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Ethel Tshukudu

Sue Sentance

Oluwatoyin Adelakun-Adeyemo

See next page for additional authors

Authors
Ethel Tshukudu, Sue Sentance, Oluwatoyin Adelakun-Adeyemo, Keith Quille, and Ziling Zhong

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ETHEL TSHUKUDU, University of Botswana, Botswana
SUE SENTANCE, Raspberry Pi Computing Education Research Centre, University of Cambridge, UK
OLUWATOYIN ADELAKUN-ADEYEMO, Bingham University, Nigeria
BRENDA NYARINGITA, GitLab Inc., Kenya
KEITH QUILLE, TU Dublin, Ireland
ZILING ZHONG, Wheaton College, USA

Motivation. As K-12 computing education becomes more established throughout the world, there is an increasing focus on accessibility for all, whether in a particular country or setting or in areas of the world that may not yet have computing established. This is primarily articulated as an equity issue. The recently developed *capacity for*, *access to*, *participation in*, and *experience of* computer science education (CAPE) Framework is one way of demonstrating stages and dependencies and understanding relative equity, taking into consideration the disparities between sub-populations. While there is existing research that covers the state of computing education and equity issues, it is mostly in high-income countries; there is minimal research in the context of low-middle-income countries like the sub-Saharan African countries.

Objectives. The objective of the article is therefore to report on a pilot study investigating the capacity (one of the equity issues), for delivering computing education in four sub-Saharan African countries: Botswana, Kenya, Nigeria and Uganda, countries that are in different geographic regions as well as in different income brackets (low-middle income).

Method. In addition to reviewing the capacity issues of curriculum and policy around computing education in each country, we surveyed 58 teachers about the infrastructure, resources, professional development, and curriculum for computing in their country. We used a localized version of the MEasuring TeacheR Enacted Computing Curriculum (METRECC) instrument for this purpose.

Results. We analyzed the results through the lens of the CAPE framework at the capacity level. We identified similarities and differences in the data from teachers who completed the original METRECC survey, all of whom were from high-income countries and African teachers. The data revealed statistically significant differences between the two datasets in relation to access to resources and professional development opportunities in computer studies/computer science, with the African teachers experiencing more barriers. Results further showed that African teachers focus less on teaching algorithms and programming than teachers from high-income countries. In addition, we found differences between African countries in the study, reflecting their relative access to IT infrastructure and resources.

Authors' addresses: E. Tshukudu, University of Botswana, Plot 4775 Notwane Rd, Gaborone, Botswana; email: tshukudue@ub.ac.bw; S. Sentance, Raspberry Pi Computing Education Research Centre, University of Cambridge, 15 JJ Thomson Avenue, Cambridge, CB3 0FD, UK; email: ss2600@cam.ac.uk; O. Adelakun-Adeyemo, Department of Computer Science, Bingham University, Karu, Nassarawa, Karu 961105, Nigeria; email: toyin@sure-impact.com; B. Nyaringita, GitLab Inc, 268 Bush Street #350, San Francisco, CA 94104-3503, USA; email: brendahnyaringita@gmail.com; K. Quille, TU Dublin, Blessington Rd, Tallaght, Dublin 24, D24 FKT9, Ireland; email: Keith.Quille@tudublin.ie; Z. Zhong, Wheaton College, 501 College Avenue, Wheaton, Illinois, USA; email: ziling625@gmail.com.

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Discussion. The findings suggest that African countries are still struggling with the lowest level of the CAPE pyramid, *Capacity for* as compared to high-income countries. This level is concerned with the availability of resources that support the enactment of a computing curriculum of high quality. The CAPE framework helps map the progression from *Capacity for* to *Experience of* computer science education as a route to equity, but to support development in low and middle-income countries, it may be helpful to have the capacity level finely grained. Such an adaptation draws out dependencies between policy and vision, infrastructure, curriculum implementation, and teacher professional development. More research is recommended to investigate these dependencies further and thus support and facilitate the development of global computing education.

CCS Concepts: • **Social and professional topics → K-12 education;**

Additional Key Words and Phrases: Curriculum, K-12 computing education, Africa, teacher education, professional development

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1 INTRODUCTION

In countries around the world, we have seen a shift in recent years from teaching basic digital skills to a knowledge-based curriculum comprising more computer science concepts, including programming. This is in recognition of the rapid technological advances that necessitate a highly-skilled workforce with advanced computational skills. Providing opportunities for all young people in this subject area should ensure that an understanding of the affordances of technology is an entitlement, not a privilege.

Many countries have made recent changes to their curriculum reflecting this shift. A recent report found that of 219 countries, 44 mandate that schools offer it as an elective or required course, 15 offer computer science (CS) in select schools and some sub-national jurisdictions (states, provinces, etc.), and 160 (73%) are only piloting CS education programs or had no available evidence of in-school CS education [79]. In a recent study on computing education in South Asia, Anwar et al. [2] point to both the lack of K-12 computing education research publications in low and lower-middle-income countries and the implications:

> This leaves the education research community with an incomplete picture of what computing education is being developed across the globe, leaving aside social justice issues like human capital and human rights as well as the necessary dialog around quality education and frameworks to support them. [2, p. 80]

Here we look specifically at the case of sub-Saharan Africa, a continent comprised of low- and middle-income countries. Although many African countries teach computer studies, there is little to no research on how this is implemented in the curriculum. This pilot study aims to generate a baseline for understanding the capacity for computing education in Africa. We do this by considering four African countries: Botswana, Kenya, Nigeria, and Uganda. Our single research question is *What is the capacity for delivering computing education in primary and secondary schools in four African countries from the teachers' perspectives?*

To address this question, we first considered the background and context of each country concerning computing education, drawing on national documentation. Second, we surveyed 58 computer studies teachers in Africa relating to their experience with the resources, curriculum, professional development, and support to teach their subject. Both the data and the survey instrument are being made publicly available. We use the survey results to make comparisons between the African countries and also with other high-income countries. Finally, we consider computing education in Africa in the context of the *capacity for*, *access to*, *participation in*, and *experience of* computer science education (CAPE) framework [30]; we consider how the CAPE framework can be applied to low- and middle-income countries to draw out dependencies between policy and vision, infrastructure, curriculum implementation, and teacher professional development.

2 RELATED WORK

2.1 Introducing Computing at K-12

The recent growth of computing in the curriculum highlights that the subject is no longer limited to a narrow group of professionals, and instead embraces a fundamental set of skills and concepts needed to prepare students for the 21st century [6]. It therefore requires a high-quality teaching workforce to implement it fully [86]. Implementing computer science in K-12 involves policymakers determining goals for implementation via standards, teacher credentials and professional development [64].

Individual countries have their views on how computing education should be delivered, what content it should include in K-12, and whether learning it is an entitlement or an opportunity [85]. Even terminology is complicated to pin down with a range of terms being used for the subject: computer science, computer studies, computing, and informatics [85]. Some countries, including many in Africa, have an ICT curriculum that may cover aspects that might also appear in a computing curriculum; in other countries, there is no pre-existing slot in the curriculum for ICT or any digital literacy. A lack of technological education received during the early stages of students' education leaves students ill prepared for study in higher education, which has to start from a lower base [62].

Policymakers also need to decide on the assessment framework for computer science and what qualifications should be available for students: There is little consensus on this [79]. Furthermore, the training of sufficient teachers to deliver computing has been a significant concern [25, 79, 86]. Both in-service and pre-service training of appropriately qualified teachers is needed. For pre-service teacher training, the rate of the pipeline is slow due to the time required to train a new teacher and the numbers being trained at once. Most countries are putting the majority of their efforts into in-service training, which involves providing professional development for teachers who in secondary schools may be currently teaching another subject, and in primary schools, may not have come across computing before. Interactive and sustainable models of professional development are needed [25].

Considerable energy has been put into computing professional development (PD) over the past decade, with many programmes designed and developed for teachers [21, 25, 36, 49, 65, 74, 87], with a recognition that teachers need both subject knowledge and knowledge of how to teach computing [33, 73, 86].

Alongside the growth of computer science in schools has been a call for it to be open to *all*, not simply a few [37] given that a lack of diversity in CS has implications not just for individuals but for society as a whole [17]. Achieving equity involves addressing not only the politics and purposes of CS education reform but also the content of the curriculum and the design of learning environments [78].

2.2 The CAPE Framework and Capacity

The lack of a skilled teacher workforce is a significant issue in providing the capacity for CS education in schools in high-income countries [39, 73, 86]. In contrast, globally, other issues may

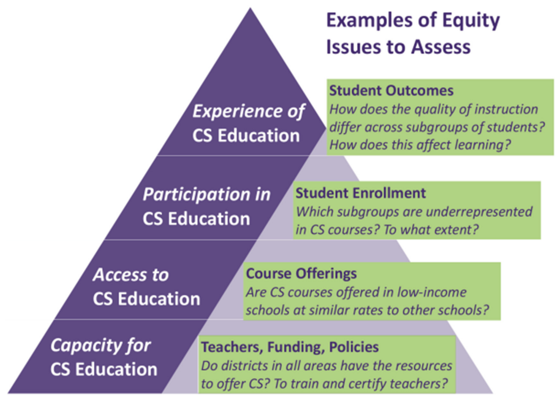

Fig. 1. The CAPE framework [19].

include IT infrastructure, internet access, and the existence of government policy to support curriculum development. Recently, the CAPE framework has emerged as a model, addressing four key components of CS education: *capacity for*, *access to*, *participation in*, and *experience of* equitable CS education [29, 30, 82]. The CAPE pyramid shown in Figure 1 demonstrates how these four components build and rely on each other.

