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Approaches to Strengthening Secondary STEM & ICT Education in Sub-Saharan Africa

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SCHOOL OF EDUCATION

APPROACHES TO STRENGTHENING SECONDARY STEM & ICT EDUCATION IN SUB-SAHARAN AFRICA

V. Gardner, M. Joubert, A.M. Barrett, and L. Tikly

The MasterCard Foundation

University of BRISTOL

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Dedication

This report is dedicated to the memory of Vicki Gardner, who tragically passed away before the report was completed. She made a significant and important contribution to the report and she was a valued colleague whose hard work, insights, intelligence and humour brought an extra dimension to the team.

List of Abbreviations

ACT	Advanced Certificate in Teaching
ADEA	Association for the Development of Education in Africa
AfL	Assessment for Learning
AMESA	Association for Mathematics Education of South Africa
ANA	Annual National Assessments, South Africa
AU	African Union
BEd	Bachelor’s Degree in Education
CAP	Common Africa Position on the post-2015 development agenda
CAPS	Curriculum Assessment Policy Statement, South Africa
CESA	Continental Education Strategy for Africa
CPD	Continuous Professional Development
CONFEMEN	La Conférence des Ministres de l’Education des pays ayant le français en partage
DBE	Department for Basic Education, South Africa
DfID	Department for International Development
ECZ	Examinations Council for Zambia
EFA	Education for All
ESD	Education for Sustainable Development
FaSMEd	Formative Assessment in Science and Mathematics Education
FLBP	Funza Lushaka Bursary Programme
GICTED	Ghana Information and Communication Technology Department
IBE	International Bureau of Education
ICT	Information and Communications Technology
IEB	Independent Examinations Board, South Africa
IQMS	Integrated Quality Management System, South Africa
iSPACES	Innovation, Science, Practicals, Application, Conceptualization, Entrepreneurship and Systems curriculum
ITU	International Telecommunication Union
JICA	Japan International Cooperation Agency
KCPE	Kenya Certificate of Primary Education
LMTF	Learning Metrics Task Force
MCF	MasterCard Foundation
MDGs	UN Millennium Development Goals

MoGE	Ministry of General Education, Zambia
MOESVTEE	Ministry of Education, Science, Vocational Training and Early Education, Zambia
MST	Mathematics, Science and Technology
NEEDU	National Education Evaluations Development Unit, South Africa
NEIMS	National Education Infrastructure Management System, South Africa
NGO	Non-Governmental Organisation
NITA	National Information Technology Agency, Ghana
NPDE	National Professional Diploma in Education
NSC	National Senior Certificate, South Africa
OBE	Outcomes Based Education
OER	Open Educational Resource
PASEC	Programme d'Analyse des Systèmes Educatifs de la CONFEMEN
PGCE	Post-Graduate Certificate in Education
PISA	Programme for International Student Assessment
SAGA	STEM and Gender Advancement
SACMEQ	Southern Africa Consortium for Monitoring Educational Quality
SAMSTIP	The South African Mathematics and Science Teacher Intern Programme
SBCPD	School-Based Continuous Professional Development
SDGs	UN Sustainable Development Goals
SEA	MasterCard Secondary Education in Africa: Preparing Youth for the Future of Work Study
SMASTE	Strengthening of Mathematics, Science and Technology Education
SPRINT	School Program of In-service Training for the Term
SSA	Sub-Saharan Africa
STEM	Science, Technology, Engineering and Mathematics
STEAM	Science, Technology, Arts and Humanities and Mathematics
STI	Science, Technology and Innovation
SUNCEP	The University of Stellenbosch's Centre for Pedagogy
TCZ	Teaching Council of Zambia
TESS	Teachers' Education and Specialised Services, Zambia
TESSA	Teacher Education in Sub-Saharan Africa
TEVETA	The Technical Education, Vocational and Entrepreneurship Training Authority, Zambia
TIMSS	Trends in International Mathematics and Science Study

TVET	Technical and Vocational Education and Training
UIS	UNESCO Institute for Statistics
UN	United Nations
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UNISA	University of South Africa
USAID	The United States Agency for International Development
WAEC	West African Examinations Council
WASSCE	West African Senior School Certificate Examination
WCED	Western Cape Education Department, South Africa
ZAMSTEP	Zambia Mathematics and Science Teacher Education Programme

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Executive Summary

Background and Introduction to the Study

This paper is intended as a forward-looking and policy-orientated paper, which will assist the MasterCard Foundation, policy makers and the international development community in implementing high quality secondary STEM and ICT education in sub-Saharan Africa, targeting disadvantaged learners in difficult delivery contexts. The specific objectives are:

- To better understand the characteristics of successful national policy frameworks for increasing access for disadvantaged groups of learners, including girls, learners from poor socio-economic backgrounds and speakers of minority languages, to good quality STEM and ICT in secondary education.
- To identify successful strategies used to address the data gap of student performance, teacher ability and school level resources available for STEM and ICT education.
- To develop a diagnostic framework enabling policy makers to analyse their particular context and identify pressure points in the system, where targeted intervention could be particularly impactful.

Methodology

The study is predominantly a desk-based literature review on national policy frameworks, specifically targeting STEM and ICT education at secondary level in sub-Saharan Africa, which includes both academic as well as grey literature sourced through the Internet. Two country scoping exercises conducted by the University of Bristol team in South Africa and Zambia, which provided grey material and data from interviews with a range of stakeholders, from policy makers to school students, have further informed the study.

It should be noted that there is an extensive body of research on STEM and ICT education outside SSA from which lessons can be learnt.

Policy Context for STEM & ICT Secondary Education in sub-Saharan Africa

The Purpose of STEM Education within International Policy Agendas

The two primary influences on education policies in sub-Saharan Africa have been the Education for All (EFA) movement and the notion of the knowledge economy. EFA goals have emphasised the importance of secondary education through the concept of *Life Skills* and *Twenty-First Century Skills*, which extend the term 'literacy' beyond reading and instead, define it as the making of connections between formal knowledge and the informal, common-sense knowledge of the home and community. Within this context, the purpose of STEM and ICT secondary education is seen as the development of knowledge and skills, with an emphasis on application in work, family and community contexts.

Development through knowledge economies has provided a powerful rationale for the use of digital technologies within education. As means of supporting the learning of curricular subjects and developing cross-curricular skills, ICTs have transformational potential. The ubiquity of smartphones in SSA has introduced new possibilities for addressing educational problems that were previously considered intransigent.

A Pan African Vision for Sustainable Development

Policy agendas developed and produced by the African Union have promoted a knowledge economy perspective on development. Science and technology innovation and research are espoused as the main economic drivers within this framework. Formal education is regarded as the primary mechanism through which scientific and technological knowledge and skills might be disseminated and developed.

National Development Policies and Implications for STEM Education

National policy rhetoric throughout the region is also consistent with a human capital perspective of development. The pathways linking STEM and ICT education to economic growth and global competitiveness, feature in various national policies, leading to a focus on the development of vocational pathways at the secondary level, in some cases. Integrated frameworks across ministries and departments show a recognition of the wider relevance of STEM and ICT education. The application of STEM and ICT knowledge and skills is also aligned with human development and sustainable development visions, though the extent to which this is reflected in national policies varies. Though educational policies are often coherent with national development visions, there is often a gap between policy and practice. In order to achieve their goals and be truly transformative, policies need to be feasible and focus on inclusion, as well as quality, content and organisation. South Africa and Zambia have been chosen as case study countries to demonstrate ways in which national development visions and educational policies have been interpreted into successful or promising practices on the ground.

Science Education and Inequalities

Though significant improvements in gender parity and equality in education have been evidenced since the turn of the century, a gender gap still remains visible, particularly in the case of STEM and ICT fields. The universalisation of secondary education constitutes a significant step in achieving gender equality, with respect to STEM and ICT and should, over a longer period of time, lead to a greater representation of women in related professions.

Challenges Facing STEM Education

Systematic and classroom challenges to providing quality STEM and ICT education were identified in a previous working paper (Tikly et al. 2018).

Addressing Issues in STEM & ICT Secondary Education – Policies, Strategies and Initiatives

Promising and successful policies, strategies and initiatives for strengthening STEM and ICT secondary education in the region have been divided into three broad categories: Curriculum and Assessment, People and Material Resources. It is important to note, however, that policies, strategies and initiatives must cut across each of these thematic areas in order to be considered as having the potential for transformation. Furthermore, in order to contribute towards the goal of achieving quality education for all, they must address disadvantaged groups of learners.

Curriculum and Assessment

Previously, curricula in SSA generally targeted students who were pursuing specialised tertiary studies. As such, the content was often highly theoretical and overly-ambitious. In order to make STEM and ICT more accessible, attractive and relevant to learners, various curriculum reforms have been implemented in the region. These reforms adopt a more learner-centred approach to learning, with a stronger focus on developing skills and competencies, such as problem-solving and critical thinking skills. Examples of promising constructivist approaches include vocationalisation, interdisciplinary approaches, assessment, and integration of local and indigenous knowledge systems.

Vocationalisation

Various countries have introduced pre-vocational streams at the secondary level, which has the potential to enrich the curriculum, raise standards, improve participation and increase attainment in education. By offering combinations of traditionally academic subjects and more vocational subjects, scientific theory and foundational skills associated with the scientific method may be contextualised within a work-related environment. Examples include Zambia's two-tier approach to vocationalisation and the integration of pre-vocational subjects into the academic curriculum in Namibia. Both strategies offer work-related STEM and ICT options and have incorporated their respective National Qualifications Frameworks, thus opening up new pathways into tertiary education and the world of work.

Interdisciplinary Approaches to STEM & ICT

Rather than the traditional teaching of science as discrete subjects - Biology, Chemistry and Physics – various interdisciplinary approaches have been adopted as means of improving the practical application of scientific theory and knowledge. The two different multidisciplinary approaches to making science more applicable and holistic reviewed herein are the Integrated Science curriculum in Zambia and the *STREAM* programme in South Africa.

Assessment

The use of formative assessment has been promoted as a means of improving student perceptions and attitudes to STEM and ICT education. Though the use of a variety of informal assessment techniques has been evidenced across the region, a lack of teacher resources, teacher subject knowledge and pedagogical skills have limited their success. Coherence of curriculum policy, teacher education and resource allocation is necessary for data on student performance and progress to be collated and used effectively, in order for formative assessment to have its full impact.

Integration of Local & Indigenous Knowledge Systems

The incorporation of local and indigenous knowledge systems has the potential to improve the practicality and relevance of STEM and ICT curricula. By contextualising theoretical science with local culture, this approach could allow for more inclusive and learner-centred teaching practices. The iSPACES framework in Northern Tanzania is used as a case study to show how curricula may set traditional scientific work in the context of real problem solving, fostering innovation and entrepreneurship.

People

The quality of teaching is vital for improved student performance in STEM and ICT fields, student uptake and perceptions of the field, and the successful implementation of curriculum reforms. However, there is stark lack of qualified secondary level teachers in many countries in SSA, which is particularly acute in the fields of STEM and ICT. Alongside demographic changes and the expansion of 'Education for All' to include secondary education, this deficit is further exacerbated by issues of teacher recruitment and retention. Consequently, teachers are often found teaching at levels beyond their expertise. Various strategies have been utilised in the region, to improve the recruitment and retention of teachers and the quality of professional development programmes, giving practising teachers the opportunity to build upon their subject knowledge and pedagogical skills.

Improving Teacher Status

Various efforts have been made to improve public perceptions of teachers in SSA, in the hope that this will attract more people to the profession. Firstly, salary increments have been allocated to teachers in rural locations and in academic fields where there are particularly acute shortages, such as STEM and ICT. Professional teaching standards have also been raised in an effort to change the perception that teachers are less skilled than other graduate professions. Finally, career pathways have been more clearly defined, with the formal recognition and accreditation of achievement providing more opportunities for progression and promotion.

Improving Recruitment to Teacher Training

As an incentive for enrolling on initial teacher training programmes, many countries are offering bursaries and scholarships. In South Africa, the Funza Lushaka Bursary Programme (FLBP) and the South African Mathematics and Teacher Intern Programme (SAMSTIP) have made significant contributions to improving enrolment on BEd and PGCE courses in STEM and ICT disciplines.

Alternative Teacher Training Programmes

Fast-track programmes, such as the TEACH South Africa initiative, have been developed to entice high performing graduates into the teaching profession. Within these programmes, a significant proportion of pre-service training is shifted toward in-service support and training, reducing costs to the system and increasing the supply of suitably qualified teachers.

