{3} \boldsymbol{W_{i.j}\, V_{i,j}} \quad (3)$$

This will result in an index calculated on the geometric mean of the three different levers previously constructed:

$$\textbf{DEIFDC} = \sqrt[3]{\prod_{i=1}^{3} L_i} \quad (4)$$

Depending on the DEIFDC score, the developing countries understudy will be grouped according to one of the categories defined in table 4:

TABLE 4
DEIFDC SCORE DISTRIBUTION

Grade	Description	Score Range
Excellent	Digital Education is incorporated at all levels of the education system	0.9-1
Good	Digital Education is properly planned and needs to expand on a massive rollout	0.8-0.9
Adequate	Digital Education is at an early stage of deployment with areas for improvement	0.6-0.8
Insufficient	There is little use of digital technologies in the classroom	0-0.6

Source: Authors' elaboration.

The following table summarises all levers and their assigned variables and weights:

TABLE 5
DEIFDC WEIGHT VARIABLES SUMMARY

Lever/Variable	Name	Description	Weight
L_1	**Students' Readiness**	**Students ready to be digitally exposed**	
$V_{1.1}$	School net enrolment	Adjusted net enrolment rate (% of primary-school-age children)	30.26%
$V_{1.2}$	Persistence to last grade	Persistence to last grade of primary (% of cohort)	32.68%
$V_{1.3}$	Literacy and numeracy skills	Proportion of children achieving a minimum proficiency level in reading and mathematics (%)	37.07%
L_2	**Pedagogical Capabilities**	**Digital Education integrated into the learning process**	
$V_{2.1}$	Digitally teaching practices	Teachers who have received the minimum organised teacher training pre-service or in-service capable of introducing Digital Education in the classroom (%)	34.5%
$V_{2.2}$	Digital learning resources	Students with access to digital learning resources (%)	33.5%
$V_{2.3}$	Personal and adaptive learning	Students with access to electronic devices to perform digital learning (%)	32%
L_3	**IT Infrastructure Deployment**	**Infrastructure deployment to meet Digital Education demands**	
$V_{3.1}$	Electricity access	Schools with electricity access to ensure availability of ICT hardware (%)	38.87%
$V_{3.2}$	Broadband coverage	Schools with internet access for pedagogical purposes (%)	34.39%
$V_{3.3}$	LMS availability	Schools with LMS installed (%)	26.73%

Source: Authors' elaboration.

The justification of each lever and its corresponding variables will be described in the following subsections:

Student's Readiness

One of the main challenges to applying Digital Education in developing countries is the fact that enrolment ($V_{1.1}$) in certain areas is still a defy; without school attendance, persistence, and continuous guidance, the benefits of introducing 21st-century skills in primary schools can be reduced.

It is also crucial that children stay in Primary School and keep on studying until the final grade ($V_{1.2}$); this is beneficial in terms of individual progress and society as additional years of schooling have proved

to be central for employment, poverty reduction, economic growth, and social cohesion. At the same time, evidence on the importance of early environments on a spectrum of health, labour market, and behavioural outcomes suggests that focus must be put on the early stages of education (Heckman, 2007) rather than on secondary or lifelong learning opportunities.

Among the benefits of introducing Digital Education at an early stage is the reduction of learning poverty (World Bank, 2019), which is mainly measured by the capacity of students to read and write and solve mathematics problems related to daily life ($\boldsymbol{V_{1.3}}$). Although several countries have been measuring the impact of education, the most extended analysis is based on PISA, the Programme for International Student Assessment, which measures the 15-year-olds' ability to use their reading, mathematics and science knowledge skills to meet real-life challenges.

Pedagogical Capabilities

Within this section, the variable with the most significant importance is the training of teachers ($\boldsymbol{V_{2.1}}$), which is critical to introducing digital teaching practices in schools (Panagiotis et al., 2015). In this sense, it is necessary to teach them how to use the new ICT tools and provide pedagogical support and continuous professional development to ensure they can apply innovative methodologies in the school and work on the competencies that Digital Education facilitates as several frameworks have proposed.