Experience of CS education at the top level of the CAPE framework is concerned with the outcomes of the learning experiences of the students [30]. This means that all students should feel a sense of belonging and self-efficacy in CS. It means that the teaching methods and curricula should be culturally responsive and give the students a positive experience, ensuring that all students have similar learning outcomes and CS enrollments [82]. As one way of measuring equitable learning experiences, Warner and colleagues used the advanced placement CS course grades to identify students who pass or fail. The results reveal that Hispanic/Latino and Black students scored lower than the Asian and White students. They recommend that educational policies should promote a positive experience for diverse students.

Before students can have equitable CS learning experiences, they must first participate in CS education.

Participation in CS education means that students are actively engaged in a CS learning opportunity regardless of their background [30]. It means addressing equity issues of the differences in CS participation based on students' socioeconomic status, gender, or race/ethnicity. For example, In 167 Indiana (U.S.A.) high schools (2018–2019), there was a disparity between males and females who participate in CS, with male students being 3.63 times more likely to participate in CS than female students [82]. Warner and colleagues recommend that educational policies consider promoting practices that encourage female enrollment and hence providing equitable CS education experiences.

Before students can fully participate, they must have equitable access to CS education.

Access to CS education is the opportunity for students to access and learn CS in a school that offers CS courses regardless of their socioeconomic status [30]. For instance, addressing equity issues of differences in rural access compared to urban school districts. To investigate access to CS education, Warner and colleagues evaluated data from four American states, Connecticut, Massachusetts, Rhode Island, and Vermont. They discovered that schools with lower proportions of economically disadvantaged students tended to offer more CS courses than schools with higher proportions of economically disadvantaged students [82]. They recommend that policies help reduce these disparities by considering the number of CS courses, diversity, and rigor of CS courses available to students.

If schools are to provide students access to CS, then they must first have the capacity for CS education.

Capacity for CS education at the lowest level of the CAPE framework is concerned with the availability of resources such as teachers, funding, and policies that support the implementation of a CS instruction of high quality [30]. Warner et al. [82] specifically explain the Capacity for CS as including multiple factors, such as CS teachers' knowledge and skills, technology and professional development funding, as well as the time to include instruction in a CS subject. They specifically focus on teacher capacity at this level, because a lack of qualified teachers has been reported as a primary reason schools did not offer CS courses in U.S. K-12 schools. They report disparities in teacher capacity between urban and rural schools. They recommend that policies advocate for teacher professional development funding for rural communities. Teacher professional development opportunities should be available in every school regardless of socioeconomic status.

The CAPE framework is a valuable model for CS education researchers to collect, analyze, and report data and track the progress of broadening participation in CS education across all levels. It was developed with equity in high-income countries like the U.S.A. in mind but had resonance everywhere. It provides a helpful framework to consider the development of computing education globally, although adaptations to the framework may be needed. The ultimate goal is a more diverse computing profession [30].

In this article, we focus on the lowest level of the CAPE framework capacity. Even though Warner et al. [83] explain the capacity for CS as including multiple factors such as teacher capacity, funding, technology, and time, they operationalize the "capacity" aspect of the CAPE framework as the availability of qualified teachers certified to teach computer science. While that is true, it may have more components for low- and middle-income countries. For example, a comprehensive review of the introduction of computational thinking and computing in European countries identified policy actions to develop capacity, which included working with stakeholders and consolidating national and international exchanges [20].

A study of issues surrounding the introduction of computer science at the university level in low- and middle-income countries (Rwanda and Afghanistan) pointed to the value of collaboration with countries with more experience and technological advancement. However, the study found it inappropriate to transplant programs as is into less economically developed countries [62]. Therefore other aspects of capacity building will include developing a localized curriculum [20] and access to technology for students [62].

Teacher capacity is, of course, very important to the development of computing education in a country once these things are in place. Teacher professional development has been shown in high-attaining countries to be necessary for improving teacher competency and student academic success [16]. Developing teacher expertise is a crucial element of the capacity layer of the CAPE framework. Thus, increasing the capacity of the teaching workforce involves curriculum reform and extension, formal teacher education and training, and guidelines instituted at a national level by a central government or partner [84].

Given that capacity may be represented in multiple sub-components in different regions, this study contributes by collecting and analyzing data on the status of K-12 CS education in four African countries and evaluating how the CAPE framework can be applied to low- and middle-income countries.

2.3 The Context in Africa

Most research in computing education in primary and secondary schools has been conducted in developed countries such as the United Kingdom, U.S.A., Norway, New Zealand, Germany, Scotland, and more [15, 34, 35, 43, 70, 73]. The most significant challenge in measuring computing education

Table 1. General Characteristics of the Selected African Countries (2020)

Country	Botswana	Kenya	Nigeria	Uganda
Population (million)	2.35	54.5	206	44.3
No. of schools	1,112	89,361	20,314	129,734
No. of students	520,110	16,060,000	27,900,000	10,220,172
No. of teachers (FTE)	30,311	496,801	834,613	125,883
African region	South	East	West	East
Income classification (World Bank[1])	Upper-middle	Lower-middle	Lower-middle	Low

in developing countries like Africa is that published data are still lacking or in their infancy [31]. This is slowly beginning to change as organizations such as UNESCO [31] and the World Bank [76] have made it their mandate to administer international data collections on the availability and use of ICT in education. Although their focus is primarily on ICT, this is an important initiative that can provide critical inputs and insights concerning computing education in Africa.

Most countries in sub-Saharan Africa have launched ICT in education policies. For example, various countries have a policy addressing ICT in education: Angola, Botswana, Côte d'Ivoire, Eritrea, Gambia, Mauritius, Rwanda, Sao Tome and Principe, South Africa, Uganda, and Zambia [31]. Some have already started to update and renew their policies based on improving and addressing challenges in their initial policies [42, 52]. The availability and accessibility of ICT in sub-Saharan Africa have been mainly concentrated in the upper-middle-income African countries rather than low-income countries [71]. For example, Seychelles, Mauritius, South Africa, Botswana, and Namibia are the highest performing sub-Saharan African countries in terms of the number of students in primary school with radio, television, and computer access [31, 71]. While most of these policies started off focusing on the availability of and access to ICT in secondary education, some are now including primary schools [31].

While ICT has been used in many parts of Africa to improve the quality and increase access to education, most African countries still face the challenge that increased expenditure on education is not necessarily achieving the expected educational benefits [88]. Furthermore, most of these countries still face challenges in implementing ICT in education. Several countries across the region do not have any policy regarding basic computer skills or computing in either primary or secondary curricula, e.g., Burkina Faso, Comoros, Guinea, Madagascar, and Niger [31].

In the next section, we describe the state of computing education in K-12 in four selected African countries.

3 COMPUTING EDUCATION IN FOUR AFRICAN COUNTRIES

This study aims to describe computing/computer science education in primary and secondary schools in Africa from the teachers' perspectives. We have selected four countries in Africa: Botswana, Kenya, Nigeria, and Uganda. These countries are from different economic income ranges (from upper middle income to low income) [5]. Botswana is from Southern Africa, Nigeria from West Africa, and Uganda and Kenya are neighbors from East Africa. The characteristics of these countries are shown in Table 1. Table 2 shows the education system for each of the four countries, set against the U.S. system for comparison. Systems can differ significantly with the naming of different stages of education varying from country to country. Table 3 shows the requirement for computer studies teaching across the four countries.

[1]https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

Table 2. K-12 Education in the Selected African Countries

Country Age	U.S.A. (for comparison)	Botswana	Kenya	Nigeria	Uganda
4–5	Pre-school	Pre-kindergarten	Pre-primary(PP-1)	Nursery 1	Nursery
5–6	Kindergarten	Kindergarten	Pre-primary (PP-2)	Nursery 2	Primary 1 (P1)
6–7	Grade 1	Standard 1 Primary	Grade 1	Basic 1 (P1)	Primary 2 (P2)
7–8	Grade 2	Standard 2 Primary	Grade 2	Basic 2 (P2)	Primary 3 (P3)
8–9	Grade 3	Standard 3 Primary	Grade 3	Basic 3 (P3)	Primary 4 (P4)
9–10	Grade 4	Standard 4 Primary	Grade 4	Basic 4 (P4)	Primary 5 (P5)
10–11	Grade 5	Standard 5 Primary	Grade 5	Basic 5 (P5)	Primary 6 (P6)
11–12	Grade 6	Standard 6 Primary	Grade 6	Basic 6 (P6)	Primary 7 (P7)
12–13	Grade 7	Standard 7 Primary	JS (Grade 7)	Basic 7 (JS 1)	Senior 1 (S1 O-level)
13–14	Grade 8	Form 1 JS	JS (Grade 8)	Basic 8 (JS 2)	Senior 2 (S2 O-level)
14–15	Grade 9	Form 2 JS	JS (Grade 9)	Basic 9 (JS 3)	Senior 3 (S3 O-level)
15–16	Grade 10	Form 3 JS	SS (Grade 10)	SS 1	Senior 4 (S4 O-level)
16–17	Grade 11	Form 4 SS	SS (Grade 11)	SS 2	Senior 5 (S5 A-level)
17–18	Grade 12	Form 5 SS	SS (Grade 12)	SS 3	Senior 6 (S6 A-level)

Table 3. Computer Studies Teaching across the Selected African Countries

Country/Age	16–18 years	14–16 years	11–14	6–10 years
Botswana	E	C	N	N
Kenya	N	E	N	N
Nigeria	E	C	C	C
Uganda	E	E	N	N

C = Compulsory; E= Elective; N= Not taught

3.1 Botswana

Computing education in Botswana has a long history, stretching back to the early 1990s, with periodic reviews. In 1994, the Revised National Policy on Education [7] recommended that every student in junior secondary (JS) should take an introductory non-examinable computer awareness course, which was implemented in 1997 [61], covering basic ICT content: introduction to computers, basic computer skills, introduction to Windows and productivity, word processing, spreadsheets, databases, presentation, graphics, and ICT in learning. Computer studies subject was later implemented in 2003 [59] and is now taught as an optional examinable subject at senior secondary (SS) level covering computer hardware and software, computer applications, social and economic implications of the use of computers, systems development lifecycle, programming concepts, data and file management, and systems and communications.