Continuing Professional Development

In order to address the issue of underqualified teachers practising at secondary level, governments have focussed on improving the subject knowledge and pedagogical skills of in-service teachers through various continuing professional development programmes. Various initiatives in the country's case studies have focussed on improving CPD programmes for STEM and ICT disciplines. These CPD programmes have been designed to be convenient, long-term and formally recognised through their work with professional organisations in schools and the designation of paid teacher time, to training. Thus, teachers have been incentivised to participate in developing their practice.

Widening CPD Opportunities Using Mobile Technologies

The integration of mobile technologies can play a motivating and supportive role in developing teachers' knowledge and skills. Mobile phones have been utilised to develop teaching practice through such programmes as the Teacher Education in Sub-Saharan Africa (TESSA) Secondary Science Project and the OER4Schools project in Zambia, which provide teachers and teacher educators with materials to support and enhance their subject knowledge and pedagogical skills. Providing CPD opportunities through digital technologies gives these initiatives the potential to reach teachers, who might not otherwise have access to training programmes.

Material Resources

Textbooks

As the primary teaching aid, textbooks are important for providing high quality education. In order to improve both the provision and quality of textbooks, South Africa has produced and distributed workbooks to all learners in Grades 1-9 in key subject areas, including Mathematics. However, an issue with textbooks concerns the language of instruction, which often differs from the teachers' and students' home language. The Language Supportive Teaching and Textbooks (LSTT) project in Tanzania has developed a mathematics and biology textbook, which uses simple language, a glossary and images to make the content language accessible and meaningful.

Science Laboratories

Access to laboratories and specialist science teaching materials allows students to view science in a more practical and stimulating manner. However, the resources required are expensive to procure, distribute and maintain. In some cases, students bear these costs themselves through school fees, which subsequently disadvantages those in rural and low socioeconomic positions. Various countries are experimenting with sustainable and affordable alternatives to science laboratories, such as low-cost science kits or the concentration of resources in centres of excellence. Low-cost science kits enable teachers to perform demonstrations, which has also been shown to improve the teacher's own scientific skills and understanding. When distributed in large enough quantities, these science kits may also provide students with the opportunity to conduct experiments themselves, as is the case in Zimbabwe.

Building ICT Capacity in Schools

The provision of hardware and software is necessary for teaching and learning ICT. However, a technocentric approach to building capacity that focuses on simply supplying new technologies in educational environments is not only expensive, but is also ineffectual when delivered without the necessary teacher training. One successful approach to integrating ICT in STEM subjects has been through the provision of content. Another has been the introduction of mobile learning initiatives. The Zambian Information and Communication Technology Authority (ZICTA) and the Ghana-India Kofi Annan Centre of Excellence in ICT are two examples of organisations working to provide access to computers and ICT teacher training.

Identifying Data Gaps for Quality Assurance

There is little data available on the quality of teaching and learning in sub-Saharan Africa. This data is required in order to monitor the performance of teachers, schools, and districts, in order to improve teaching practice, student outcomes and educational systems.

Data on Student Performance

Data on student performance across countries provides information for exploring correlations between student outcomes and contextual factors. Large-scale international assessments, such as TIMSS, PISA, SACMEQ and PASEC, have been shown to have a positive impact on schools, teachers and learning outcomes and have initiated various educational reforms and reviews.

Data on student performance within countries is widely used in sub-Saharan Africa to inform educational policies, though only seven countries have assessed student performance in at least one STEM and ICT subject, at lower secondary level. These tests are cross-sectional rather than longitudinal and thus, provide snapshots of student performance rather than demonstrating student progress. One exception is the Annual National Assessments in South Africa, which provide, longitudinal data on students' performance in literacy and numeracy. The ANAs provide an example of how the data collected from compulsory examinations, which are common in SSA, could be analysed, disseminated and used more effectively.

Data on Teacher Performance and Skills

Collecting data in teacher performance is deeply problematic, as it is difficult to measure and teachers are often resistant to the idea. However, classroom observations and measuring student performance are two approaches to monitoring the quality of teaching. The Teacher Competence Framework by the Teaching Council of Zambia and the Integrated Quality Management System in South Africa provide examples of policies aimed at improving teacher quality.

Data on School Level Resources

Reliable data on laboratory equipment, textbooks, computer hardware/ software, running water, electricity and internet is scarce in SSA. South Africa provides an exception, with its regular NEIMS reports.

Data on the Success of Policies and Initiatives

Though a variety of strategies have been developed across the region to strengthen STEM and ICT secondary education, gaps between policy and practice are evident. A rigorous and accessible evidence-base is required in order to properly evaluate the contributions that policies are making to improve STEM and ICT education. South Africa provides a model for other countries in the region to follow.

Conclusion and Diagnostic Framework for Sustainable STEM & ICT Education

The diagnostic framework on p.65 summarises the key issues identified in the report, in the form of questions that are of relevance for policy makers. Based on the detailed discussion in earlier chapters, they are intended as a starting point for developing national strategy in the area of STEM and ICT education.

Chapter 1: Background and Introduction to the Study

Substantial gains in access at the primary level has increased the pipeline of students moving into secondary education, as has the recent expansion of the concept of basic education to include lower secondary level, through the Sustainable Development Goals agenda (United Nations 2015). As a result, there will be a significant increase in the number of students entering secondary education systems across sub-Saharan Africa (SSA) in the coming years.

The supply of school places for this large, impending youth cohort is a critical issue facing policy makers today. A subsidiary question is how to ensure that attending school is accompanied by learning; how to provide a high-quality education for all. A problem highlighted by the World Bank and others (Burnett 2014), is that in very many low-income countries, including most of SSA, although young people are increasingly able to attend school, learning outcomes are poor: in other words, 'schooling is not the same as learning' (World Bank 2018b, p. 3). The World Bank identifies four immediate causes for this lack of learning as children arriving to school ill-prepared to learn (e.g. illness, malnutrition), teachers lacking skills or motivation (e.g. lack of subject knowledge, absence from school), resources such as textbooks not reaching classrooms or remaining unused when they do. Finally, poor school management and governance often undermine the quality of schooling.

Of particular concern for this project is learning in the specific subject areas falling within the umbrella term 'STEM', which is used an acronym for Science, Technology, Engineering and Mathematics. STEM also includes the Natural Sciences (Biology, Chemistry and Physics), technology-related subjects; including Computing and, for example, Computer Applications Technology and Mathematics. In schools offering vocational education, STEM also includes subjects such as Agriculture, Technical Drawing and Domestic Science.

In many contexts, the vision for STEM education is of an interdisciplinary approach, wherein students apply science, technology, engineering and mathematics, as appropriate, to solve real-work problems, thus reflecting the interdisciplinary nature of the work of STEM professionals (Chalmers et al. 2017). This type of education may involve any combination of STEM disciplines, or a STEM discipline and another school subject, but the aim is that it is an integrative approach (Sanders, 2008). STEM education is seen as something new and exciting, which promises to engage students because it involves solving real-world challenges such as energy, health and environmental issues (Durik, Hulleman, & Harackiewicz, 2015; Kennedy & Odell, 2014). In contrast, the traditional school curriculum, where different disciplines are taught separately, is seen to lack relevance to students (Wang, Chow, Degol, & Eccles, 2017).

However, in many schooling contexts the term STEM appears, in every practical sense, to denote science and mathematics (Sanders, 2008). This report, therefore explicitly adds the term ICT to emphasise the fact that subjects based around digital technologies are also included in the discussion.

However, the term ICT is also used much more widely than to refer only to an area of teaching and learning. It is used, for example, in reference to hardware (e.g. computers, mobile telephones) and software (e.g. email clients, web browsers). ICT is generally seen as crucial in underpinning and enabling economic prosperity through, for example, digital economies and enhancing the delivery of services (Wallet 2015). In terms of education, ICT offers the potential to connect learners in remote and rural contexts (Ford & Herselman 2017), deliver distance learning to teachers (Tikly et al. 2018) and provide content to teachers and learners (Wolfenden et al. 2012). Thus, although the Millennium Development Goals and Education for All did not provide objectives or goals related to ICT in education, the World Summit on the Information Society (WSIS) did include two targets in this area. The first of these refers to connecting all primary and secondary schools in terms, mostly, of hardware (e.g. computers, Internet access) and the second to what is taught in schools and how it is taught (e.g. computer-assisted instruction). Specific approaches to policies addressing ICT in education are discussed further in Chapter 2.

For STEM subjects, ICT has the potential to improve teaching and learning in a wide variety of ways. These include connecting learners as discussed above, which enables a variety of models of blended learning involving combinations of face-to-face and remote interactions between learners and teachers, and various approaches to supporting students through mobile telephone apps (e.g. the Microsoft Maths service (Roberts 2016)). Computer-based educational resources, such as e-books and courseware (e.g. Open Educational Resources, or OERs) can be employed as useful educational aids and simulation software could be used in Physics classrooms for experimentation (Ramnarain & Moosa 2017). Similarly, graphing software would provide an insightful means of exploring hypotheses in Mathematics classrooms (Vadachalam & Chimbo 2017) while combinations of sensors and software could assist in the collection of data in Chemistry lessons. (English et al. 2016).

The role of ICT in these various examples of potential uses ranges from an organisational tool to a calculating device to a research gateway; with many other roles in between. There are many ways to frame our understanding of the ways in which technology is used, as pointed out by Joubert (2013), for example, who used 'grand challenge' themes to begin to understand the landscape of computer use in mathematics classrooms: connecting learners, orchestrating learning and contextualisation; on the other hand. Others look more at the function of the technology, perhaps thinking of the technology in the role of an amplifier or reorganiser, where as an amplifier it performs tedious processes such as computations, that could be done by hand, and as a reorganiser the technology shifts the focus of the students' thinking by, for example, by allowing them to explore a representation and to ask 'what if?' questions. This categorisation reflects that of Noss and Pachler (1999), for whom technology allows us to do old things in new ways or to do new things.

There are two key issues in which, the literature on the integration of technology into science and mathematics classrooms agree. The first is that the promise of new technologies in everyday classrooms remains largely unrealised (Hérold & Ginestié, 2018; Joubert, 2013; Weigand, 2010). The second point is that technology alone cannot and will not improve teaching and learning in STEM subjects and that the role of the teacher, and the tasks set by the teacher, are crucial (Bottino & Chiappini, 2002; Hérold & Ginestié, 2018). Related to this is the point that, frequently, the technology does not improve student learning (Drijvers, 2015a; Joubert, 2017) and teachers need to understand the potential role of technology better in order to deploy it effectively (Drijvers, 2015b; Hérold & Ginestié, 2018; Joubert, 2017).

Also of concern to this project is the particular phase of school; in this case, secondary education as defined in accordance with the Education Sustainable Development Goal (SDG4) and the Incheon Declaration (World Education Forum 2015), which extend the cycle of basic education to include lower-secondary.

It is usual in SSA for the sciences to be taught as an integrated subject in lower secondary years, whereas in upper secondary the different science subjects are taught separately. In South Africa, for example, at lower secondary level, Life Science and Physical Science are usually taught as one subject whereas at upper secondary they become two separate independent subject areas. (Ottevanger, den Akker, & de Feiter, 2007).

Generally, teachers of science at lower secondary levels tend to have lower qualifications than those at upper secondary. Teachers of lower secondary science in Zambia, for example, require only a teaching diploma whereas to teach at upper secondary level, a postgraduate qualification is essential. Upper secondary level requires more specialised equipment and all three taught sciences are more resource intensive. This report, however, has lower secondary as its focus.

This project is one strand of the wider MasterCard Secondary Education in Africa: Preparing Youth for the Future of Work (SEA) study. The goal is to develop a forward-looking and policy-oriented background paper that can assist the MCF, policy makers and the international development community in implementing a good quality secondary STEM and ICT education, targeting disadvantaged learners in difficult delivery contexts. The specific objectives are:

- To better understand the characteristics of successful national policy frameworks for increasing access for disadvantaged groups of learners including girls, learners from poor socio-economic backgrounds and speakers of minority languages to good quality STEM and ICT in secondary education.
- To identify successful strategies for addressing the data gap on student performance, teacher ability and school level resources available for STEM and ICT education.
- To develop a diagnostic framework which allows policy makers to analyse their particular context and identify pressure points in the system, where targeted intervention could be particularly impactful.

As part of the MCF SEA study, impact from this project will be achieved through:

- The generation of insights that inform the design of the MCF SEA, ensuring in particular that it is effective in meeting the needs of disadvantaged secondary school learners;
- The dissemination of insights to policy makers, teacher educators and education researchers within Ministries of Education, parastatal organisations, research institutions, teacher education institutions, non-governmental organisations within target countries, with the aim of enhancing their readiness to engage with MCF's teacher education strategy;
- The sharing of insights with international agencies, non-governmental organisations and think-tanks, to add to the knowledge base and inform their activities, thus strengthening the delivery of STEM and ICT secondary teacher education in SSA.