The second variable in terms of importance is the availability of suitable content and resources ($\boldsymbol{V_{2.2}}$). Advanced digital content has traditionally been exploited by EdTech companies that made the content available through web access, applications and different licences. However, new regulations on Open Educational Resources (UNESCO, 2019) have made plenty of digital content available, especially after the Covid-19 crisis and to students and teachers with an Internet connection. Although this is a progression that can make a difference in developing countries, it is necessary to adapt it to the specific curricula of each environment (Trucano, 2010), local languages (Reed, 2019), contexts without an Internet connection or specific devices different from laptops like tablets or mobile phones.

Personal and adaptative learning, measured by the penetration of electronic devices per student ($\boldsymbol{V_{2.3}}$) has been considered less relevant as it has been proven that deployment of ICT labs and equipment sharing is also a good practice to introduce Digital Education in the learning process. However, it is essential to ensure unique login to identify students' sessions and relevant to apply some of the advantages of Digital Education in terms of personalisation (Lucking, 2016), gaming and certification.

IT Infrastructure Development

The adequate deployment of infrastructure is critical to ensure that children can receive the initial instruction required in developing countries' schools as family technical support, which is usually the first step of Digital Education introduction in developed countries, cannot be ensured. Electricity access ($\boldsymbol{V_{3.1}}$) has been given the most relevant load as the ICT equipment (computers, tablets, routers or projectors) must be charged appropriately. When no standard electricity access is possible due to geographic or economic conditions, there are other ways to ensure batteries can last during the school day, and several deployments have been proved successful such as solar panels or solar chargers for specific equipment; however, typically their capacity is conditioned to weather circumstances and the quality of the equipment provided. Other renewable energy technologies like wind turbines, small-scale hydroelectric projects and other forms of self-sufficient energy can provide rural communities in the developing world with the electricity they need to power schools (Solar Energy International, 2018).

Even if educational resources can be made available and previously uploaded, internet access ($\boldsymbol{V_{3.2}}$) ensures that broad knowledge and content can be used in the classrooms (International Telecommunication Union, 2013). This is particularly relevant in contexts where advanced individual or collective learning tools are introduced, such as adaptive learning and gamification (Internet Society, 2017).

Although it seems Digital Education deployments should start with the delivery of a laptop or tablet to children in school for individual use, the standard approach that has been carried out in more advanced Education Systems is through the usage of Interactive White Boards, Learning Management Systems and projectors in the classroom ($\boldsymbol{V_{3.3}}$). This introduction allows the Primary Education teachers to expose

content and familiarise the children with Digital Education. Particularly, educators can use IWBs to empower students with 21st-century skills and create exciting new learning opportunities for promoting STEM education, problem-solving, critical thinking, and collaboration skills among their students (Yinghui, 2012).

Data Analysis

The existing data suitable for constructing the DEIFDC was obtained from reputable available national and international sources through desk research. Data sources include global databases like the UNESCO UIS Database and the World Development Indicators from the World Bank, as well as local Kenyan sources provided by the Ministry of Education on their biannual basic education statistical booklets based on the information collected through the National Education Management Information System (NEMIS) platform. The Kenya National Examinations Council (KNEC) provides monitoring data on examinations and national assessments like the Early Grade Mathematics Assessment (EGMA) and the National System for Monitoring Learning Achievement (NASMLA). The Ministry of Energy and the Ministry of ICT, Innovation and Youth Affairs also provide data on electrification and internet access in schools, respectively. The Kenya National Bureau of Statistics (KNBS) was also helpful to measure general education statistics information.

The use of international databases will be useful to build a base for comparison among other developing countries where the DEIFDC will be applied. However, we still encounter other limitations like the availability of annual data to determine future evolution and the monitorisation of SDG 4 targets at a sufficient disaggregation level that will allow deep dive into a particular social (gender, ethnic groups, special needs) or geographic (rural, urban, coastal, savannah) groups.