In its efforts to achieve Vision 2016 [8], Botswana has made strides in ensuring that most secondary schools have access to computers and the internet, and the corporate sector has supported this by donating computers to public schools [42, 52]. Botswana's Vision 2036 [9] includes the introduction of computing education at the primary school level, indicating the country's view that knowledge of technology is a key driver of productivity and economic growth [9]. Computing education policies in Botswana seem to be sufficient, although there is still room for improvement. However, they focus more on the computers and internet accessibility and availability than on empowering the teachers on how to use these resources to teach computing. While computers and the internet are available in almost all secondary schools, some primary schools still struggle with a lack of physical ICT infrastructure and internet [52]. In addition, the teaching of computing at primary is still in its infancy: inconsistent and not compulsory [52].

3.2 Kenya

Computer education in Kenyan schools was first introduced as an optional subject in 1996 with the Ministry of Education implementing the curriculum [60] in secondary schools (from Form 1 to Form 4) [47, 57]. This was a result of collaboration between UNESCO and the Ministry of Education on computer education in 1996 [57]. The Ministry later published policy and curriculum guidelines in 1997 approving the teaching of computer education in secondary schools. The computer studies syllabus [60] has more basic ICT content, which includes, among others: Computer Systems, operating systems, word processors, spreadsheets, databases, desktop publishing, data processing, and elementary programming principles and system development. In January 2006, Kenya developed a National ICT Policy with the aim of encouraging the use of ICT in schools [26]. In an effort to fulfil this, the government and some NGOs supplied computers and ICT to teacher training Colleges and some schools [57]. The ICT policy was reviewed in 2019 to advocate for the integration of ICT subjects in the curriculum at all levels of education [50]. Vision 2030 has been an enabling factor in ensuring the adoption of ICT skills in schools, which resulted in the government rolling out a project to distribute laptops to students in primary schools, and this was partially implemented in some schools [47, 53]. The Competency-Based Curriculum was launched in 2017 with one of its main drives toward improving digital literacy (use of digital content for class). However, it was not implemented in many schools [1, 18]. Although Kenya has ICT policies and initiatives to promote the teaching of computing in schools, there are still significant challenges in implementing them [56]. These include inadequately trained teachers, a high student/teacher ratio, unavailability of teaching material as well as inadequate ICT resources [18, 44]. Furthermore, public schools lag in the acquisition of technology resources and infrastructure, increasing the gap between them and private school students.

It should be noted that at the time of completing writing this article, the Kenya government approved the first programming syllabus for primary and secondary schools [45].

3.3 Nigeria

The first policy on computer education was issued in 1988 in response to the growing popularity of computers across the world. However, teachers taught with unapproved documents or self-compiled topics until 2002, when the National Education Research and Development Council produced the first "Computer Education Curriculum for Primary Schools" [75]. The 2004 National Policy on Education then made "computer education" a compulsory subject for all students in primary and junior secondary schools [68]. In 2012, the National ICT policy mandated the integration of ICT into all tiers of education [58, p. 30]. The basic education IT curriculum topics cover three themes: basic computer operations, basic concepts of IT, and computer application packages [40, 66, 67]. The content covers materials that impart knowledge to the students with some opportunities for seeing computers in action and possibly using them. Computer studies is an option at senior secondary education within the science and mathematics field. Students may select one to three subjects outside their major field [69, p. 18–21], which gives opportunity for all students to elect computer studies. The Senior Secondary Computer Studies syllabus from the West African Examination Council includes the following topics: computer fundamentals and evolution, computer hardware, computer software, basic computer operations, computer applications, managing computer files, developing problem-solving skills (including programming in BASIC), computer ethics, and human issues [14].

Some of the endemic challenges of CS/IT education in Nigeria are poor availability of equipment (hardware and software), power supply, and quality of teachers. Private schools tend to fare better than public schools in this regard [75], although less than 20% of students in basic and senior secondary education attend private schools [28].

3.4 Uganda

The computer studies syllabus was introduced into upper secondary education and covers knowledge areas like computer hardware and software, data communication, system security, ICT ethical issues, and emerging technologies [11]. In response to Uganda's Vision 2040, which advocates for quality education, the Ministry of Education and Sports developed a competency-based lower secondary computer education curriculum in 2019 [12]. It consists of 16 topics distributed across four thematic areas (computer systems, data management and sharing, ICT safety, and environment and publications). The computing curriculum in the country is largely limited to teaching basic computer-use skills (with emphasis on word processing applications) with some focus on the use of the internet for accessing educational materials. In 2014, the Revised National Policy on Education recommended that every primary, secondary, and tertiary education level should pedagogically integrate ICTs into the teaching and learning process [51]. As of 2020, there has been no formal ICT curriculum for primary schools; however, due to the high demand for ICT skills in developing countries, extracurricular activities tend to offer these opportunities.

Some of the challenges facing the implementation of computing education are that most rural schools lack electricity, ICT resources such as computers and the internet, and qualified ICT teachers. Some initiatives and projects with support from international organizations have been rolled out to reduce the rural-urban schools' ICT digital divide by providing computers and training teachers [3]. This has resulted in the general increase in ICT use in Uganda's education system. However, these challenges persist [54]. Furthermore, some students do not complete school, primarily due to poverty and poor academic performance [48].

4 METHODS

4.1 Study Design

The pilot study intended to generate a baseline for understanding the capacity for computing education in primary and secondary schools in Africa by answering the research question:

What is the capacity for delivering computing education in primary and secondary schools in four African countries from the teachers' perspectives?

As well as an analysis of countries' policies and curricula, a study was designed to gather data from teachers in the four countries (Botswana, Kenya, Nigeria, and Uganda) around their experience of computing education through the use of a survey instrument and quantitative analysis. The existence of a publicly available and recent dataset for high-income countries opened the possibility of carrying out a comparative study between the four African countries and between African teachers and teachers from high-income countries. This part of the research was planned around three stages as follows:

(1) Instrument design and localization
(2) Participant recruitment and data collection
(3) Data analysis (including comparative)

4.2 Instrument Design and Localisation

Many researchers have sought to look at K-12 curricula for computing in specific countries with a range of survey instruments [4, 32, 46, 72]. In 2019, an international working group was formed to develop a survey instrument to support the evaluation of computing curricula around the world. The intention was that the survey instrument could be used to investigate the intended and enacted curriculum for computing in K-12 and teacher capacity, skill, and confidence in teaching the subject. The resultant instrument is MEasuring TeacheR Enacted Computing Curriculum (METRECC).

4.2.1 Development of the Original METRECC Instrument. The process of developing METRECC involved the development and curation of suitable questions and constructs and a pilot study consisting of 244 teachers across seven countries (Australia, England, Ireland, Italy, Malta, Scotland, and the United States). Finally, a review (including validity and reliability tests) led to revisions and the final published survey instrument. The instrument was intended to be as comprehensive as possible. In terms of reliability, the project group tested the instrument for internal consistency reliability, inter-rater reliability, and test–retest reliability. The METRECC study published the data openly to allow for replication or re-validation studies [41]. The work from this international group continued with several follow-up studies, all based on the work of the original pilot study, where these included the following: an international comparison of K-12 computer science education intended and enacted curricula [23], an international pilot study of K-12 teachers' computer science self-esteem [81] and comparing programming self-esteem of upper secondary school teachers to CS1 students [22].

4.2.2 Adopting the METRECC Instrument for the African Study. Concerning our research, we use the METRECC instrument, as it also consists of questions that address capacity factors that impact the enactment of a CS curriculum. These include teacher professional development, support, and resourcing (access to infrastructure, facilities, equipment, curriculum content taught, access to teaching materials and resources). These questions align with our research objective of understanding the capacity for delivering computing education in primary and secondary schools in Africa. Details of factors affecting capacity are already discussed in Section 2.2 (the CAPE framework and capacity). By using an adapted version of the METRECC instrument for this particular study, we can further the aims of the METRECC project, whereby researchers collectively work together toward a global picture of computing education in schools over time. In addition, we analyze the survey results using the CAPE framework to track the progress of broadening participation in the African countries.

4.2.3 Localisation of the METRECC Instrument. There was some adaptation needed to ensure that the instrument was appropriate for teachers in Africa. It was essential to have local knowledge of each country being studied to be able to localize the survey instrument.