The study is predominantly a desk-based literature review on national policy frameworks specifically targeting STEM and ICT education at the secondary level in SSA. The literature includes academic as well as grey literature accessed through the Internet. The initial approach to searching the literature was to examine the literature that had been used for the previous report produced by the team at Bristol (Tikly et al., 2016); the search was extended by methodically gathering World Bank, UNESCO, EPCD material relevant to STEM education in sub-Saharan Africa and supplementing this with available grey material as appropriate. Finally, a key-word literature search was conducted. It should be noted that there is an extensive body of research on STEM and ICT education outside SSA from which lessons can be learnt.

The study also draws on country scoping exercises undertaken by the Bristol team in two SSA countries: Zambia and South Africa. The teams in the two African countries interviewed a range of stakeholders including policy makers, teacher trainers, teachers and students and collected grey material, reports and research; each produced a report which was used to inform this study.

Whilst the current literature provides a clear picture of the challenges associated with the delivery of high quality STEM and ICT education in sub-Saharan Africa, the aim of this paper is to build on existing research and to be forward-looking and solutions-oriented. As such, the focus is on successful or, given that we are still in the early stages of achieving the targets set in Agenda 2063 and the Sustainable Development Goals, promising policies, strategic plans and initiatives, which have been devised in order to address the challenges posed in delivering a high-quality STEM and ICT secondary education in the region. These policies, strategies and initiatives have been classified into three broad categories:

- **Curriculum and Assessment**, which refers to approaches to curriculum development in terms of content, skills and teaching approaches. As a means of strengthening both the relevance and accessibility of STEM and ICT education, a constructivist approach to curricula has been adopted, using strategies such as vocationalisation, interdisciplinary approaches, the integration of local and indigenous knowledge systems and assessment.

- **People**, which is concerned with strategies deployed to address issues of recruitment, deployment, professional development and retention of suitably qualified personnel in secondary STEM and ICT education. These strategies comprise improving teacher status, increasing recruitment to teacher training programmes, and CPD initiatives to improve classroom practice;
- **Material Resources**, which deals with policies and initiatives devised to improve infrastructure in secondary schools to support STEM and ICT education. Strategies to improve textbook quality and distribution, access to specialist science equipment and ICT capacity in schools are reviewed.

Policies, strategies and initiatives must cut across each of the above thematic areas, in order to be truly successful (Chisholm & Leyendecker 2008; Nsengimana et al. 2014; Ramnarain & Padayachee 2015; Rogan & Grayson 2003; Verspoor 2008); acted upon in isolation, neither curriculum development, teacher recruitment and development, nor infrastructure improvements will transform the quality of secondary STEM and ICT education (as further evidenced below). Furthermore, to contribute towards achieving the goal of providing quality education for all, it is necessary to address inequalities in access to and quality of STEM and ICT secondary education for disadvantaged groups of learners (including girls, learners from lower socio-economic backgrounds, speakers of minority languages and those with multiple disadvantages).

In the light of the above, the report identifies three cross-cutting themes that are traced in the body of the report. The themes were derived inductively from the review of the literature and relate to the overall purpose of the study. They provide a practical set of categories for capturing the key issues arising from the analysis of national policy frameworks and strategies that can pragmatically feed into a diagnostic framework. Key questions are identified in relation to each theme at the end of Chapters 2, 3 and 4 and these are brought together in an over-arching diagnostic framework in Chapter 5. The themes are as follows:

Relevance and Coherence refers to the relevance of national frameworks and initiatives in the area of STEM and ICT education for national development priorities on the one hand and to the background of learners on the other hand. It also refers to the extent to which there is coherence between national policy agendas and STEM/ ICT strategy and between different areas of STEM/ ICT policy and practice.

Feasibility refers to the extent to which national frameworks and initiatives are realisable in practice given the nature of the challenges facing STEM and ICT education.

Inclusion refers to the extent to which frameworks and initiatives are designed in a way that recognises and meets the needs of all learners regardless of their gender, socio-economic status, ethnicity or language.

Chapter Outline

'Chapter Two: Policy Context for STEM and ICT Secondary Education in sub-Saharan Africa' provides a rationale for the focus on STEM and ICT education at secondary level, as well as a brief overview of the challenges inherent in strengthening access to and quality of STEM and ICT secondary education.

'Chapter Three: Addressing Issues in STEM and ICT Secondary Education – Policies, Strategies and Initiatives' draws together the challenges faced in delivering STEM and ICT secondary education in sub-Saharan Africa and analyses national policy frameworks and initiatives for strengthening access and quality to these subjects, in the region.

'Chapter Four: Identifying Data Gaps for Quality Assurance' provides examples of successful country strategies for collating data on student performance, teacher ability and school level resources available for STEM and ICT education in sub-Saharan Africa.

'Chapter Five: Diagnostic Framework for Sustainable STEM and ICT Education' builds on the insights developed in Chapters 2 and 3 to develop a diagnostic framework that allows policy makers to analyse their particular context and identify pressure points in the system, where targeted interventions could be particularly impactful. **It** briefly summarises the report, makes some conclusions and points to areas for potential further research.

Chapter 2: Policy Context for STEM & ICT Secondary Education in sub-Saharan Africa

The introduction of the sustainable development goals in 2015, marked a significant shift in the global policy agenda with profound implications for STEM and ICT education. Since the mid-nineties, the concepts of knowledge economy and knowledge society, which were championed by economists, rationalised investment in STEM and ICT education in low to middle income countries as necessary for economic growth (Dahlman et al. 1998). The new sustainable development agenda rejects an instrumentalist view of science and technology at the service of economy and society. *Sustainable* development is now understood within the rhetoric of global policy as social and economic progress within planetary boundaries (United Nations 2014). Science, and hence science education, has a central place within this new agenda. Indeed, scientists, particularly environmental scientists, have played a leading role in shaping the agenda. In the context of global challenges such as climate change and shrinking biodiversity, the task of educating young people with knowledge and curiosity about their natural world has never seemed more urgent.

This new agenda has profound implications for how science education, in particular, is conceptualised. Science education can no longer be understood as learning abstracted facts about an objective reality that is external to the human world. Rather, science education is beginning to be understood as a process of active inquiry that informs inquirers' social values and actions (for example, how they access health care, manage waste or respond if local industry is degrading the environment). A small group of environmental educationalists, including within sub-Saharan Africa (Lotz-Sisitka et al. 2017), have developed curriculum and pedagogy for sustainable development. However, policy makers are still working out what it means for secondary STEM education.

At the national level within Africa, commitment to developing STEM and ICT education is apparent in long term national development visions drawn up in the noughties, many of which will remain current into the 2020s. Hence, the discourse of knowledge economy/society that influenced global development agendas at the turn of the century, continues to be prevalent within African education policy. The knowledge economy view of development regards high level scientific and technological research as imperative for economic take-off on the African continent. STEM and ICT education at the secondary level is seen as important for preparing a pool of talented, well-educated youth, who can take up different employment and entrepreneurship opportunities within a growing knowledge economy, where technological skills are in demand.

This chapter starts by highlighting elements of international and regional policy agendas that have influenced national development visions and education sector policies in sub-Saharan Africa. At the international level, policy trends are outlined, going back twenty years. This is because long-term national development visions typically have a life cycle of 20-30 years. Two influential trends are identified: the close association between life skills and secondary education within the EFA agenda and the prominence given to ICTs in education, as a feature of knowledge economies. At a regional level, the discussion focuses on African Union (AU) documents that set out a vision for sustainable development on the continent which is founded on scientific knowledge, driven by technological innovation and dependent on the spread of digital technologies. Moving to the national level, the influence of international and regional agendas on national policies is considered. Examples of ICT education policies, developed towards achieving development visions of 'knowledge societies' or 'knowledge economies', illustrate the tension between coherent policy architectures and feasibility of implementation. These examples demonstrate how the two dimensions of coherence and feasibility are essential to successful policies. However, these criteria can only be achieved through detailed attention to the design of curricula relevant to the context, and through adequate provision of staff and resources for implementation.

The Purpose of STEM & ICT Education Within International Policy Agendas

The Education for All (EFA) movement and the notion of knowledge economy, as promoted by the World Bank, were the greatest international influences on education policies in sub-Saharan Africa. EFA emphasised the role secondary education plays in preparing young people for work and life, ascribing to it a pre-vocational, and even semi-vocational, role. The concept of knowledge economy provided a rationale for investment in the expansion of digital technologies and the introduction of ICTs into formal secondary curricula.

EFA, Life Skills and Literacies

The six EFA goals did not include an explicit goal for secondary education as this was considered infeasible in 2000. The alternative put in place, however, was a Youth and Life Skills Goal (World Education Forum 2000). *Life Skills* is a rather fluid term, used in different but overlapping ways by various international organisations. It was first defined by the World Health Organization as:

> *A group of psychosocial competencies and interpersonal skills that help people make informed decisions, solve problems, think critically and creatively, communicate effectively, build healthy relationships, empathize with others, and cope with and manage their lives in a healthy and productive manner*. (International Bureau of Education 2013, p.39)

Within the Dakar Framework, *Life Skills* was a catch-all phrase term for skills for work and life, since:

> *All young people and adults must be given the opportunity to gain the knowledge and develop the values, attitudes and skills that will enable them to develop their capacities to work, to participate fully in their society, to take control of their own lives and to continue learning.* (World Education Forum 2000)

Whilst the third EFA goal talked about Life Skills programmes, the Dakar Framework stressed that *Life Skills* are most effectively developed through formal secondary education (World Education Forum 2000). Hence, secondary education was presented as encompassing pre-vocational and even vocational education. This association was reinforced and elaborated in the 2012 EFA Global Monitoring Report, themed around youth and skills (UNESCO 2012).

Twenty-First Century Skills, like *Life Skills*, can serve as a catch-all, imprecise term. They have been described as a broad set of knowledge, skills, work habits and character traits 'that are critically important to success in today's and tomorrow's world' (Siekmann & Korbel 2016a, p.27). Recent attempts to elaborate on *Twenty-First Century Skills* signal a change in our understanding of the purpose of secondary education. A World Economic Forum (2015) publication grouped these skills into three categories: foundational literacies, competencies and character qualities (see Table 2.1).

Table 2.1: Twenty-first Century Skills. *Source: World Economic Forum (2015).*

Foundational Literacies How students apply core skills to everyday tasks	**Competencies** How students approach complex challenges	**Character Qualities** How students approach their changing environment
Literacy Numeracy Scientific literacy ICT literacy Financial literacy Cultural and civic literacy	Critical thinking/ problem-solving Creativity Communication Collaboration	Curiosity Initiative Persistence/ grit Adaptability Leadership Social and cultural awareness

The extension of the term *literacy* beyond reading is consistent with the extension of the basic education cycle into secondary education. At Lower Secondary level, children start to engage with formal codified knowledge and make connections between formal knowledge and the informal, common-sense knowledge of the home and community, often associated with disciplines (Barrett 2017). As far back as the 1950s, scholars of science education used the term 'scientific literacy' or 'scientific literacies' as a heading under which to debate which kind of scientific knowledge and skills should be available to all citizens, as part of basic compulsory education and what this would mean for secondary school curricula (Aikenhead 2007).

The Learning Metrics Task Force (LMTF) also refers to scientific literacy and financial literacy. It was set up by the Brookings Institute and UNESCO Institute of Statistics to inform the formulation of a post-2015 development goal for education that would focus on learning outcomes rather than access to schooling. The task force included representatives of national and regional governments, donor agencies, civil society organisations and agencies prominent in the Education for All (EFA) movement. Its purpose was to build a consensus around precisely what type of learning should be covered in early years, primary and post-primary education and how learning outcomes should be measured (LMTF 2013). LMTF identified seven domains of learning; 'Numeracy and Mathematics' being one and 'Science and Technology' another. Influenced by PISA assessment frameworks, there is an emphasis on application of knowledge in how these are defined at post-primary level. 'Numeracy and Mathematics' is presented as 'mathematical literacy', which is:

> *the capacity of students to analyze, reason and communicate ideas effectively as they pose, formulate, solve and interpret mathematical problems in a variety of situations*
> (Learning Metrics Task Force 2013, p.43)

Four of these subdomains (Numbers, Algebra, Geometry, Data and Statistics), however, are described in terms of abstract mathematical knowledge. The other three infer contexts for using mathematics - Everyday Calculations, Personal Finance and Informed Consumer.

For 'Science and Technology', the LMTF report argues for moving beyond an understanding of scientific knowledge as 'a collection of objective neutral facts', towards critical inquiry, elaborated as questioning the universalism of 'the Western model' and including 'the uses and contexts of scientific concepts' (LMTF 2013, p.48). The seven subdomains identified include the three traditional disciplines of Western science – Biology, Chemistry and Physics. Earth Sciences and Environmental Awareness are added as two other subdomains, defined as knowledge content areas. The last two, however, cut across content areas. 'Scientific approaches' concerns problem solving. 'Digital learning', the only subdomain to explicitly reference technology, is explained as 'engaging with digital communication technologies in each step of the learning process' (*ibid*, p.49).