RESULTS

The analysis and application of the DEIFDC came with relevant insights on the development of Digital Education in Kenya. Despite the efforts during the last five years, with an overall result of 0.576, Kenya is situated among the countries with Insufficient Digital Education deployment. The Kenyan Government introduced DigiSchool as part of their Vision 2030 program to promote Digital Education in primary education. However, the Covid-19 pandemic, on the one hand, slowed down the deployment of devices in schools and the training of teachers to lead transformation. On the other hand, it boosted the availability of locally produced educational resources on digital platforms, mobile applications and radio and television broadcasts.

As we can see in figure 4, in terms of Students' Readiness, Kenya has considerable room for improvement, especially in literacy and numeracy skills. The net enrolment recorded in primary schools fluctuates around 79,96% and has been negatively affected by the Covid-19 pandemic. The Ministry of Education measures the percentage of students previously enrolled who return to school once the education system is fully operational. The persistence to the final grade is 93%, greatly supported by different Government programs like the School Meals Program, benefiting 2.5 million students (Langinger, 2011) and the Sanitary Towels Program reaching 3.7 million girls, which focuses on reducing absenteeism and dropout of girls between grades 6 and 8 (Austrian et al., 2021). However, the learning outcomes are inferior, and only 53.1% and 42.1% achieve the minimum proficiency level for literacy and numeracy, respectively. This information is gathered periodically by the Kenya National Examinations Council through the National Assessment System for Monitoring Learner Achievement (NASMLA), whose objective is to assess learners' acquisition of the knowledge, skills and attitudes stipulated in the national curriculum and provide insights into the factors that impact upon learner achievement intending to allow for appropriate interventions (Karogo et al., 2020). In this sense, the new Competency-Based Curriculum aims to reinforce skills acquisition through improved pedagogy to allow students to acquire critical subject-specific content and skills.

The development of pedagogical capabilities is also feeble, especially regarding digital teaching practices. As part of the Digital Literacy Program, only 66 ICT champions and 80,980 teachers have been

trained at the primary school level to integrate ICT into curriculum delivery, leaving 80% of teachers still with knowledge gaps in IT (Teacher Service Commission, 2019). Looking into the future, the Kenyan government has integrated ICT and computer usage subjects into the teachers' training curriculum at the college level. Regarding digital education resources, the Kenyan Institute of Curriculum Development (KICD) estimated that about 47 per cent of learners have been accessing the existing cloud platform with a 600% increase in content download since the school closure. A mapping the free available resources is underway by the KICD to determine how the content created or approved by the government covers topics in the national curriculum considering the different official languages. Digital education resources are diverse and include online classes with discussion forums, videos, e-books, games, lesson plans, or lecture-style presentations.