The original METRECC questionnaire took 1 hour and 14 minutes to complete and was subsequently shortened by the team, giving an estimate for the completion time of 30 minutes [24]. Given that computer studies/computer science is not well developed in our participant community, we sought to shorten the questionnaire to less than 20 minutes. We also wanted to facilitate completion by removing questions that were not relevant in the African context and adapting those that needed different terminology.

We removed some questions that were not relevant to capacity and related to non-teaching qualifications, classroom research, self-esteem, motivation, the teaching of cognitive and affective skills, and primary native language. We included some questions that were related to the capacity of resources and teacher professional development. We adapted some other questions to ensure that the questionnaire was meaningful to African teachers as follows:

- We changed computer science to computer studies/computer science and explained what was meant by computer science and computational thinking at the beginning of the questionnaire.
- The list of topics was also changed to include some typical ICT topics such as word-processing, spreadsheets, and so on. This was because the researchers representing the African countries felt this would make teachers feel more comfortable completing the survey.

- We created different questions for Botswana, Kenya, Nigeria, Uganda, and “Other” to capture the stages of school being taught (see Table 2).
- The question about programming environments was localized to reflect the difference between learning programming in a text-based language using pen and paper, pseudocode, and unplugged activities as three different approaches to programming without computers to more fully represent teachers’ experience.
- We adapted the type of school question to add international and non-profit schools.

The described changes were made iteratively by the authors in consultation with teachers in their country to ensure face and content validity.

4.3 Data Collection

The researchers associated with the selected countries in the study were able to contact teachers who taught computer studies directly through their networks. Sampling was purposive [13] to locate teachers who would identify as teachers of computer studies/computer science and therefore be willing to complete the survey. A variety of sources were used to find initial participants, both through school networks and through links to non-profit organisations/industry partners engaging in educational programmes. Contact was made by personal phone calls, email, and instant messaging; social media was used but was not thought to be effective in this context. Snowball sampling [13] was then used as those contacted passed on the survey in their own networks. Finally, in addition to circulating the survey, the researcher from each country completed the METRECC country template.

The survey was open from December 1, 2020, to January 31, 2021. Survey Monkey’s estimated completion time was 17 minutes, and the actual time taken to complete the survey was from 9 minutes to 1 hour 58 minutes, with the median time being 24 minutes. Fifty-eight teachers completed the survey in its entirety and gave permission for the data to be shared publicly. In addition 10 teachers completed the survey but did not give this permission, and another 128 did not complete the survey to the end. Of the 58 teachers, 23 were from Botswana, 10 from Kenya, 15 from Nigeria, 9 from Uganda, and 1 from Zimbabwe. The final dataset has been made publicly available [77].

4.4 Data Analysis

The following data analysis steps were followed:

(1) Finalisation of the analytic sample. Only the data for participants who fully completed the survey ($n = 58$) was used. The data relating to the teacher from Zimbabwe were removed for comparative analysis between countries as an $n = 1$ result was not felt to be valuable in this case but utilized when reporting across all respondents. Survey data were downloaded into MS Excel.
(2) Descriptive statistics. Data were analyzed using excel and statistical analysis scripts in Python. The responses were summarised by country and across all the African countries.
(3) Comparative statistics. The descriptive statistics were compared to those from an open-access dataset for the same questions and differences presented. This dataset ($n = 244$) is from the original METRECC survey conducted in 2019 by the ITICSE working group [24]. The pilot study of the METRECC instrument involved only high-income countries (Australia, England, Ireland, Italy, Malta, Scotland, and the United States). Therefore, for the rest of the article, we will refer to this dataset as “teachers from high-income countries” to contrast it with “African teachers,” our dataset. This included an analysis of the barriers to professional development to identify any statistical differences that highlighted a capacity issue for the African countries under consideration.

(4) Statistical test. The test used to compare the two ordinal datasets for (Q26) was a Mann–Whitney U test [27]. This test assumes that the data are non-parametric and is used to compare two independent populations, assuming that the observations from both groups are independent, the responses are ordinal, and that under the null hypothesis H_0, it assumes that the distribution of both groups is equal [63]. The confidence interval that will be used for comparison of the p-values are 95%.

5 SURVEY RESULTS

5.1 Participant Demographics

Of the 58 teachers completing the survey, 33% ($n = 19$) identified as female and 67% ($n = 39$) as male. The majority of teachers were less than 50 years old (98%, $n = 57$), with a median age of 30–39 years. Forty percent ($n = 23$) of teachers described their location as rural or extremely rural, with another 40% as urban and 19% ($n = 11$) as peri-urban (close to a town). Most teachers' (65%, $n = 38$) highest qualification was a Bachelor's degree or higher, with 22% ($n = 13$) having postgraduate qualifications. Twenty-three teachers were from Botswana, 10 from Kenya, 15 from Nigeria, and nine from Uganda.

5.2 Experience of Teaching

Teachers were asked to share their CS teaching experience, e.g., years of experience teaching CS. Overall, the teachers had the experience of teaching computer studies/computer science in school. Sixty-six percent ($n = 38$) had more than 3 years' experience, and 33% ($n = 19$) had more than 10 years of experience. Botswana teachers were the most experienced, with over 50% ($n = 13$) of the Botswana teachers completing the survey having more than 10 years of experience in teaching computer studies/computer science. Most teachers (65%, $n = 38$) reported that less than 50% of their students had a low socioeconomic status. Sixty-nine percent ($n = 40$) of teachers taught in public or government-funded schools, with the remaining 31% teaching in non-government, independent, non-profit, or international schools.

Twenty-three of the 58 (40%) teachers taught computer science/computer studies for more than 50% of their time. Fifteen of the teachers stated that more than 50% of their time had been spent teaching computer science without computers. Seventeen percent of the Botswana teachers said that they had been teaching computer science without computers, as compared to 30–33% in the other three African countries. This difference is discussed further in Section 6.3.

5.3 Capacity in Terms of Curriculum

The intended curriculum relating to each of the four countries in our study has already been described in Section 3. As already elaborated in Section 2.2, the curriculum is integral in capacity building; therefore, teachers were asked to stipulate what curriculum they followed and the subjects they taught. Sixty-two percent of the teachers used a national or provincial standard curriculum to teach computer studies/computer science, but there was some variation by country (Botswana, 87%, Kenya, 70%, Nigeria 33%, and Uganda 33%). In Nigeria and Uganda, 55–60% of the teachers used either their own or their school's computer studies/computer science curriculum, which was higher than for Botswana and Kenya.

Topics taught in the different countries are shown in Table 4. The top half of this table shows the topics that were included in the original version of the survey instrument and for which there are data from high-income countries. The lower half of the table includes game design, which was added to the revised version of the full METRECC survey but for which there are no 2019 data.

Table 4. Topics Taught: African Teachers vs. Teachers from High-income Countries

Topic	Botswana	Kenya	Nigeria	Uganda	Africa	High-income
Programming skills and concepts	48%	70%	47%	22%	48%	90%
Privacy	61%	60%	40%	11%	48%	62%
Robotics	43%	0%	20%	0%	24%	42%
Databases	96%	90%	33%	56%	72%	43%
Ethics	65%	70%	40%	44%	57%	67%
Web Dev/Web 2.0	13%	30%	13%	56%	24%	48%
Data representation	43%	80%	53%	44%	53%	70%
Machine learning	30%	0%	20%	11%	19%	19%
Cybersecurity	65%	60%	33%	11%	48%	59%
Algorithms	52%	90%	47%	33%	55%	84%
Hardware	100%	90%	60%	67%	83%	68%
Information systems	70%	80%	47%	44%	62%	42%
Data analysis and visualisation	43%	30%	33%	11%	34%	36%
Network and digital systems	70%	90%	40%	33%	60%	52%
Computational thinking	26%	20%	47%	0%	28%	74%
Artificial intelligence	52%	40%	20%	11%	36%	27%
Design process	48%	70%	27%	0%	40%	61%
Added to survey localised to Africa						
Computer applications	96%	100%	80%	78%	90%	N/A
Word-processing	96%	100%	67%	56%	83%	N/A
Computer software	96%	70%	73%	56%	79%	N/A
Operating systems	83%	100%	53%	44%	72%	N/A
Spreadsheets	96%	80%	47%	33%	71%	N/A
Data and file management	87%	40%	60%	56%	67%	N/A
Social and economic implications	74%	80%	47%	22%	60%	N/A
Systems development lifecycle	57%	90%	47%	11%	53%	N/A
Computer graphics	61%	60%	47%	22%	52%	N/A
Game design	4%	10%	7%	11%	7%	N/A

Also, additional topics that the researcher team felt were more pertinent to Africa and would help African teachers who were completing the survey.

Across the teachers in Africa, the seven most commonly taught topics were computer applications, word-processing, computer software, databases, hardware, and spreadsheets. On average, 55% of the African teachers taught algorithms and 48% programming skills and concepts. This was much higher among Kenyan teachers, with 90% teaching algorithms and 70% teaching programming.

Table 4 also shows a comparison between the “high-income dataset” and African teachers. The table shows that the teachers from high-income countries were teaching more algorithms, computational thinking, and programming, and the African teachers were teaching more databases and hardware topics. There are fewer differences between the two datasets concerning ethics, cybersecurity, and networks.