The shifting life skills discourse within international policy agendas has led us to a point where the purpose of science and mathematics education at lower secondary level is seen as being about knowledge and skills that are applicable within work, family and community contexts. With mathematics, there is a focus on numeracy. A universal secondary education should reinforce and extend the foundational numeracy acquired during primary school. Life skills also emphasises cross-curricular skills such as creativity, communication skills and problem-solving. Similar skills have also been identified as priority within the field of education for sustainable development by those debating how education can prepare young people for uncertain futures (e.g. Bangay & Blum 2010).

Knowledge Economy, ICTs and Learning

Information infrastructure and capabilities have consistently been positioned as central to building knowledge economies (Robertson et al. 2007). This includes the use of digital technologies within education (Kozma 2011a). More recently, the notion of the fourth industrial revolution (4IR) has taken hold (Bloem et al., 2014; Schwab, 2017) and is sometimes closely associated with the 'Internet of

Things'. Schwab explains that endless possibilities are presented by the fact that billions of people are connected through mobile devices with extensive processing powers and storage capacity, particularly as they are increasingly able to articulate with a wide range of new and developing technologies such as 3D printing, nanotechnology, materials science and robots. The 'Internet of Things' consists largely of robots or robot-like devices and machines in a range of contexts, from factories to homes, which can be controlled by smartphones or computers (Bloem et al., 2014).

4IR presents opportunities and challenges, such as having the potential to improve the quality of life for many groups of people around the world; from making it easier to order a cab or watch a film (Schwab, 2017) to taking over the 'three Ds' of industry: dirty, dangerous and dull work (Bloem et al., 2014). However, this revolution is also likely to have a major effect on labour markets, replacing factory workers, for example, with machines and increasing numbers of safe and rewarding jobs (Schwab, 2017). A challenge for education systems around the world is to prepare young people for the latter kind of job. This provides further rationale for a focus on STEM, and digital technologies in education, a fact emphasised in July 2018 by the president of South Africa, Cyril Ramaphosa, who reportedly suggested the need to provide populations of developing countries with the skills required to thrive in a digital society. He further recommended that governments should support re-skilling the workforce by formulating and implementing policies (Mzekandaba, 2018).

Kozma (2011b) argues that ICT policies have the potential to contribute towards system transformation through the 'unfreezing' of educational systems. However, he stresses that this depends on articulation with strategic visions and detailed planning. Kozma (2011b) identifies a number of ways in which the introduction of ICTs can articulate with other policy goals, including teacher professional development, pedagogical change, curriculum development and assessment reform. However, the contribution that ICTs can make in each case depends on the extent to which computers are available across the education system and the availability of more sophisticated applications. Overall, however, transformational potential is contingent on a move from learning about ICTs (how to operate computers and common software applications) towards the use of ICTs to support learning of curricular subjects and the cross-curricular skills associated with *Twenty-first Century Skills*.

When Kozma was writing, in 2011, this 'unfreezing' potential seemed at best limited for low-income countries. A mere seven years on, there are signs that the increasing ubiquity of smartphones in sub-Saharan Africa (GMSA, 2018) can make possible a significant change in education systems. WhatsApp groups, for example, now connect subject specialist teachers across disparate locations, so they are able to provide quick responses to specific professional queries (see Teaching Biology project in Chapter 3). Translation apps allow teachers and students to hear standard pronunciation of academic vocabulary. Teachers have set up websites, such as Shule Direct in Tanzania, as open access repositories of teaching and learning resources. Such initiatives demonstrate the potential of ICTs to address systemic problems, which previously appeared intransigent, such as: professional isolation of teachers in remote schools, prevalence of non-standard pronunciation, and teachers withholding parts of the curriculum from students during the school day in order to force them to pay for after-school 'private tuition'.

A Pan African Vision for Sustainable Development

African leaders set out regional priorities within the *Common Africa Position (CAP) on the post-2015 development agenda* (AU 2014a) and then later, in *Agenda 2063* (AU 2015). *Agenda 2063* explicitly espouses a knowledge economy perspective on development. Its central vision is for a 'peaceful and prosperous Africa, integrated, led by its own citizens and occupying the place it deserves in the global community and in the knowledge economy.' One of the six guiding principles put forward as a compass for 'decision makers' is:

Quality and relevant education, training and research are core for scientific and technological innovation, creativity and entrepreneurship. (AU 2016, p.21)

The Continental Education Strategy for Africa 2016-2025 (CESA) (AU 2016) outlines the contribution of education to this vision. It sets out 12 strategic objectives, including:

Harness the capacity of ICT to improve access, quality and management of education and training systems

a) *Formulate policies for ICT integration in education and training Build ICT capacities of learners and teachers to take full advantage of the potentials of technologies*
b) *Build capacities of education managers and administrators on use of ICTs in the planning, implementation, monitoring, strategies and programs*
c) *Promote the development of online contents taking into account African and local specificities*
d) *Capitalize on existing and successful ICT-driven initiatives that enhance access including the Pan-African E-University*
e) *Provide appropriate and sufficient equipment facilities (e.g. connectivity, power) and services*
f) *Create mobile and online education and training platforms and accessibility to all students regardless of their circumstances*

And:

Strengthen the science and math curricula and disseminate scientific knowledge and the culture of science in the African society

a) *Introduce science at early stage of education and create attractive extra-curricular activities such as science parks and clubs*
b) *Encourage practical training and reward innovation and innovators c. Facilitate the implementation of incubator projects and mentorship programs*
c) *Employ informal and non-formal means of disseminating scientific knowledge and culture*
d) *Embed contextualized scientific knowledge in curricula and alternative delivery modes*
e) *Promote indigenous scientific knowledge and culture*

(AU 2016, pp.23-25)

Hence, Agenda 2063 and CESA together sketch out a strategy within which science and technology innovation and research are seen as the main drivers of the development of knowledge economies. However, it is closely tied to scientifically literate citizenship. Formal education is the chief mechanism for disseminating scientific knowledge, both through the formal curriculum and extracurricular activities. Finally, scientific knowledge includes scientific indigenous knowledge. ICTs are a powerful tool for improving formal education and making it available to more people, in more places, throughout their lives.

Government investment in research and development in STEM and ICT fields has increased since 'Africa's Science and Technology Consolidated Plan of Action 2005-2014' (NEPAD 2006) called for the establishment of regional networks of centres of excellence and for a greater mobility of scientists across the continent. This was later replaced by the 'Science, Technology and Innovation Strategy for Africa 2024' (AU 2014b). A number of countries in the region have embraced this strategic vision, with Kenya reporting an R&D intensity of 0.79% of GDP in 2010, Ethiopia reported 0.61% in 2013 and Gabon 0.58% in 2009 (UNESCO 2015d, p.48). However, the shortage of skilled personnel in fast-growing industrial sectors, such as mining, energy, water, manufacturing, infrastructure and telecommunications, impinges on the efficiency and capabilities required for countries in the region to effectively strengthen and diversify their economies and move away from a dependence on revenue from the exportation of raw commodities.

National Development Policies and Implications for STEM & ICT Education

The importance of STEM and ICT education at secondary level, for the development of human capital is also a prominent feature in the national policy rhetoric of various sub-Saharan African countries (Barrett 2017, p.964). Policies stipulate with different degrees of detail, the pathways linking changes in STEM education to national development plans. Sometimes, even vague references to the need for science and technology expertise in new industries are enough to justify investment in STEM. In 2016, the Tanzania's Education Minister unexpectedly announced that, to meet the demands of the industrial sector, science subjects would be compulsory up to the end of lower secondary level, (Barrett & Mtana 2017). The utilisation and integration of ICT in the education system is identified in Botswana's Education and Training Sector Strategic Plan 2015-2020 (Ministry of Education and Skills Development 2015) as a driver for economic growth and global competitiveness. Kenya's Vision 2030 (Government of the Republic of Kenya 2007) aims to improve the quality of mathematics, science and technology education in order to raise productivity and efficiency levels. Rwanda's plan to grow its service sector and develop as a regional communications hub, provided a rationale for introducing Entrepreneurship and ICT as compulsory subjects at secondary level (Hayman 2005).

An articulation between economic and education planning can lead to the development of vocational pathways at the secondary level. Senegal is improving the quality and access to STEM education and modifying its technical education pathways as a step towards developing and growing sustainable industries that add value to its large agricultural sector and diversify its economy (Diouf & Reeves 2017). This is a central part of its long-term plan to achieve 'emerging economy status'. The introduction of Environmental Education into secondary education is another example of integrated planning, as the National Environmental Education Strategy formed part of the National Policy on Natural Resources Conservation and Development (Velempini 2017). Similarly, an integrated framework, involving various ministries, has been set up for the development of STEM and ICT skills, capacity, research and development in South Africa (see below).

National policies have also recognised the wide range of problems and contexts to which people apply STEM and ICT knowledge and skills. South Africa's National Development Plan, 2030 (National Planning Commission 2011) recognises the importance of good quality STEM education to increase the livelihood and opportunities of the people of South Africa. The Mauritian Education and Human Resources Strategy Plan 2008-2020, states in its plans for curriculum development that 'all attempts will be made to embed a culture of scientific thinking in line with the drive for sustainable development' (Ministry of Education, Culture & Human Resources 2009, p.78). Ghana's Mission Statement for Education, which states its aim as 'to provide relevant education with emphasis on science, information, communication and technology to equip individuals for self-actualisation, peaceful coexistence as well as skills for the workplace for national development' (Ministry of Education 2012, p.20). The extent to which development and education policies articulate the specific pathways through which STEM and ICT contribute to these aspirations varies. In Ghana and Namibia, for example, a strong emphasis is placed on the role of ICT in contributing not only to the country's economy, but also to human development:

> *'To articulate the relevance, responsibility and effectiveness of utilising ICTs in the education sector, with a view to addressing current sector challenges and equipping Ghanaian learners, students, teachers and communities in meeting the national and global demands of the 21st century'* (Republic of Ghana 2008, p.13).

And:

> *'The Namibian Government commits to harness and utilise the benefits of ICTs to achieve the objectives of socio-economic development through poverty alleviation, raised educational standards, boosting individual capabilities, improving health standards and*

replenishing environmental resources. The Government promotes gender equality, and the empowerment of women and disabled persons through access to ICTs' (Namibia Ministry of ICT 2009, p.9).

Strengthening ICT provision and usage is not only key *in* education, but also *for* education. As well as being able to equip students with the knowledge and skills required for socioeconomic development, the integration of ICT in education systems is perceived as able to improve student outcomes, teacher skills and practices and access to resources (Kozma 2011a). However, where 'the onus is placed on the school system and the teachers to make the promise of using ICT for socio-economic development a reality' (Awuku 2011, p.14), these policies may become 'de-energised'. In the case of Ghana, a technocentric approach to ICT integration, whereby policymakers and governments were quick to provide computers and equipment, but slow to evaluate the impact of its implementation, led to a gap in policy and practice. As the primary policy implementers, teachers needed to be consulted, engaged and guided to avoid misinterpretation and misalignment of key issues and to find the ideal ways forward, for development to be enabled (Awuku 2011).

Whilst top-down planning can produce a high degree of coherence between educational policies and national development visions, it can be out of touch with the experiences of teachers and students on the ground, particularly those who are marginalised or living at a distance from the urban centres where policy decisions are made. Educational policies also need to be feasible – politically, financially and in terms of the capabilities of the professionals expected to implement them. If STEM education at secondary level is to contribute to the weight of aspiration placed upon it, then policies need to focus not just on the quality, content and organisation of STEM education but also, crucially, on inclusion.

Country Case Study 1: South Africa

South Africa has prioritised STEM and ICT education in policies such as the National Strategy for Mathematics and Technology Education in General and Further Education and Training (NMSTE) (Department of Education 2001), the National Development Plan 2030 (National Planning Commission 2011), the Action Plan 2019: Towards the Realisation of Schooling 2030 (Department of Basic Education 2015) and the National Integrated ICT Policy White Paper (Department of Telecommunications and Postal Services 2016). Having already achieved middle-income status, South Africa provides a potential role model in the region and showcases how the development of STEM and ICT knowledge and skills may contribute towards national economic development.