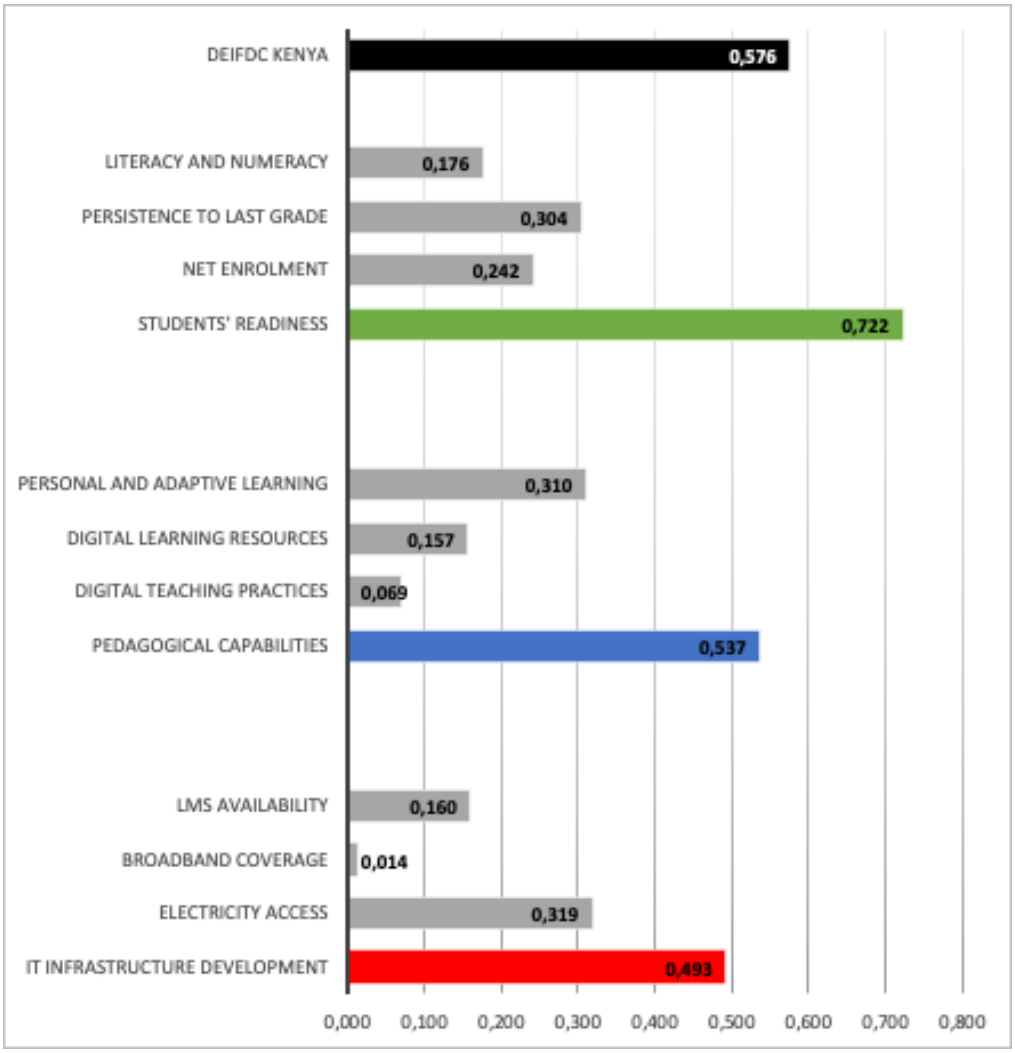
Regarding personal and adaptive learning, since its foundation, the Digital Literacy Program has focused on distributing digital devices in primary public schools with the mission to expose students to digital literacy in their initial years and promote personalised learning through the usage of the Learner Digital Device, already preloaded with content on Kiswahili, English, Mathematics, Science and Social Studies. The rollout has been very successful; currently, 97% of schools have received all the equipment. Conversely, recent studies found that many schools were not using the devices because of lack of electricity and poor network coverage; additionally, teachers could not operate the devices even after training, and digital resources did not correspond to the current syllabus content (Wanza et al., 2019).

School infrastructure development is also impoverished, particularly in terms of internet access. Of the 22,259 schools targeted in the DigiSchool program connected to power, 83% have been connected to the power grid supply, and 17% rely on solar power. However, many schools in rural and semi-urban areas suffer constant power fluctuation, especially in remote counties such as Turkana, Samburu, West Pokot and Northern Kenya (Ngaril et al., 2020).

Concerning internet connection, Kenya is one of the most connected countries on the eastern coast of Africa, with four submarine cables that offer connectivity to the rest of the world via redundant routing. Inland, the 6,000 kilometers of the National Fibre Optic Backbone Infrastructure (NOFBI) across all 47 counties provide a robust infrastructure; however, this infrastructure does not provide broadband internet connectivity to all the schools. The National Broadband Strategy 2018-2023 (Republic of Kenya, 2017) aims to provide by 2030 a 1Gbps connection to 100% of schools; however, as of mid-2020, only 4% of primary schools counted with an internet connection. This rollout has been mainly promoted by the Kenya Education Network (KENET) initiative (Mwangi et al., 2013) that has built a private and public consortium to provide high-speed connectivity and cloud services to education and research and government institutions affiliated with the education sector, including hospitals. In August 2020, the government earmarked $140 million in partnership with the United Nations Children's Fund to reach 1,000 schools as a pilot project before the massive rollout (Paul, 2020). This investment is extraordinary given that schools still lack appropriate classroom structures and have inadequate WASH infrastructure: nearly 50% of schools have no handwashing facilities and poorly maintained toilets (Alexander et al., 2016).