One of the areas of interest in this study was the amount of time teachers spent teaching programming and the type of environments they used. As described in Section 4.2, the question was adapted to understand if the African teachers had resources to teach the programming content in the curriculum, if any. Teachers were asked whether they used unplugged activities, block-based

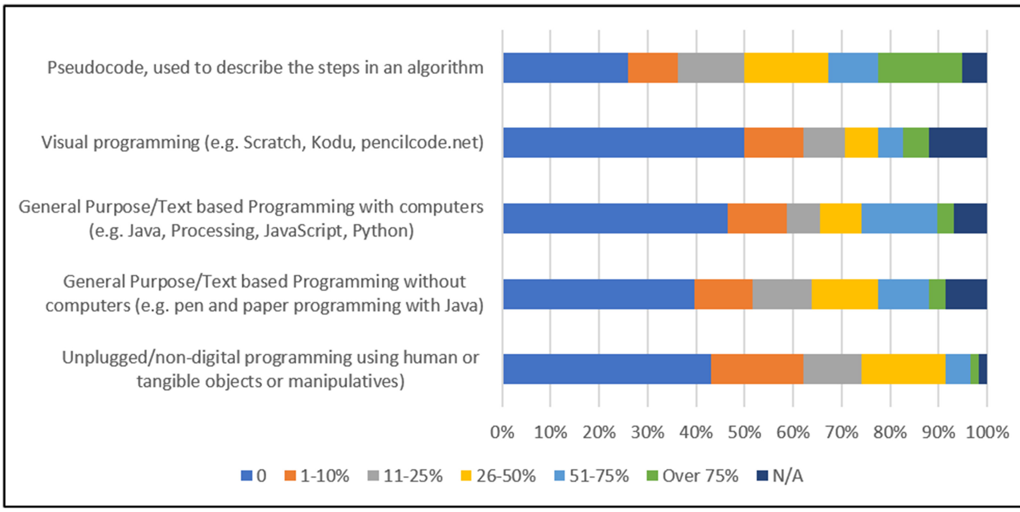

Fig. 2. Programming environments used.

(visual programming), or text-based programming environments and additionally if they taught text-based programming through pen-and-pencil methods and the extent to which they used pseudocode. The response to this question is shown in Figure 2. It shows that 69% teachers used pseudocode to some extent, 52% taught text-based programming using pen-and-paper methods, 38% used visual (block-based) programming environments, and 47% taught programming using text-based programming environments on computers. Although the question was asked differently in the original pilot study, comparing the amount of time teachers said they used text-based programming environments is possible. Sixty-five percent of the teachers from high-income countries said that they taught text-based programming (on computers), using languages such as Java and Python. In contrast, only 47% of the African respondents did so.

5.4 Capacity for Professional Development

Capacity for computing education includes the knowledge and skills of the CS teachers. The teachers' CS knowledge and skills can be enhanced through professional development. Therefore, teachers were asked (Q24) about the types of professional development they have accessed in computer studies/computer science over the last 12 months. These include a range of options, including peer observation, personal research, observation visits to other schools or industries, and courses and formal training. The most frequently accessed forms of professional development for the African teachers completing the survey were courses, workshops, and seminars, with 59% teachers saying that they had accessed these, closely followed by reading and peer observation. Only 28% of African computer studies teachers said they had participated in a teacher network. Figure 3 shows these data compared to the high-income countries. Teachers were also asked if they would like to access the forms of professional development they had not been able to previously access, and 65% ($n = 38$) said they would value participation in a teacher network or the opportunity to observe computing in a business or industry setting.

5.5 Capacity in Terms of Support and Resources Available

To understand the capacity for resources in African schools, teachers were asked (Q14) about the support they had for their computing teaching during the last 12 months from the following list:

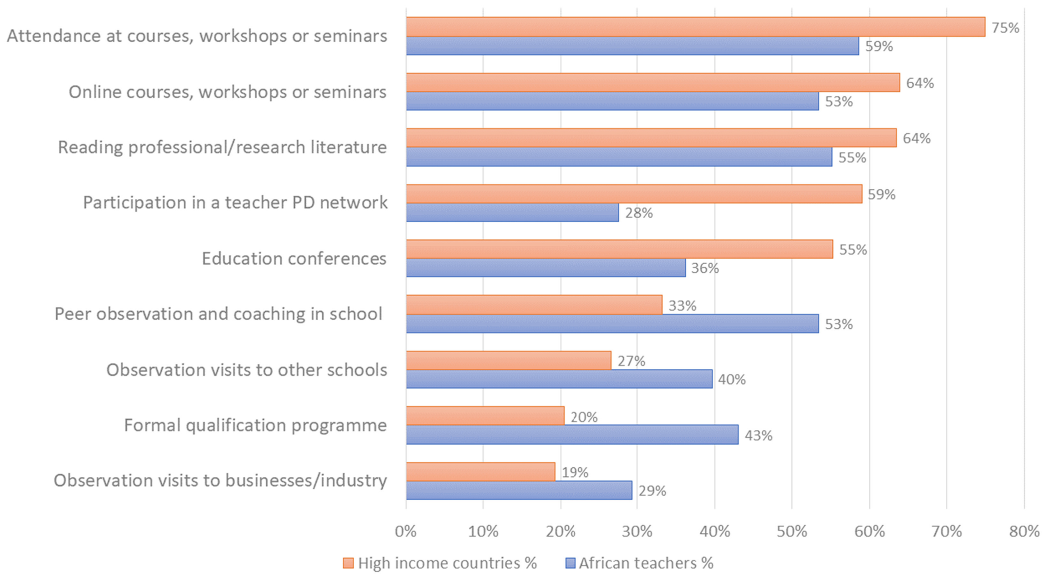

Fig. 3. Types of PD accessed by African teachers responding to survey compared to high-income countries.

Table 5. Support Teachers Have Access to Teaching Computer Studies/Computer Science

Resources	Africa (all)	Botswana	Kenya	Nigeria	Uganda	High-income
School ICT Support Staff/lab attendant/technician	**57%**	78%	60%	33%	44%	**67%**
Computer lab	**78%**	100%	80%	67%	33%	**84%****
Additional time allotted for class preparation (e.g., planning time during the day)	**26%**	100%	80%	67%	33%	**56%**
Time off to attend Professional Development	**17%**	13%	50%	7%	0%	**76%**
Team teaching or team support	**28%**	30%	40%	20%	22%	**28%**
Funding to purchase computing equipment	**16%**	17%	20%	7%	11%	**52%**
I have none of these	**16%**	0%	10%	33%	33%	**N/A**

**Question differently phrased.

- School ICT support lab/technician
- Computer lab
- Time for preparation
- Time off for professional development
- Team teaching/support
- Funding for equipment

Botswana teachers (100%, $n = 23$) had access to a computer lab, whereas only 33% ($n = 3$) in Uganda. Thirty-three percent of Nigerian and Ugandan teachers ($n = 5$, and$n = 3$, respectively) said that they had no access to any of the items in the list (see Table 5). This is despite the fact that most of the Ugandan teachers in the sample are in non-government-owned schools. There is also more access to technician support in Botswana at 78% ($n = 18$). This points to the fact that more infrastructure is available in Botswana to support the teaching of computing than in other countries.

Table 6. Support Needed by Country

Support needed	Africa (all)	Botswana	Kenya	Nigeria	Uganda	High-income
Non-CS specific technology equipment (e.g., computers, tablets)	52%	48%	50%	60%	56%	25%
CS-specific technology (e.g., robotics, CS software)	57%	70%	70%	40%	33%	48%
Improved technology infrastructure (e.g., Internet)	67%	65%	90%	40%	100%	32%
Support to carry out classroom research	38%	30%	40%	40%	44%	31%
Professional Network/Community	59%	61%	40%	60%	67%	N/A
I do not need any additional support teaching Computer Science.	2%	0%	0%	0%	11%	N/A

In terms of time off for professional development, only 13% of the Botswana teachers received this. Only in Kenya did teachers report (n = 5, 50%) that they had some provision to attend professional development in school time.

Table 5 also includes teachers responding positively to this question from the data on high-income countries, although one of the questions in the METRECC survey is slightly different. The METRECC survey asks about a "single CS classroom or shared computer room," whereas we translated this to "computer lab" for this survey version. This may make it difficult to compare that particular item. When comparing the resources available across all teachers in the African survey and the high-income countries, the most considerable differences are shown in terms of time off to attend professional development (17% compared to 76%) and funding for computer equipment (16% compared to 52%).

To understand more about the capacity for resources, we asked the teachers what they had used for teaching computer science over the last 12 months. This includes computers, textbooks, and phones/tablets. Teachers in Botswana all used laptops or PCs, with only 78% (n = 11) and 73% (n = 7) in Nigeria and Uganda, respectively. However, 60% (n = 9) of teachers from Nigeria said they were using smartphones or tablets to teach, which was higher than the other countries. Across all the teachers in the survey, only 33% were accessing programming resources online and 24% using online question banks.

In the next two sections, we identify the needs expressed by the teachers in terms of support needed and perceived barriers to professional development.

5.6 Capacity in Terms of Support Needs for Resources

To understand more about the teachers and resource capacity in the four countries, we asked the teachers (Q25) what support they would need to help them teach computer science/computer studies. The question specifically enquires about the teachers' ICT infrastructure needs and their professional development needs to implement a successful CS curriculum. Up to three answers were permitted (see Table 6).