With the establishment of the MST Integrated Framework, which was set up by the MST Ministerial Task Team in 2014, responsibility for improved MST education is shared between the Department of Basic Education, Department of Higher Education and Training and the Department of Science and Technology. The National Education Collaboration Trust (NECT) has also been set up to strengthen partnerships among business, civil society, government and labour to both support and influence the agenda for reform of basic education (Roberts et al. 2015a). In consultation with provincial educational departments and other relevant stakeholders, these organisations have worked to meet the challenge of national development targets, which include increasing the number of students eligible to study towards maths and science-based degrees, to 450,000 by 2030, and improving average Grade 8 scores in TIMSS from 264 to 420 points, by 2023 (National Planning Commission 2011).

Though South Africa's performance in TIMSS was disappointing in comparison to other countries around the world, a comparison of results from 2003 and 2015 do confirm 'noteworthy growth patterns'. At Grade 9 level, South Africa has shown the largest improvement of 87 points in Mathematics and 90 points in Science (Department of Basic Education 2016, p.10). The Department of Basic Education has been very proactive in its attempts to build on these improvements; with such interventions as the launch of the Mathematics, Science and Technology (MST) conditional grant to improve school infrastructure (see Chapter 3), the development of diagnostic reports for Grade 9

Mathematics and Science teachers (see Chapter 4), and the introduction of the Funza Lushaka Bursary Programme (FLBP) (see Chapters 3 and 4). There is a clearly a drive for strengthened STEM & ICT education.

As a middle-income country, South Africa boasts a supportive infrastructure for STEM and ICT secondary education. The gross enrolment rate in lower secondary is 111%, with a student transition rate to secondary school of 90% (EPDC 2015a); government expenditure on education is more than 6% of GDP (UIS 2018), which equated to 2567.25 PPP$ per student at secondary level in 2012 (UIS 2018); 95% of lower secondary schools have electricity (UIS 2015 in Wallet 2015) The learner-to-computer ratio is low for the region, at 54:1 for combined secondary (Wallet 2015, p.14) and there are significant disparities in terms of access and quality of education for learners, who are often disadvantaged by rurality, gender and socio-economic status (EPDC 2015b; Statistics South Africa 2016). How South Africa is addressing these inequalities is of particular interest for this study.

In comparison with most of sub-Saharan Africa, South Africa has a mature assessment climate, with Annual National Assessments for all learners to Grade 9, National Senior Certificate examinations quality-assured by Cambridge International Assessment, and participation in TIMSS, PISA and SACMEQ. It also has a Council for Quality Assurance in General and Further Education, otherwise known as Umalusi, and a National Education Evaluation and Development Unit. Such evidence for success in addressing improved access and quality of secondary education is readily available.

Country Case Study 2: Zambia

In recognition of the fact that 'education and skills development are instrumental in creating societies that are better able to respond to social and economic development challenges' (Ministry of National Development Planning 2017, p.94), Zambia has made a commitment not only to the provision of free and compulsory secondary education in its Education Sector National Implementation Framework III (Ministry of Education 2010), but also to the development of skills in science, technology, engineering and mathematics.

Mathematics and Science are compulsory subjects at the junior secondary level. Curriculum development has been particularly innovative, with interdisciplinary approaches to STEM and ICT offered at the lower secondary level in the form of Integrated Science and in Agricultural Science and Environmental Science, which are offered as part of the newly introduced vocational secondary education pathway (see Chapter 3).

Though the learner-to-computer ratio is 145:1 at the lower secondary level (UIS 2015 in Wallet 2015), the adoption of a national ICT policy in 2007 (Ministry of Communications and Transport 2006) has provided 'an enabling policy environment to promote far greater access and use of ICTs across all sectors of Zambia's education system (Isaacs 2007, p.3). Objectives for basic computer skills inform the national curriculum from as early as primary level and substantial efforts are being made to increase access to ICT education, with the establishment of the Zambia Information and Technology Authority (ZICTA) (see Chapter 3).

Through the enactment of the Teaching Profession Act in 2013 (National Assembly of Zambia 2013), which also facilitated the establishment of the Teaching Council of Zambia, the Zambian government has made a pledge to promote quality teaching and learning. Frameworks such as the ZAMSTEP fast-track teacher training programme and the SPRINT policy on Strengthening of Mathematics, Science and Technology Education (SMASTE) (see Chapter 3) illustrate this commitment.

These efforts and reforms have yet to be translated into positive student learning outcomes and mathematics and science assessment scores have remained below the benchmark of 40 percent (World Bank 2016, pp.1-2). The stagnation in student learning outcomes has, however, taken place within a mature assessment climate; the Examinations Council for Zambia (ECZ) conducts a biannual assessment of student learning and teachers, which allows for policies, strategies and initiatives to be evidence-based. This may be further supported by the fact that Zambia has signed up for PISA for Development and will thus, be working with OECD and the World Bank to focus on improving Science and Mathematics education, as well as its data collation and usage.

STEM & ICT Education and Inequalities

Whilst significant global improvements have been made with regard to gender parity and equality in education since the Dakar Framework for Action and the UN Millennium Development Goals (MDGs) in 2000, the average number of girls enrolled in secondary education relative to boys in sub-Saharan Africa has only risen slightly since 1999, with 84 girls for every 100 boys reported in 2012 (UNESCO 2015a, p.160). According to the UNESCO (2017b) report on girls' and women's education in STEM, 'Cracking the Code', the obstacles preventing female learners from completing or benefiting fully from good quality education of their choice increase in adolescence, with the gender gap in STEM participation becoming apparent in advanced studies at lower secondary level. PISA 2015 results (OECD 2018) indicate that, in most countries, boys typically outperform girls in mathematics and science at secondary level.

Universalisation of secondary education in Africa is the single largest and most significant step that can be taken towards achieving gender equality with respect to STEM. It would lead quite quickly to gender equity in measures of learning outcomes in STEM. Already in a context where secondary education is, or very nearly is, universal (most large urban centres, Botswana, Mauritius) the differences between girls' and boys' performance are small or non-existent. SACMEQ III data showed that in countries with universal primary education and near universal secondary education (Botswana, Mauritius, Seychelles and South Africa), girls marginally outperformed boys in mathematics by the end of primary school. Over a longer period of time, universal secondary education would lead to greater representation of women in STEM-related professions, including graduate and postgraduate level occupations.

Gender disparities in sub-Saharan Africa intersect strongly with poverty and rurality. For example, PASEC (2014) assessments found that 5% of girls in Cameroon from the poorest quintile of households had learned enough to continue their schooling, compared with 76% of girls from the richest quintile. The Centre for Development and Enterprise (2014), which is responsible for assessing the need for high quality teachers and teaching in South Africa, found that the learners obtaining passes in mathematics and science continue to be situated in the most privileged schools, despite more than twenty years having passed since the abolition of apartheid; only 6.6% of the 6270 secondary schools in South Africa were responsible for 50% of the national mathematics passes and only 5.5% produced 50% of the science passes upon graduation from secondary level education. Achieving gender equality in secondary education will depend on a long-term commitment to concentrated planning and resources within poor, rural contexts and for disadvantaged groups. This will include ensuring that STEM education is relevant to poor, rural youth, for whom opportunity costs are high.

The SAGA STI Gender Objectives List (UNESCO 2017, p.21) recommends targeted strategies for engaging girls in STEM primary and secondary education:

1. *Promote S&E vocations to girls and young women, including by stimulating interest, fostering in-depth knowledge about S&E career issues, and presenting role models;*
2. *Mainstream the gender perspective in educational content (teacher training, curricula, pedagogical methods, and teaching material);*
3. *Promote gender-sensitive pedagogical approaches to STEM teaching, including encouraging hands-on training and experiments;*
4. *Promote gender balance among STEM teachers;*
5. *Promote gender equality in STEM school-to-work transitions.*

Findings from surveys such as Uwezo, SACMEQ and PASEC have highlighted the problem of poor learning outcomes in literacy and mathematics in disadvantaged districts. However, the documents we have reviewed for this chapter make little mention of the role that numeracy and literacy make to STEM learning in secondary education. Within much policy on education and development, primary education is viewed as the appropriate educational level for building foundational literacy and numeracy, which is then developed in secondary schools. If secondary education is expanded as rapidly as CESA recommends and SDG4 exhorts, a large number of students enrolled in lower secondary education will still need support to develop their literacy and numeracy skills. Developing specific literacy and numeracy skills, such as subjective specific vocabulary and writing genres, visualisation skills and the use equations, is integral to STEM education (Barrett and Bainton 2016). However, there is scope for paying more attention to the curriculum and resources that would best support students, who have not achieved the learning outcomes at primary to benefit from STEM education at secondary level (Chapter 3).

Challenges Facing STEM & ICT Education

This chapter has focused on policy frameworks, mainly at the international and regional level while demonstrating how these relate to national level policy making. They set out lofty aspirations and highlight, in particular, the role that ICTs could play if made widely available and the priority that needs to be given to preparing STEM teachers.

In this final section we recap and expand on some of the challenges facing STEM and ICT secondary education, which were identified in an earlier paper (Tikly et al. 2018).

The first of these is a shortage of suitably qualified teachers in Mathematics, Science and ICT. In part, this has resulted from increased enrolment in secondary education with an associated demand for more teachers. In response, in many areas, teachers without the requisite knowledge and experience are employed. For STEM and ICT subjects this is problematic because it can lead to the reproduction of common misconceptions throughout society and the perception that STEM subjects are 'too difficult' for most people.

Attracting suitably qualified teachers in STEM subjects is difficult because of a shortage of people with well-developed subject knowledge who want to take up teaching. There is a tendency for those with good subject knowledge to choose other careers, which are seen as more attractive and better-paid. Even those who decide to go into teaching often choose to leave, and retention of teachers in STEM subjects is generally recognised as problematic.

As a result of the lack of teachers and other resources, in many sub-Saharan contexts, classes are large and often accommodate learners at different stages of learning. It is always difficult for teachers to cope in these circumstances, but in science and technology subjects it is often even harder as these subjects require students to work hands-on, with scientific equipment.

STEM subjects, especially science and technology, have high demands in terms of resources including computers and laboratory equipment, consumable materials such as chemicals, and textbooks. This puts a strain on the system which may already be struggling to provide a basic infrastructure. Textbooks, which are considered critical in all STEM subjects, are often of poor quality and in short supply.

At the classroom level, partly due to lack of resources and overcrowded classrooms, and despite the rhetoric encouraging child-centred approaches, the tendency is for teachers to rely on theoretical explanations and teacher-led approaches. This means that students miss out on crucially important aspects of learning in STEM subjects, such as experimentation. Furthermore, formative assessment, which is a crucial element of child-centred approaches and is clearly encouraged by policy in most SSA contexts, is weakly implemented. Instead examinations are high-profile and dominate, in terms of assessment, which encourages 'teaching to the test'.

The language of instruction is also considered problematic. Learning STEM subjects is challenging even for students studying these subjects in their first language, but for the majority of learners in SSA are learning in a second or third language. Many teachers are not fluent in the language of instruction, and although teachers switch to indigenous languages to explain, learners frequently gain only a superficial understanding of the lesson's content.

A final challenge relates to societal attitudes towards the STEM subjects and education in general. Attitudes towards STEM subjects tend to be negative in many countries in SSA and learners' belief that they can achieve well in these subjects is often low. It appears to be socially acceptable to be bad at these subjects. These attitudes are deeply engrained in society and are difficult to shift, but without a change of attitude it is unlikely that learners will be willing to try hard in these subject areas.

Conclusion

Generally, governments within sub-Saharan Africa see improving STEM and ICT education as a priority. This includes the development of ICT infrastructure for education and the use of ICTs to improve educational quality. There are examples within the African continent where a national programme to improve or extend STEM and/or ICT education is part of coherent a plan to achieve a long-term development vision. However, even when not part of a specific strategy, the widely accepted logic of knowledge economy means that STEM and ICT are seen as important and a priority for investment over and above other secondary school curriculum subjects.

Contemporary international development agendas have implications for curriculum and pedagogy in STEM and ICT. Within the EFA movement, the life skills agenda placed an emphasis on scientific literacy, numeracy and ICT skills that are useful in young people's work, home and community contexts. More recently, the sustainable development agenda reinforces this emphasis as so-called 'soft skills' are seen as essential for adapting to uncertain futures. This means teaching science not just as abstract facts but as inquiry that informs how we live and act. These views have had some influence on curriculum design (see chapter 3) but are less evident in national policy. Where learners are not proficient in the language of instruction at secondary school, this is a significant barrier to engaging in STEM inquiry that shows them how knowledge is useful to their lives outside school. Perversely, the knowledge economy view of development as participation in a global economic competition is often interpreted by policy makers as an imperative for learning STEM through a global (i.e. European) language.

The current trend of rapid expansion across many African countries, whilst improving access, is creating teacher shortages, especially in STEM subjects. Preparation, recruitment and retention of STEM and ICT teachers with the requisite subject knowledge and pedagogical skills is a key challenge to realising policy ambitions. Fast track programmes designed to get a large number of teachers into schools in a short time may mean that those teachers are poorly prepared. This is a challenge, which requires long term planning (see chapter 3).