On March 15th, 2020, Kenya's Ministry of Education (MoE) indefinitely closed primary and secondary schools to mitigate the impact of Covid-19, thus interrupting the studies of 13,36 million students. At that point, most Digital Education programs were experiencing little success, mainly due to low levels of computer literacy; however, to ensure students remained engaged during the closing period, the Ministry of Education and the Kenyan Institute of Curriculum Development (KICD) developed remote learning systems and educational resources supported through several channels: Radio broadcasting, Education Television Channel, Education YouTube Channel and the Kenya Educational Cloud. As a result, it has been estimated that about 60% of primary and secondary school students have been accessing remote and online distance learning platforms and maintained increased exposure to learning infrastructure. However, there is no equitable access to learning solutions as internet costs in rural and underserved areas are prohibitive for many students; for example, only 12.1%, 2.1% and 4.4% of households in Turkana County have access to radio, TVs and internet respectively (Global Partnership for Education, 2020).

FIGURE 4
DEIFDC KENYA'S RESULTS



Source: Authors' elaboration with data from world development indicators and world data reports (world bank), uis UNESCO database, national assessment system for monitoring learner achievement (nasmla) from the Kenyan national examinations council (knec), Kenyan ministry of information, communications and technology, Kenya national bureau of statistics and digital literacy program updates.

CONCLUSIONS, LIMITATIONS AND FUTURE RESEARCH

Education is the key to reducing poverty, ensuring global sustainability, eradicating diseases, and fostering peace. To ensure that digitalisation advancements do not broaden the existing educational divide, developing countries must introduce Digital Education at the early stages of schooling to prepare students with the skills required in a 21st-century workforce. However, Digital Education must develop to become a tool to strengthen education systems by providing knowledge dissemination, quality and effective learning and development of competencies to achieve universal literacy to live and work in a technology-driven world.

In this research, through RQ1, we analysed the different metrics that affect implementing a Digital Education program and defined the Digital Education Index for Developing Countries framework to measure and compare the degree of Digital Education deployment in different developing countries. The

methodology used selected nine different variables (school net enrolment, persistence to the last grade of primary, literacy and numeracy skills, digitally teaching practices, digital learning resources, personal and adaptive learning, electricity access, broadband coverage, and LMS availability) that were grouped in three levers (Students' Readiness, Pedagogical Capabilities and IT Infrastructure Development) and weighted thanks to a quantitative study launched to educational experts worldwide.

The specific application to Kenya was analysed through RQ2, where we studied the Kenyan context from a social and educational perspective, focusing on the applications and digital education programs developed. Although a major increase in the usage of educational resources and learning platforms was observed due to the Covid-19 school closure, in the application of the DEIFDC for the Kenyan case, the results show Insufficient Deployment of Digital Education mainly due to poor internet connectivity, lack of trained personnel and main challenges on students' learning performance. The DigiSchool program, part of the 2030 Vision agenda of the Kenyan government, aims to introduce Digital Education in all public schools; however, according to the latest Class 7 Monitoring Learner Achievement, 44.3% of teachers had not yet adopted the use of ICT in teaching their subjects, and no effect has been recorded on the improvement of basic skills. At the same time, important differences are still present for the most vulnerable population, especially children attending schools in rural areas, refugee camps and slums.

Proposed further research will dive deep into the evolution of the Kenyan Digital Education system. Its future impact will need to explore both the evolution of DEIFDC in subsequent years, its possible application in higher education (technical and university) and different social and geographical disaggregation levels, the evolution of the digital workforce competencies and Digital GDP growth, as well as the comparison with other countries of similar economic development, given we overcome limitations encountered like the availability of annual data to monitor variables at a sufficient disaggregation level.

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