The results indicate that in Uganda and Kenya, the greatest need is for improved technology infrastructure. In contrast, in Botswana, it is for CS-specific resources such as robotics, and in Nigeria, the greatest need is for both computers and tablets and a professional network. Across the four African countries, the greatest needs are for improved infrastructure (n = 39, 67%) and also a professional network for the teaching of computer science in primary and secondary schools (n = 34, 59%). However, when comparing between countries, there are differences in the need for infrastructure: Ugandan teachers (n = 9, 100%) said improved technology infrastructure would be valuable in contrast to 40% (n = 6) Nigerian teachers and 65% (n = 15) teachers from Botswana. Section 3 highlighted that there is more provision for infrastructure in Botswana than in Uganda, and this may be reflected in this data.

Table 7. Barriers to Professional Development: Percentage Responses

	High-income countries (n = 242)					Survey data from African countries (n = 58)				
Question	SA	A	N	D	SD	SA	A	N	D	SD
I do not have the prerequisites (e.g., qualifications, experience)	2%	16%	16%	22%	43%	14%	10%	12%	29%	33%
Professional training is too expensive	11%	33%	26%	18%	12%	31%	38%	14%	10%	5%
There is a lack of support from my school	10%	22%	22%	28%	18%	12%	31%	24%	24%	7%
I do not have time because of family responsibilities	18%	34%	19%	19%	10%	5%	5%	24%	40%	24%
The training or PD conflicts with my work schedule	8%	22%	22%	30%	18%	5%	19%	31%	31%	10%
There is no relevant training or professional development offered	6%	22%	20%	33%	18%	19%	24%	17%	28%	10%
There are no incentives for participating in PD	13%	30%	21%	22%	14%	17%	28%	21%	22%	7%
The distance to travel is too great	17%	31%	26%	17%	9%	14%	26%	26%	26%	7%
I don't have the resources (equipment, network access) to participate in PD	5%	19%	33%	26%	17%	16%	29%	9%	36%	7%

SA = Strongly agree; A = Agree; N = Neutral; D = Disagree; SD = Strongly disagree

5.7 Capacity in Terms of Barriers Experienced for Professional Development

To understand teacher capacity in professional development, teachers were asked (Q26) about barriers to professional development: "How strongly do you agree or disagree that the following present barriers to your participation in CS professional training or development?," which consisted of nine Likert scale statements, using a five-point scale ranging from *Strongly agree* to *Strongly disagree* with a Neutral option. Table 7 presents the percentage of responses per question per study.

We undertook a statistical comparison between the data from the high-income countries and the African study responses. Acknowledging the selection of anchor points and the use of varying weighted means for analysis, the comparison used in this study selected the following weighted values to calculate the mean: 5 is *Strongly agree*, 4 is *Agree*, 3 is *Neutral*, 2 is *Disagree*, and 1 is *Strongly disagree*. This data are summarised in Figure 4, which shows the summed strongly agree and agree on responses compared across the two populations.

To compare the two study cohorts' responses to each statement, we selected and conducted a Mann–Whitney U test (as described in Section 4.4) and present the p-value. The Mann–Whitney p-values for the comparison of the two studies' responses are presented in Table 8.

Statistically significant differences: The statement with a statistically significant p-value (<0.000) was "I do not have time because of family responsibilities," where the teachers from high-income countries were more in agreement with this statement than participants from African countries. The cost of professional development ("Professional training is too expensive") also reported a statistically significant difference (p-value < 0.0000), where, in this case, African participants reported that this might be more of a barrier for them. Access to PD is another barrier with a statistically significant difference ("There is no relevant training or professional development offered"). Access to resources ("I don't have the resources (equipment, network access) to participate in professional development") highlights another statistically significant difference. This is also the case for support within the school ("There is a lack of support from my school"). For all these statements, the barrier is greater for African teachers than for the cohort from high-income countries.

Marginal differences: Only one of the statements reports a marginal/borderline comparison. This was the statement "I do not have the prerequisites (e.g., qualifications, experience)." While the

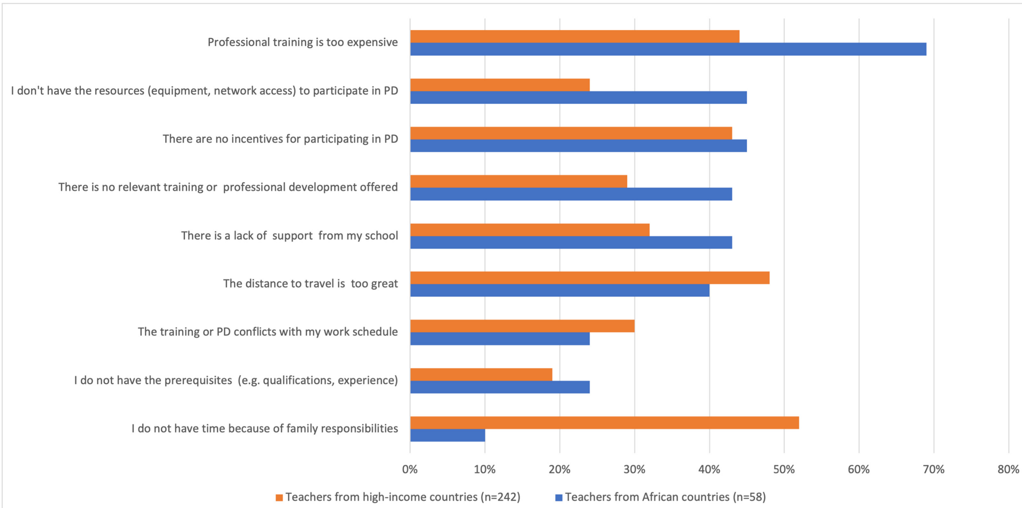

Fig. 4. Barriers to professional development.

Table 8. High-income Countries and African (All Four Countries) Analysis

Question	Mann–Whitney *p*-value
Professional training is too expensive	<0.0000
I do not have time because of family responsibilities	<0.0000
There is no relevant training or professional development offered	0.0053
There is a lack of support from my school	0.0141
I don't have the resources (equipment, network access) to participate in professional development	0.0189
I do not have the prerequisites (e.g., qualifications, experience)	0.0843
There are no incentives for participating in professional development	0.1346
The distance to travel is too great	0.1485
The training or PD conflicts with my work schedule	0.3523

p-value did not report a statistically significant difference between the cohorts. African teachers reported that they feel like they have fewer prerequisites. The remaining three statements showed no statistical differences.

6 DISCUSSION

This study aimed to understand the capacity state of computing education in primary and secondary schools (K-12) in Botswana, Kenya, Nigeria, and Uganda. We used the METRECC instrument to survey 58 CS teachers specifically about their implementation of the CS curriculum to understand the ICT resources available to them, the curriculum content they are using, their professional development, and the barriers they are facing. We also use the CAPE framework as a model to analyze the capacity of CS education in these African countries. The METRECC survey instrument captures data that allow for comparisons between countries. Therefore, we also use the survey results to compare the African countries and other high-income countries (England, Scotland, U.S.A., Australia, Italy, and Malta). This discussion section presents the emerging differences and explains the potential reasons for the difference, building on the capacity level of the CAPE framework.

From the survey findings, together with the analysis of the country backgrounds, five major themes that affect the implementation of CS have emerged: programming in the curriculum, teacher professional development, ICT infrastructure (computers, hardware, internet, software, etc.), funding, and policies. This section will start by discussing these five themes in the first five subsections, and the last part of the section will discuss how they can be applied to the CAPE framework.

6.1 Capacity in Terms of Curriculum

6.1.1 Comparison amongst the African Countries. The findings reveal that across all the four African countries, the commonly taught topics in the computing curriculum focus on the use of computers/ICT resources, and less focus is given to the teaching of programming. For example, only 57% of the teachers taught programming skills and concepts across three countries. Furthermore, the programming content in the syllabus across all these countries covers topics that teach facts compared to giving the students the ability to be program developers. For example, the content covered in the Botswana syllabus includes "programming techniques, representing algorithms using pseudo-code, showing understanding of different programming languages and program translators" [59]. At the same time, the Ugandan curriculum has no programming content at all [11]. Unlike the other three countries, Kenya has a syllabus with a minor component aiming to teach students to write and run programs [60], which explains why 90% of the teachers in Kenya are engaged with teaching programming. These results also show us that the intended computing curriculum influences the teachers' choice of programming environments. Less than half of the teachers use programming languages (text/blocks), and two-thirds use pseudo-code. The preference for pseudo-code over programming languages may also be because teachers are not trained to teach such content or the available infrastructure is inadequate to use these programming environments [55, 56].

6.1.2 Comparison between High-income Countries and Low-middle-income Countries (African Countries). Comparing the two datasets shows that African teachers are teaching more databases and hardware topics. At the same time, high-income countries have shifted from basic ICT skills to a more knowledge-based curriculum that includes computational thinking, programming, and algorithms. "Learning and acquiring digital competencies go beyond pure ICT skills, it involve the creative use of ICT, including coding" [20]. Crucially, while most of the African countries in the study have not reviewed their computing curriculum since implementation, most of the high-income countries have had the opportunity to review their curriculum more than once [43]. This allows countries to keep up with the rapid CS developments and teach relevant content that students will need to understand and fully participate in modern society.