The expansion of ICT infrastructure in Africa, particularly the ubiquity of mobile phones, is opening up possibilities for improving education, including teachers' knowledge and skills. In South Africa, national policy has supported the use of ICTs to improve education at the system level. However, in many other NGOs and self-organised groups of teachers have taken the lead in making use of the new infrastructure to build professional networks and expand access to teaching and learning resources.

Policy frameworks for STEM education and ICTs in education need to be coherent, feasible and, above all, must address inclusion. The questions below summarise the main issues arising from the discussion, presenting them as questions for inclusion in a diagnostic framework.

Relevance and Coherence:

- Do STEM and ICT education policies articulate with national development vision, TVET policies, education sector development plans and policies, science and technology policies and gender policies?
- Do ICT policies set out a plan for using digital technologies to improve learning?
- To what extent does STEM education address issues of environmental sustainability?

Feasibility:

- Do STEM and ICT education policies and plans start from a realistic baseline assessment of enrolments, resources, professional capabilities of teachers and performance at the end of primary?
- How detailed are plans to improve STEM education and policy?
- Are plans for monitoring and evaluation embedded within national plans and strategies?
- Are realistic budgets drawn up and sources of funding identified?
- Is an incremental approach taken to expanding access to interventions in the field of STEM and ICT?

Inclusion:

- Do baseline assessments identify different starting points for different groups of learners?
- Do gender strategies acknowledge and target intersectionalities of disadvantage?
- Do policies include plans for students failing to achieve expected learning outcomes at the end of primary education?
- What autonomy and support do schools serving disadvantaged learners have, to adapt curricula and pedagogy for their learners?

Chapter 3: Addressing Issues in STEM & ICT Secondary Education – Policies, Strategies and Initiatives

The focus of this chapter is on successful or, given that we are still in the early stages of achieving the targets set in Agenda 2063 and the Sustainable Development Goals, promising policies, strategic plans and initiatives, devised to address the challenges posed in delivering of high-quality STEM and ICT secondary education in the region.

As discussed in Chapter 1, these policies, strategies and initiatives have been classified into the three broad categories of curriculum and assessment, people, and material resources. Each category is considered in relation to three cross-cutting themes of relevance and coherence, feasibility and inclusion.

Curriculum and Assessment

With the expansion of basic education to now include free and compulsory secondary level education for all, as part of the Sustainable Development Goals agenda, it is necessary for STEM and ICT education to develop a broader focus than curricula solely targeting those students aiming to pursue specialised tertiary studies. In order to realise STEM and ICT education's role in 'sustainable work' for economic, social and environmental development, there is a need to better understand opportunities for improving the relevance of curricula to the current realities of the informal and agricultural sectors (Tikly et al. 2018).

Science, Mathematics and ICT curricula tend to include theoretical concepts which appear to be unrelated to the realities of day to day life or to the vocations that the majority will pursue (Ottevanger et al. 2007). As such, there is a strong perception that Science and Mathematics are more difficult than other options and students, therefore, avoid them (Juan et al. 2016).

Curricula are at times overly ambitious, covering a wide range of topics in a short amount of time, making it difficult to ensure that students are absorbing the material and truly making progress in the understanding of scientific content and procedures. Many curriculum reform processes have introduced new modules covering topics related to development objectives, such as health or the environment, but have not scaled back coverage of other subjects, thus overburdening teachers and students alike (Ottevanger et al. 2007; Gado 2005).

Various policies in the region have attempted to make STEM and ICT curricula more relevant, attractive and accessible to all pupils, using a variety of methods such as vocationalisation, the adoption of interdisciplinary approaches and the integration of local and indigenous knowledge systems (as detailed below). Increasingly, curricula include the teaching of skills and competencies (e.g. problem-solving, collaborating), in addition to the subject specific knowledge that young people should be taught. Many curricula also promote more learner-centred approaches to teaching, including for example, formative assessment and a variety of teaching methods which encourage active participation on behalf of the students. Such approaches to the teaching and learning of STEM and ICT has the potential to 'break down the boundary between in-school and out-of-school contexts' (Stears 2009, p.406) and, therewith, increase learner engagement with the field (Stears et al. 2003) and enhance the construction of conceptual understanding (Owusu 2015).

Vocationalisation

As recognised in the CESA (AU 2016, p.8), there is a need to include technical and vocational education and training (TVET) opportunities at secondary level and to strengthen linkages to the workplace (Barrett 2017, p.970). TVET is considered to be key to tackling human development issues of unemployment, employability, poverty and inequality, by a large number of countries (Marope et al. 2015, p.25). By providing a meaningful context, work-related learning can enrich the curriculum as well as help to raise standards, improve participation and increase attainment in education (Rolfe & Crowley 2008, p.13). Where foundational skills associated with the scientific method (e.g. logic-based reasoning, critical thinking and problem solving) have wide ranging relevance in the agricultural and informal/ entrepreneurial sectors of current labour markets, the vocational contextualisation of STEM and ICT subjects is particularly pertinent. This is recognised in Ghana, for example, where one of the nine objectives for incorporating technical and vocational subjects in the secondary school curriculum is 'to provide trained human resources in science, technology and commerce, matching supply of skilled labour with demand' (Akyeampong 2002, p.4), whilst another is 'to enable the youth to have an intelligent understanding of the increasing complexity of science and technology through systematic exposure to modern technology' (*ibid*).

Zambia is trialling vocationalisation at junior secondary level, in an attempt to bridge the gap between academic and skills education (MoESVTEE 2015) as well as providing a career pathway for those students usually 'pushed-out' of the traditional academic stream at Grade 7 or 9 (Kakupa 2017). Students in the vocational stream attend normal academic lessons in the morning, where Mathematics and Science are compulsory subjects, and then take pre-vocational courses such as Carpentry, Automotive Mechanics, Computer Studies, Plumbing and Sheet Metal in the afternoon. The revision and harmonisation of MoGE and TEVETA curricula required in order to implement this two-tier system, provides an opportunity for academic STEM and ICT knowledge and skills to be linked to the world of work. Though TVET has traditionally been regarded as 'the poor relative' of the academic educational stream and has largely been representative of a 'dead end' (UNESCO 2015b, p.27), the demand for this revised pre-vocational stream has been overwhelming, according to in-country consultants. It is unclear, as yet, where the school places will come from in order to accommodate the high number of students eligible for the vocational stream (Kakupa 2017). Currently, only six TEVET institutions are taking part in the initiative and limited funding is hampering the policy from being rolled out on a national scale.

Vocational streams have long been established at secondary level in many other countries in sub-Saharan Africa, including Botswana, Côte d'Ivoire, Kenya and Senegal, most of which integrate STEM and ICT in some form. Namibia, however, has recently taken an integrated approach to vocationalisation at lower secondary level where all students are required to opt for two pre-vocational subjects in Grades 8-10, in which they are formally examined. For each of these pre-vocational subjects, amongst which STEM options include Agriculture, Computer Studies, Design & Technology and Home Economics, four 40-minute lessons are allocated per week. This approach could be seen to demonstrate a real commitment to the development of scientific, mathematical and technological skills, as well as recognition of the need for relevance in the current labour market. Through the modularisation and integration of pre-vocational subjects into the national qualifications framework, the status of TVET might be elevated (Marope et al. 2015, p.45). Furthermore, alternative routes for the development of STEM and ICT skills may open up as pathways to tertiary levels of TVET become more transparent and attractive.

It seems that some countries are finding ways to make vocational education attractive to students, by, for example, offering combinations of traditionally academic subjects with more vocational subjects as in Zambian education, described above. Another approach, adopted in Namibia, is to formally integrate vocational subjects into the qualification framework, thus raising the status of these subjects. These examples suggest that, although it is recognised that introducing vocational courses at secondary level is challenging, where African governments have taken flexible yet serious approaches, they have had some success.

Interdisciplinary Approaches to STEM & ICT

Interdisciplinary approaches to teaching STEM and ICT allow for the practical application of scientific theory and knowledge and, as such, serve as a pathway to understanding the relevance, as well as improving the equity of access to, secondary STEM and ICT education (deChambeau & Ramlo 2017; Watters & Christensen 2013). One area in which interdisciplinary approaches to STEM and ICT have already been introduced and are, thus, already being practised in sub-Saharan Africa is through vocational education pathways, which are often non-compulsory and not universally available. However, the teaching of 'everyday science' has been written into various mainstream academic pathways in the region. In Namibia, for example, the Life Science curriculum combines 'biology (emphasis on human physiology), agriculture (emphasis on animal husbandry) and environmental education' (Ottevanger et al. 2007, p.14) and thus makes 'natural sciences more accessible to learners at [the secondary] level and opens up curriculum space for exploring the interconnections between natural systems and human systems' (Barrett 2017, p.972).

An interdisciplinary approach to STEM and ICT education has been a feature of Zambian curricula since the 1960s, with subject choices including Industrial Arts, Agricultural Science and Home Economics at secondary level. More recently, the subject Environmental Science, later renamed Integrated Science, has been built into both vocational and academic pathways at the lower secondary level in Zambia. As a compulsory subject for both educational streams, the Integrated Science syllabus aims to 'provide young learners an opportunity to do hands-on, minds-on and hearts-on activities through manipulation of objects and models, interaction with nature through observation of living and non-living things in their environment as is required in the field of science' (MoESVTEE 2013, p.vi). Textbooks to support the course, which develops the topics of The Human Body, Health, The Environment, Plants & Animals and Materials & Energy, over the course of the basic education cycle, have been designed and published by both Cambridge University Press and Pearson and examinations have been developed to test practical skills by the Examinations Council Zambia. Though an official evaluation of the outcomes of the course could not be determined (an issue further examined in Chapter 4), it is clear from a preliminary look at examination questions (used to assess students at the end of Grade 9) that attempts have been made to bring together the different disciplines and skills associated with the various STEM fields (see Figure 3.1). The content assessed is, in some cases, applicable to real life situations and the world of work (see Figure 3.2 and Figure 3.3) and practical skills are also tested in the form of experiments. However, the examination mainly relies on knowledge recall and very little application or understanding required (further discussed below in section on Formative Assessment).

Figure 3.1: Environmental Science Examination Question 1. *Source: ECZ 2012*.

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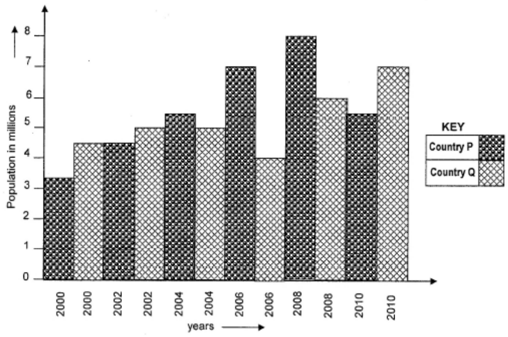
10 ECOLOGY

The graph below shows the population of two neighbouring countries P and Q for the period 2000 to 2010.



(a) In which year was the population of country **P** seven million? [1]

(b) In which country was the population increasing yearly between 2000 and 2008? [1]

(c) Suggest two reasons why the population of the country mentioned in **(b)** above, kept on increasing during that period. [2]

(d) Give one reason why the population of Country **Q** remained constant between 2002 and 2004. [1]

(e) Suggest a year in which Country **Q** could have experienced a civil war. [1]

Total = 6 marks

Figure 3.2: Environmental Science Examination Question 2. *Source: ECZ 2012.*

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8 MAN

In modern farming, farmers practice cross and in breeding.

(a) Why do farmers practice;

(i) cross-breeding? [1]

(ii) in-breeding? [1]

(b) Write down one quality a farmer would like to have in each of the following.

(i) chickens that produce eggs (layers) [1]

(ii) maize [1]

(c) In each case state one advantage and one disadvantage of artificial insemination. [2]

Total = 6 marks

Figure 3.3: Environmental Science Examination Question 3. *Source: ECZ 2012.*

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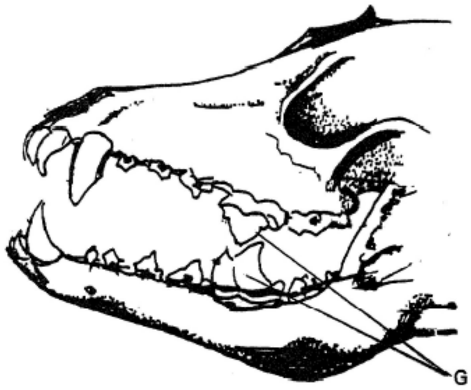
6 ANIMALS

The diagram below shows the skull of a dog.