6.2 Capacity in Terms of Teacher Professional Development

6.2.1 Comparison amongst the African Countries. There is not much variation amongst the African countries regarding accessibility to PD. However, more Kenyan teachers (50%) have reported that they are given time off to attend professional development compared to the other African countries. In contrast, Ugandan teachers have reported that they are given no time off to participate in professional training. On average, 17% of all African teachers have reported that they are given time off to attend professional training. Furthermore, the teachers report a lack of support from their schools and that there is no relevant training for them to attend. This could be because the implementation of ICT education policies is still very much focused on accessibility and availability of ICT infrastructure in the schools as compared to the training of teachers [52, 56].

6.2.2 Comparison between the High-income Countries and Low- middle-income Countries (African Countries). For African teachers, the main issue as far as PD is concerned is the cost, and there was a statistically significant difference ($p < 0.0000$) between teachers from African and high-income countries for this question. The data reveal that African teachers have relatively more access to PD activities with fewer cost implications, including peer observations and school visits. Teachers from high-income countries report more access to potentially costly activities with internet implications, such as workshops, seminars, short courses, education conferences, and PD networks. African teachers also reported having comparatively more challenges accessing ICT resources for training and not being offered relevant training.

ICT infrastructure has the potential to increase access to training and improve the quality of teacher training in Africa and bridge the gap between high-income countries and low-income countries. There are now many free online training materials as well as free online workshops for computing teachers that are provided by experts around the world [56]. The ability of the African teachers to take full advantage of the internet as an educational resource and as a means of sharing educational content remain key challenge [52]. Furthermore, teachers who do receive professional training are often unable to use their skills because of the lack of access to infrastructure [26]. ICT education policies in the African countries, as in the high-income countries, have recommended teacher training [50–52, 68].

6.3 Capacity in Terms of ICT Infrastructure

6.3.1 Comparison amongst the African Countries. Results show a wide variation in teachers' access to ICT infrastructure in the four African countries. As the only upper-middle country, Botswana has more ICT infrastructure in secondary schools, with 100% of the surveyed secondary school teachers reporting access to labs, computers, and laptops. It should be noted that each lab may consist of only 15–20 computers though [42]. The two lower-middle-income countries (Kenya and Nigeria) follow behind Botswana in terms of access to ICT. Ugandan teachers report the least access to ICT infrastructure, with only 33% of Ugandan teachers reporting having access to a computer lab; Uganda is a low-income country. Furthermore, the findings suggest that teachers from Uganda (100%) and Kenya (90%) have the greatest need for improved technology infrastructure (e.g., internet), as compared to Botswana (65%) and Nigeria (40%). The data reveal that Uganda, as the lowest middle-income country among the African countries, is the most affected by a lack of capacity for ICT infrastructure. Although still not enough, the availability of and access to ICT infrastructure in Africa has primarily been concentrated in the upper-middle-income countries as compared to low-income countries [71]. The inequalities amongst countries concerning access to infrastructure have already been reported in prior research [31, 79]. Lack of access to basic ICT infrastructure hinders the ability of the African schools to successfully implement their CS curricula. The availability of ICT infrastructure seems to correlate with the socio-economic status of the country.

6.3.2 Comparison between the High-income Countries and Low-middle-income Countries (African Countries). The data also show ICT infrastructure access disparity between African and high-income countries. More teachers have access to ICT infrastructure in high-income countries (84%) compared to African countries (78%). This is not a big difference, but it is skewed by the Botswana (upper-middle) teacher data. In addition, the data show that 73% of the African teachers need improved ICT infrastructure (e.g., internet) as compared to just 33% of the high-income countries. The gap between developed and developing countries seems to keep widening concerning access and availability of ICT infrastructure, as recently reported by Vegas and colleagues [80].

Although there are many ICT education policy initiatives in these African countries, efforts have been mainly geared toward deploying ICT infrastructure in secondary schools. This means that primary school students in these countries do not have the same access to computing education as secondary school students. For example, in some primary schools surveyed in Botswana, students in primary schools share two, three, or four computers that are available and functioning in the whole school [52]. These are problems that high-income countries may not face as they tend to introduce computing literacy as early as kindergarten/primary level [24]. The availability of ICT infrastructure in schools seems to be no longer frequently discussed in high-income countries [82], which allows them to focus more on teacher professional development.

Our findings seem to reveal that the ICT infrastructure is heavily affected by funding, as shall be discussed in the following subsection.

6.4 Capacity in Terms of Funding

6.4.1 Comparison amongst the African Countries. This study gave us insights into the capacity for funding in the African countries from a computing teachers' perspective. We acknowledge this may be a limited scope, yet still helpful to understand barriers to implementing computing education curricula. The findings reveal that only a few teachers in all the four African countries (average, 16%) have access to funding to purchase computing equipment. Uganda (11%) and Nigeria (7%) have the least access to funding to purchase computing equipment. As elaborated in Section 3, these two countries also have been reported to lack funding for basic electricity, a crucial prerequisite for all ICT usage in schools. This may explain why these two countries have the least number of teachers having access to computer labs. These results suggest that countries with low-middle income are less likely to have funding that supports purchasing of ICT infrastructure to support the implementation of computing education in schools hence affecting opportunities for computing education for their students.

6.4.2 Comparison between the High-income Countries and Low-middle-income Countries (African Countries). The findings reveal that the teachers in high-income countries (54%) have more funds available for ICT resources than in African countries (16%). Furthermore, teacher professional development is also affected by funding. The African teachers report that their main issue as far as PD is concerned is the cost of participating in PD. This was discussed in detail in the teacher professional development subsection above.

It appears that the African countries still struggle more with funding issues, which directly impedes budgets for IT equipment, curriculum reform, and teacher training. The lack of funding greatly affects the implementation of ICT policies, as shall be discussed in the following subsection.

6.5 Capacity in Terms of Policy

6.5.1 Comparison amongst the African Countries. As discussed in Section 3, the four African countries all have policies that support building capacity for computing education. Most of these policies have been implemented as early as the 1990s. These national policies, among other things, recommend the implementation of ICT infrastructure, ICT curriculum, and teacher training. Although there are many ICT education policy initiatives with periodic reviews in each country, efforts have been mainly geared toward deploying ICT infrastructure in secondary schools rather than primary schools due to limited resources.

6.5.2 Comparison between the High-income Countries and Low-middle-income Countries (African Countries). Just like the African countries, the high-income countries have policies that support building capacity for computing education, including implementation of ICT infrastructure, ICT curriculum, and teacher training. However, unlike the African countries, the high-income countries have now adopted initiatives and policies to introduce the development of Computational thinking skills in the school curricula [38]. For example, England, with support from industry, managed to persuade the government to change the policies and curricula to focus more on computational skills than basic ICT skills [10]. The ICT education policies in African countries, despite being reviewed several times, remain focused on establishing the availability of and accessibility to ICT infrastructure in schools [50, 51, 58] as compared to teacher training and curricula reform. The gap of policy capacity-building efforts to expand CS education between developed and less developed countries has also been reported in Reference [80].

Despite all the policy efforts from different countries, there is still much room for more supportive CS policies, such as addressing equity issues, as computing education grows across the globe.

6.6 Revisiting the CAPE Framework

In this subsection, we review our results through the lens of the CAPE framework. As already explained in Section 2.2, the CAPE framework is a valuable model for analyzing, reporting data, and tracking the progress of broadening participation and implementing CS curricula across all its levels (capacity, access, participation, and experience).

The CAPE framework was designed in the context of the U.S. as a lens for assessing equity in computing education. Based on the teachers' perspective and the data examined, our findings indicate that high-income countries and African countries may be at different stages of implementing computing education in schools. High-income countries, although still addressing capacity issues (e.g., teacher professional development), seem to be also focusing more on addressing issues at higher levels of the CAPE pyramid, such as *Participation in* and *Experience of* while the African countries are still struggling with *Capacity for*, the lowest level, and starting point of the CAPE pyramid, which is concerned with the availability of resources that support the implementation of a CS curriculum of high quality. We aim to contribute to Fletcher's CAPE framework in Reference [30] proposing that the Capacity level be more fine-grained for the African context. This will be useful in the African context to assist in monitoring progress around computing education implementation over time. We draw out dependencies among policy, funding, infrastructure, curriculum implementation, and teacher professional development.

Table 9 is based on the discussion points in the previous Sections 6.1–6.5 that explains the capacity levels in detail and how they relate with each other. The table shows specific examples from our dataset that demonstrates how we analyse and draw out dependencies within *Capacity level* between policy, funding, infrastructure, curriculum implementation, and teacher professional development. We demonstrate this by using measurements of a Likert scale, *highly sufficient* (76–100), *moderately sufficient* (51–75), *slightly sufficient* (26–50), and *insufficient* (0–25). This is to allow us to provide simple valuation between the capacity sub-components. It can be observed that while the African countries have moderately sufficient policies with good recommendations, they struggle with their implementation due to limited government funding [52, 56]. This means that until the basic needs of funding ICT infrastructure in schools are met, these countries cannot put their focus on the other issues such as computing curriculum and teacher PD. Table 9 illustrates how we draw the dependencies that lead to the development of the fine-grained models in Figures 5 and 6 that illustrates the dependencies between these components and how they may build and rely on each other. In the case of Africa, we have the following.

- **Teacher PD and CS Curriculum development:** Currently there is insufficient teacher PD as reported on average by the four African countries' teachers and the computer studies curriculum lacks relevant content regarding programming and computational thinking. Teacher

Table 9. Aspects of Capacity for CS Education in African Countries Compared to High-income Countries

Level	**Survey questions and research evidence used**	**Botswana**	**Kenya**	**Nigeria**	**Uganda**	**All-Africa**	**High-income**
Teacher PD (e.g., Q14, Table 5: How many teachers have time off to attend PD?)	Q24, Figure 3; Q14, Table 5; Q26, Table 8, Section 3	insufficient *(13%)*	slightly sufficient *(50%)*	insufficient *(7%)*	insufficient *(0%)*	insufficient *(17%)*	highly sufficient *(76%)*
Curriculum (e.g., Table 4 Does the curriculum include (1) computational thinking (2) programming skills and concepts?)	Q19, Table 4, Table 3, Section 3; Q22, Figure 2	slightly sufficient *(1–26%. 2–48%)*	slightly sufficient *(1–20%, 2–70%)*	slightly sufficient *(1–47%, 2–47%)*	insufficient *(1–0%, 2–22%)*	slightly sufficient *(1–28%, 2–48%)*	highly sufficient *(1–74%, 2–90%)*
ICT Infrastructure *(e.g., Q25, Table 6: How many teachers* ***do not need*** *support with improved ICT infrastructure?)*	Q25, Table 6; Q26, Table 8, Q14, Table 5 Section 3	slightly sufficient *(35%)*	insufficient *(10%)*	moderately sufficient *(60%)*	insufficient *(0%)*	slightly sufficient *(33%)*	moderately sufficient *(68%)*
Funding *(e.g., Q14, Table 5: How many teachers have access to funding to purchase computing equip?)*	Section 3, Q26, Table 8, Q14, Table 5	insufficient *(17%)*	insufficient *(20%)*	insufficient *(7%)*	insufficient *(11%)*	insufficient *(16%)*	moderately sufficient *(54%)*
Policy *(Section 3, e.g., Do policies recommend ICT infrastructure, ICT curriculum, teacher training, computational thinking/programming?)*	Section 3	moderately sufficient	moderately sufficient	moderately sufficient	moderately sufficient	moderately sufficient	highly sufficient

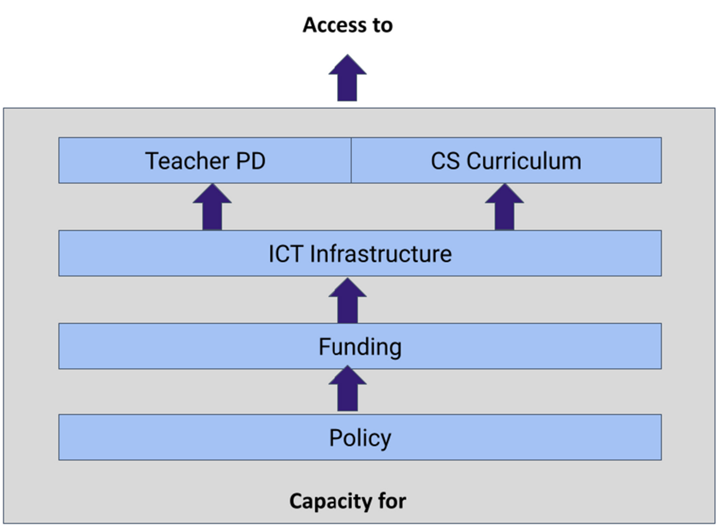

Fig. 5. A multi-faceted view of capacity for computing education.

PD and curriculum development need to progress in tandem, e.g., teachers need to be trained for relevant content in the curriculum, while the curriculum cannot be implemented effectively without trained teachers. Table 9 shows that implementing sufficient teacher PD and the curriculum may depend on adequate ICT infrastructure, funding, and the right policies in schools as can be evidenced for high-income countries.

- **ICT Infrastructure:** African countries still face the challenge of providing all students from both primary and secondary with ICT resources for computing education. Before ICT integration into schools can be effective, there has to be an adequate amount of funding.

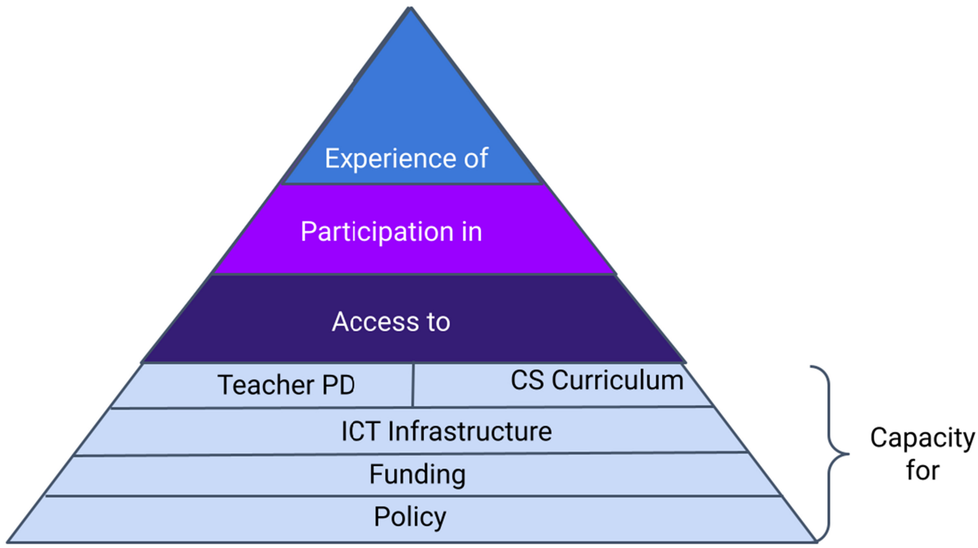

Fig. 6. Extending the CAPE framework for the international context.

- **Funding level:** Teachers have reported a lack of funding for teacher PD and ICT infrastructure. Table 9 shows funding is the most problematic for all the African countries. This may explain why the African countries, unlike the high-income countries, continue to lack the capacity for resources in the top levels of teacher PD and ICT infrastructure. Before funding can be released, there has to be a policy recommendation on resources that need the funding. In this case, the policies are sufficient. Therefore, the deficiencies at this level seem to be linked to the country's economic status.
- **Policies:** African countries have deliberate policies that encompass an enabling environment for computing education, such as recommendations for ICT installations in schools and teacher training. However, there is more room for improvement in these policies.

Figure 6 shows the model developed in Figure 5 embedded into the CAPE framework. By expanding the *capacity for* level, the framework may be more helpful for a global context and can represent the journey of more countries. It should be noted that the dependencies we are proposing in the sub-components of the capacity level may overlap each other. Depending on an individual country, the lower levels may come before the upper levels and vice versa (see Table 9). For example, some countries like Kenya may lack sufficient funds but may still get a lot of support from industry and non-governmental organizations on training teachers and teaching students programming in extra-curricula activities. This strategy is also very common in high-income countries [10, 82]. However, a country like Uganda seems to be following the pattern of dependencies as expected.

We conclude that our data show that African countries are still focusing on the *capacity for* level and until the needs of that level are met, they will struggle to progress to issues around providing access to the curriculum across the population. It is clear that African countries still have the challenge of providing all students with equal opportunities to computing education as compared to high-income countries.

7 THREATS TO VALIDITY

The focus of this study was to identify insights in K-12 computing education in four African countries (while comparing the teachers' responses with the participants from the original METRECC study); however, some threats to validity should be noted with the pilot study. The following threats to validity should not detract from the process implemented, as they provide a road map for future studies in this area, as well as early insights that have not been investigated to date in African countries (as discussed in Section 6).

The sample size was relatively small per country, with a maximum participation of 23 and a minimum participation of nine teachers, in countries that have populations up to 206 million. While 197 teachers started the survey (which is comparable to the original METRECC study with 244 participants), 10 completed the survey but did not give their permission to publish the data, but more concerning is that 128 did not complete the survey to the end. Finally, only one teacher from Zimbabwe participated in the study and was subsequently removed due to low sample size for that country. This drop off in numbers (especially for teachers who started but did not complete the survey) could be investigated further to avoid this large number of dropoffs for future studies.

8 CONCLUSION AND FUTURE WORK

In this article, we have sought to understand the capacity for computing education in four African countries, across three different areas of Africa, through a comparison of policy, funding, infrastructure, curricula, and professional development using a survey of 58 teachers. The survey was conducted using the METRECC instrument, and the results were analysed through the lens of the CAPE framework's capacity level.

Our analysis has shown that in some areas of Africa, there is still a need for resources and infrastructure for computing and that it is difficult to instigate teacher professional development in topics like programming while that is still being developed. Evidence for this includes the number of teachers who say they use pen-and-paper methods to teach text-based programming where it exists in the syllabus. In addition, while the policies around the provision of ICT and computing education are being implemented, these do not extend to an extensive provision in primary education for digital or computing education. In investigating this with the CAPE framework [30] in mind, it seemed that the underlying layer of "capacity for" underlying the provision of computing was more multi-layered than it has been represented in CAPE, particularly if this framework is to be helpful outside the context of high-income countries. In the interest of equity, models that allow us to examine all contexts may be helpful, and in doing so, it will be easier to identify opportunities for collaborative work where high-income countries can support low- or middle-income countries. We intend to repeat the survey in subsequent years and analyze the data through the proposed capacity sub-components to develop a fuller picture as Africa develops its capacity for formal computing education. We hope that this article contributes to future international work that sees the development of global computing education for all, potentially be aided by country collaborations and shared resources.

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