(a) Identify the modified teeth labelled **G**. [1]

(b) Using the letter H, label on the diagram in your Answer Booklet the teeth used for gripping and tearing flesh. [1]

(c) Complete the dental formula below for the dog by identifying I and J

$i\frac{3}{3},\ c\frac{i}{\boxed{I}},\ pm\frac{\boxed{J}}{4},\ m\frac{2}{3}$ [2]

(d) During the nursing period most bitches (female dogs) become fierce and aggressive. Suggest one reason for this behaviour. [1]

(e) Give one difference between dentition in a dog and that of a goat. [1]

Total = 6 marks

There appears to be a worldwide trend to integrate Arts and Humanities subjects with STEM and ICT as a means of promoting versatility, creativity and innovation in the field. It is thought that STEAM (Science, Technology, Engineering, Arts and Mathematics), rather than traditional STEM, allows students to execute both the convergent and divergent skills necessary for global competitiveness (Land 2013).

This holistic and multidisciplinary approach has been adopted by the Western Cape Education Department in South Africa, who are exploring the inclusion of Reading, English and Arts in their *STREAM* programme. Though it is yet to be implemented, the Chief Director of Curriculum Development and Teacher Development in the Western Cape appears to have the aim of systematically coordinating a range of key players with new or existing interventions, in order to develop and initiate the programme. For example, a coordinated *STREAM* forum will provide an opportunity to engage with the Western Cape Education Department to discuss progress with curriculum delivery, to support their initiatives and to explore alternatives, innovations, context-sensitive and future-focused curriculum implementation. The inclusion of a variety of stakeholders to encourage ownership and ensure relevance of the *STREAM* curriculum is promising.

This section on interdisciplinary approaches began by looking at integrating scientific disciplines in a variety of ways and with a range of different foci. Generally, it appears that the intention is to find ways to make science subjects more relevant and accessible to all learners. The section concluded by explaining the rationale for, and development of, programmes which are wider in their scope than STEM and ICT and quoted the example of the *STREAM* programme in South Africa.

The overall message is clearly that governments in sub-Saharan Africa are exploring ways in which to package scientific knowledge and skills so that the curriculum is more relevant and accessible to students and their teachers, by shifting the focus to an understanding of the world around them.

Integration of Local & Indigenous Knowledge Systems

African educationists point towards 'the indelible legacy of colonialism… [as] the reason for the irreparable rupture to African education' (Semali & Mehta 2012, p.226), discontinuities and contradictions in curricula pervade, whereby scientific knowledge is presented as factoids divorced from local culture or knowledge systems. In this context, STEM curricula have, in the past, been characterised by a colonial perception of indigenous knowledge as 'a monopoly of *trials and error* while western (modern) knowledge is *science* characterized by *experimentation*' (Eyong 2007, p.121). The prevailing thinking suggests that in current or very recent practice, the long-established indigenous coping systems concerning the interactions between the economic, ecological, political and social environments are marginalised and ignored and opportunities to strengthen sustainable development are missed. At the same time, it is considered that bringing local and indigenous knowledge into the curriculum will make it more relevant to learners.

In the light of this thinking, there has been a move in many countries in SSA to recognise the value of indigenous knowledge and to revise policy accordingly. The South African Revised National Curriculum Statement, for example, states that 'Mathematics is a product of investigation by different cultures; it is a purposeful activity in the context of social, political and economic goals and constraints. It is not value-free or culturally-neutral'(2002, p.21). Curricula in many countries now address the potential for discordance between Western approaches to scientific inquiry and traditional belief systems (Aikenhead & Jegede 1999; Asabere-Ameyaw et al. 2012; Ezeife 2003; Glasson et al. 2010).

Since science, mathematics and computing are often seen as value-free and highly conceptual, the notion of integrating local and indigenous knowledge into these school curricula might appear as contradictory, despite policy recommendations to do so (Hewson & Ogunniyi, 2011). For many teachers, resolving this contradiction remains at the level of reference to local language or contexts (Onwu et al., 2006). It appears that a change in the mindset of teachers is needed though, in the main, they are not well enough prepared to integrate local and traditional knowledge with Western scientific knowledge (Ogunniyi & Hewson, 2008).

Attempts to prepare teachers to take full advantage of indigenous knowledge systems within their STEM curricula include a course in argumentation which included studies in aspects of science (e.g. History and Philosophy of Science), African indigenous knowledge systems and also some Anthropology and Linguistics. The teachers participating in the course appeared to have shifted their beliefs and delayed post-tests suggest that these shifts were sustained. However, it is clear that while such an intensive approach is neither scalable nor sustainable, what it does point out is that simply telling teachers to change the way they teach will not work.

Alongside a general emphasis across sub-Saharan Africa on high-stakes assessment, Eurocentric curricula encourage methods of 'teaching to the test' and rote memorisation (Paulo 2014) in part, perhaps, because students and teachers find it difficult to integrate their indigenous knowledge systems with the knowledge approach within the curricula they are given. Teachers struggle to explain scientific theories exclusively in English, as is often required, and are not aware of pedagogies that would enable them to contextualise theoretical science with local culture (Glasson et al. 2010, p.137). This leads to strategies of repetition and a focus on low-order thinking skills in the classroom. In contrast, 'indigenous conceptualization of intelligence includes dimensions of social responsibility and reflective deliberation' (Serpell & Simatende 2016, p.1).

It can therefore be argued that the incorporation and application of local and indigenous knowledge systems within secondary education curricula could allow for a more learner-centred and inclusive approach to teaching and learning.

Other initiatives which aim to address these concerns, and which have the potential to inform policy, exist across sub-Saharan Africa. In Northern Tanzania, for example, the Innovation, Science, Practicals, Application, Conceptualization, Entrepreneurship and Systems (*iSPACES*) curriculum has been developed as a pedagogical framework 'that utilizes a socio-cultural approach to teaching and learning that rests on core principles of science systems, and entrepreneurship useful to science learners' negotiating "border crossings" between western, modern science and indigenous science' (Semali & Mehta 2012, p.226). 'Informed by theories of culturally responsive pedagogy' (Barrett 2017, p.975), the *iSPACES* curriculum provides an alternative to the instruction methods of 'chalk and talk' and instead, focuses on the construction, deconstruction and reconstruction of knowledge through a range of pedagogical methods that promote exploration and innovation. In an evaluation of the project, Semali (2013, p.43) suggests that the approach adopted was successful in providing 'workable solutions to overcome everyday problems associated with poverty, famine, and disease in culturally responsive pedagogy. Perhaps predictably, while pointing out the crucial role of the teacher, he also goes on to suggest that the contributions of all stakeholders (e.g. industry, parents, professional development experts) are needed to make such a curriculum work.

Both the *iSPACES* initiative and the Zambian example demonstrate the local will to develop more responsive curricula.

Assessment

It is generally recognised that assessment, in the context of schools and schooling, takes a variety of forms. The South Africa Curriculum and Assessment Policy Statement (Department of Basic Education 2013a), for example, distinguishes between four kinds of assessment: baseline, diagnostic, formative and summative. Formative assessment, which is sometimes used as an umbrella term for baseline, diagnostic and formative assessment, is seen to have particular potential to improve learning, firstly because it involves ongoing feedback to learners and secondly because assessment data can 'be used by teachers to inform their methods of teaching'(*ibid*, p.13). According to Booyse and Chetty (2016, p.147), such 'constructive assessment encourages and fosters motivation by emphasising progress and achievement rather than failure'.

It can be argued that, where STEM and ICT subjects are often considered to be difficult to master, the effective use of formative assessment may be key to improving student perceptions and attitudes. Furthermore, in Bethell's (2016) research into mathematics education in sub-Saharan Africa, it was found that activities and training focusing on the use of adaptive teaching strategies and formative assessment yielded the greatest rewards, in that it allowed learners to explore alternative methods, reveal common misconceptions and, thereby, develop deeper understanding.

Government policies supporting formative assessment – continuous assessment or assessment for learning (AfL), as it is sometimes called – have been adopted in Ghana, Lesotho, Malawi, Nigeria, South Africa and Zambia. In an analysis conducted by Liberman and Clarke (2012), 18 out of 41 student assessment projects in the region included examples of Assessment for Learning, rather than simply emphasising summative assessments such as examinations. According to Perry (2013), a variety of informal AfL techniques, such as oral questioning, are common practice in Africa, as are more formal activities, such as tests and quizzes. However, in many cases, implementation does not match the vision of policy makers, as in Sudan and Ghana (Bethell 2016, p.107), suggesting that 'the powerful engine of assessment for improving learning remain[s] unharnessed' (Paulo 2014, p.137). There are many reasons for this: usually lack of resources, teacher subject knowledge and pedagogical skills (Maodzwa-Taruvinga & Cross 2012; Nsengimana et al. 2014).

As suggested above, informal assessment practices which look much like formative assessment, may already be used by teachers across sub-Saharan Africa. However, it seems that aspects of this need to be strengthened, as indicated, perhaps by putting governmental policies to support formative assessment in place. Through strategies such as mobile CPD programmes and the provision of low-cost science kits and OERs (see below), formative assessment might become easier for teachers to implement in the classroom as it will be easier for them to collect information about their students' knowledge and understanding. However, a challenge lies in the way the teachers use this information and it seems that teacher subject knowledge and pedagogical skills need to be improved. One approach to teacher professional development is to provide teachers with detailed guidance about how to gather and use the data they collect, as in the FaSMEd project in South Africa; another is to focus on formative assessment within lesson study initiatives, such as in Zambia.

Overall, however, coherence of curriculum policy, teacher education and resource allocation is necessary for formative assessment to be implemented effectively (Perry 2013; van der Nest et al. 2018).

People

In this section on people, the focus is on teachers: attracting teachers of STEM and ICT into the profession, retaining good teachers and improving the subject and pedagogic knowledge of teachers in schools. The section ends, however, with an example of an intervention which, in a sense, bypasses the teacher and acts directly with students.

As stressed in the Dakar Framework (UNESCO 2000), the role of teachers is pre-eminent to providing basic education of good quality (Bashir, Lockheed, Ninan, & Tan, 2018). However, there is a stark lack of qualified secondary level teachers in many countries in sub-Saharan Africa. UNESCO (2015a) reports that fewer than three quarters of secondary school teachers on the continent are trained, though in some cases the picture is much bleaker. In Cameroon, for example, only 32% of teachers are trained and in Senegal only 54.6% of teachers have the minimum qualifications required to teach at secondary level (Bainton et al. 2016a, p.12).

Alongside demographic changes and the expansion of 'Education for All' to include secondary education, this qualification deficit is a result of difficulties with teacher recruitment and retention, which are particularly acute in the fields of STEM and ICT (Ogunniyi & Rollnick 2015, p.67), where greater labour market opportunities are available to those who have attained qualifications in Science and Mathematics (Bainton et al. 2016b, p.5). In a report on the supply, training and management of teachers in Anglophone Africa, for example, Mulkeen (2010) found that only 17% of mathematics teachers were suitably qualified and the SACMEQ III report shows 79% of Grade 6 mathematics teachers in South Africa obtained below the pass level at that grade (Spaull 2013, p.5). The shortage of qualified teaching professionals in STEM and ICT secondary education has been recognised in various national policies. Working examples of this are Cameroon's Vision 2035, which sets a target of raising the proportion of teachers in engineering fields (UNESCO 2015d, p.517),a key policy recommendation in the TIMSS 2015 national report in South Africa 'to maintain efforts to recruit and retain subject specific teaching professionals in public schools' (Zuze et al. 2015, p.79), and plans for investing in a new science teacher training programme announced in Senegal (Barrett 2017, p.966).

In the majority of countries in the region, there is concern about the subject knowledge and pedagogical skills of teachers, who, particularly in STEM and ICT fields, are often teaching beyond their level of expertise (Ogunniyi & Rollnick 2015). Initial teacher training for prospective science teachers in countries such as South Africa, Botswana, Lesotho and Malawi involves the study of specific science content, scientific methods and pedagogical theory, as well as supervised teaching practice. However, the qualifications required to teach STEM and ICT at secondary level vary across the region and teacher training in subject specific teaching methods in the sciences in often lacking (Atebe & Schäfer 2011; Komba & Mwandanji 2015; Lewin & Stuart 2003; Ramnarain et al. 2016; Vavrus & Bartlett 2012).

In terms of the pedagogical skills of teachers and the delivery of lessons, there appears to be something of a mismatch between the intended curriculum, as laid out in policy documents, and the implemented curriculum, which is more concerned with the day to day teaching in classrooms. In theory, for example, the curriculum in South Africa strongly recommends practices of formative assessment, whereas little genuine formative assessment is seen in lessons. This is also true of scientific experimentation, which is written into the curriculum documents (e.g. conduct an investigation to test for the presence of starch and grease in food) but which seldom happens in practice. To some extent, this might be explained by the summative examinations, which (as discussed elsewhere in this report) usually have high stakes and drive what happens in classrooms. Since they do not generally examine experiments, for example, experiments are seen as ‘optional’ classroom activities.

Related to experimentation and learner-centred approaches in the classroom is the use of ICT in the teaching of science and mathematics. Throughout the world, it is accepted that ICTs have the potential to contribute to teaching and learning in these subjects (Clark-Wilson, Oldknow, & Sutherland, 2011; Hérold & Ginestié, 2018; Sutherland, 2007) but that integration of ICT into everyday classroom subject teaching is difficult to achieve (Artigue, 2010; Clark-Wilson et al., 2014; Hérold & Ginestié, 2018). The reasons for this include: technology not being reliable enough, teachers not knowing how to use the technology effectively and teachers not believing that the technology offers enough benefits to be worth the effort of learning how to use it and make it work in the classroom (Farrell, 2007; Wallet, 2015). For experienced teachers, who use traditional approaches to teaching and whose students achieve good enough results, there appears to be little incentive to change. However, calculators and graphical calculators are used regularly in Mathematics and Science classrooms, although more at upper secondary level than lower secondary level.

In order for curriculum reforms to be successful, close attention must be paid to teacher development programmes (Makgato 2012; Naidoo & Savage 1998; Ogunniyi 2007). However, teacher education has been a neglected area of policy development and several countries in sub-Saharan Africa did not have a national teacher education policy or strategy until as recently as 2007 (Buckler & Gafar 2013). In-service training programmes are often fragmented and disjointed and reactive rather than proactive, responding to the immediate needs of a new policy or the priorities of the implementing donor/ NGO. In STEM and ICT, where content and teaching methods are particularly specialised, there are insufficient opportunities for upgrading subject-based knowledge and subject specific pedagogical approaches (Tikly et al, 2017).

The shortage of qualified teachers in STEM and ICT secondary education not only impacts on student performance in these subjects, but also affects students’ uptake and perceptions of the field. As part of a three-year study into Improving Progress through Formative Assessment in Science and Mathematics Education in South Africa (Joubert 2015), a survey found that the public attributed mathematics problems to negative societal attitudes towards the subject and poor teaching. In a workshop held at Munali Boys Secondary School in Zambia, facilitated by the Zambia Association of Mathematics Education (Gertrude 2010), two major causes for very low ICT results were given: that the majority of Computer Studies teachers are lacking in ICT subject knowledge and/or pedagogical skills, and that the majority of teachers were working from out-of-date or unofficial syllabi.

With regard to improving access and attainment in STEM and ICT for girls, who are often less confident in their own mathematics ability due to gender stereotyping and societal expectations (Bharadwaj et al. 2012 in UNESCO 2015, p.184), investing in teachers is crucial. According to a study of girls in Grades 1-5 in the United States, anxiety about mathematics could be reduced if female teachers received more training in teaching mathematics and addressed stereotypical beliefs about gender differences in students’ ability (Antecol et al. 2015). Enhancing the status, morale and professionalism of STEM and ICT teachers, may encourage students to regard the disciplines more favourably (Marginson et al. 2013).

In summary, the problems relating to teachers and teaching concern the recruitment and retention of teachers and the lack of subject knowledge and pedagogical skills of practising teachers. There appears to be some commitment throughout the region to improving both the supply of teachers and the quality of teaching. The following strategies are intended to address the prevailing concerns.

Improving Teacher Status

One approach to addressing the shortage of teachers in STEM and ICT subjects is to change public perceptions of the profession, in the hope that more young people will be attracted to teaching., In most of sub-Saharan Africa, teachers are poorly paid, leading to high staff turnover rates, propensity for absenteeism and low staff morale (Bainton et al. 2016b, p.9; Beyani 2013). Where salaries are small, and often delayed, teachers are not only less motivated, but often required to take up casual work to supplement their income, resulting in less time for lesson planning and professional development (Hennessy et al. 2015, p.238). To address the issue of poor pay, some countries have put policies in place, which aim to attract teachers of STEM and ICT in particular, such as the salary increments allocated to Science, Mathematics and TVET teachers in Ghana. In South Africa, allowances were paid to rural teachers which, according to Poti et al. (2014) led to improved retention of teachers by rural schools, low teacher absenteeism, high teacher morale and improved learner performance. The effect of higher pay is also seen in other incentives to retain teachers in rural and remote contexts. In a bid to ensure a more equitable deployment of teachers, hardship allowances, salary increases, and subsidised loans have been used in Africa to incentivise teachers to work in rural postings, as well as providing suitable housing (Bainton et al. 2016b). While these latter examples do not, perhaps, aim to improve the status of teachers and are not aimed at teachers of ICT and STEM, they do demonstrate that financial rewards appear to have some degree of success.

Teacher status also seems to be affected by a perception that teaching is less difficult than other professions. According to Bainton et al. (2016b, p.5), 'teachers are often perceived to be less skilled that other graduate occupations because education programmes accept entrants with lower academic qualifications. In efforts to change this perception, many countries – including South Africa, Zambia and Uganda – have raised teaching professional standards. However, this does have the potential to restrict access for disadvantaged groups and thus may reduce diversity and gender parity within the profession (UNESCO 2014, p.234). Alternative pathways into teaching, that neither impede disadvantaged groups from entering the profession nor the status of the profession itself, need to be devised. This is particularly significant for vocational education streams (Marope 2015, p.116).

A third factor affecting public perceptions of teacher status may be a lack of clarity about how teachers can progress within the profession. As Mataka (2010) suggests, clearly defined career structure, with opportunities for progression and promotion, is requisite to attract and retain talent in any employment sector, but particularly in the case of teaching, which is marked by a shortage of professionals. Recognition and accreditation of achievements is one strategy that has been adopted in both South Africa and Zambia, as a means of motivating teachers to improve their practice and to remain in the profession. With the introduction of the National Professional Diploma in Education (NPDE), a qualification-linked professional pathway has been introduced for in-service teachers in South Africa. Upon achievement of the NPDE, teachers are then able to progress towards the Advanced Certificate in Teaching (ACT), whereupon specialisation in phases and subjects takes place. The ACT qualification is in operation in most universities in South Africa as a face-to-face, blended or distance learning programme across a range of specialisms, including secondary Mathematics and Science. The NPDE allows teachers to obtain and upgrade university-accredited qualifications, including the Advanced Diploma in Education, which is now offered at Stellenbosch University and funded by the Education Training and Development Practice Sector Education and Training Authority. This supersedes the previous teacher training qualification, namely REQV12, which did not secure a clear career pathway for teachers.

In summary, in order to raise public perceptions of the profession of teaching, three main strategies appear to have had some degree of success: increasing pay, publishing professional standards and developing clear career pathways.

Improving Recruitment to Teacher Training

A second approach to addressing the shortage of teachers in STEM and ICT is to provide incentives for young people enrolling on initial teacher education programmes. In many countries in sub-Saharan Africa, bursaries and scholarships are provided for prospective teachers to fund, or partially fund, their study to gain teaching qualifications.

In South Africa there appear to be a number of different initiatives offering such bursaries. In 2007, for example, the South African government introduced the Funza Lushaka Bursary Programme (FLBP) to attract students to pursue a BEd and to encourage graduates to enrol on PGCE courses. Preference was given to teaching majors in two of the following disciplines: African Languages, English, Mathematics, Natural Sciences and Technology at the Intermediate Phase or Accounting, Agricultural Technology, Civil Technology, Computer Applications Technology, Economics, Electrical Technology, Engineering, Graphics & Design, Geography, Information Technology, Life Sciences, Mathematics, Mechanical Technology, Physical Sciences, Languages, Technical Mathematics and Technical Science at the Further Education & Training Phase. In order to facilitate equity, the Department for Basic Education deploys newly qualified teachers in areas where there is a shortage of these specialised skills. In return, recipients of the FLBP are legally bound to work in public schools for a period equivalent to the duration of their bursaries.

In their evaluation of FLBP, Lewin et al. (2016, p.32) concluded that the programme design is ‘relevant in terms of its political, economic and social context [and]… largely appropriate in terms of the complex environment in which it is implemented, characterised by multiple role players and stakeholders’. Since the establishment of FLBP, enrolment in initial teacher education has increased from 29,000 in 2007 to over 86,000 in 2012. Though this cannot be solely attributed to FLBP, it has definitely made an important contribution.

In their survey of 3,200 FLBP recipients, 86.2% were training in a priority subject. Due to ineffective supply and demand projections, however, the majority of these FLBP graduates were not teaching their specialised subject (*ibid*, pp.33-34). Though a much higher percentage of FLBP graduates were reported to be working in public schools than the national average (82.8% compared with 60%), further improvements can also be made regarding their deployment. Many bursary recipients were found to be employed in quintile 4 and 5 schools (i.e. the top 40% of schools in terms of socio-economic status), despite programme objectives of placing teachers in the poorest schools.

In another South African initiative – The South African Mathematics and Science Teacher Intern Programme (SAMSTIP), run by the Independent Schools Association of South Africa, bursaries are provided to prospective teachers of Mathematics, Science and English to study either on a four-year BEd programme or on a two-year, part time PGCE at The University of South Africa. These programmes provide in-school training and mentoring and are, according to their website, ‘based on a decade of… schools’ experience’. However, there does not appear to be any evaluation of the programme available in the public domain.

Funza Lushaka’s figures indicate that recruitment into initial teacher education programmes has increased dramatically since 2012. They appear to be confident that their programme has made a positive difference. These South African examples provide evidence that financial assistance for prospective STEM and ICT teachers is an approach that might be successfully adopted more widely, elsewhere.

Alternative Teacher Training Programmes

A third approach to addressing the shortage of STEM and ICT teachers is to consider different approaches to teacher training. A number of countries across the globe, including the UK, Chile and Burkina Faso, have created alternative pathways into teaching for highly qualified graduates, which have extra subsidies or prestige attached to them and work to fast track trainees into full salaries (Bainton et al. 2016b). These programmes appear to recognise teacher education as a three-stage process, involving the three 'I's – Initial, Induction and In-career training. A significant proportion of pre-service training is therefore shifted toward in-service support and training, thus reducing costs to the system as well as increasing supply (Verspoor 2008).

One example of this fast-track approach to initial teacher training is the 'TEACH South Africa' initiative, which works with The Department for Basic Education in South Africa in the Gauteng, Western Cape and Limpopo provinces to improve the quality of teaching and learning and to ensure that learners in rural areas and township schools have access to key subjects such as Maths, Science, Technology and English. High performing graduates from leading South African Universities are recruited to become TEACH Ambassadors for a minimum of 2 years. In partnership with the University of South Africa (UNISA), TEACH Ambassadors undergo a crash course on the content knowledge and pedagogy of Mathematics or Science required to teach at a secondary school and are then placed in a largely disadvantaged school. Since 2009, TEACH South Africa has recruited, trained and placed 478 TEACH Ambassadors in 186 schools across seven provinces (Teach South Africa 2018). This initiative provides an incentive for teachers to work in schools where there are acute shortages, which is a key policy recommendation in the TIMSS 2015 national report (Zuze et al. 2015, p.79). However, it is relatively small in scale and does little to address the issue of restricted access for disadvantaged groups into the teaching profession. Furthermore, an evaluation of the programme with regard to such indicators of quality and sustainability as TEACH Ambassador attrition rates and student performance in TEACH South Africa partner schools, is yet to be made publicly available.

Continuing Professional Development

So far, this section has focused on recruiting and retaining teachers of STEM and ICT, and in the remainder of the section the continuing professional development (CPD) of teachers in these subject areas is considered. CPD is important because not only is the quality of teaching in STEM classrooms in sub-Saharan Africa often low and requiring improvement (see Chapter 2), but also teachers are clearly crucially important in the implementation of any reform (Darling-Hammond & Bransford, 2007). CPD takes a wide variety of forms, from formal academic courses such as Masters degrees to informal school-based mentoring. The detailed landscape review of over 50 mathematics education interventions (aimed at teachers, students or both) in South Africa, produced by Nicky Roberts and colleagues (2016) provides a snapshot flavour of the CPD opportunities available to teachers of Mathematics in this country.

There are very many examples of CPD initiatives across the region, so two examples from each of the country case studies have been selected for analysis below:

As suggested above, a continuing concern is the subject knowledge of teachers. In Zambia, for example, almost all teaching staff have some form of teaching qualification, though the level of qualification does not necessarily correspond to government policy targets (UNESCO 2016, p.66). Teachers qualified to diploma level, for example, should be restricted to teaching at lower secondary level, but are often found teaching at upper secondary level. The paucity of teachers with adequate content knowledge presents a serious difficulty in providing a quality secondary education, particularly for Mathematics and Science, as content training cannot be compressed (Verspoor 2008, p.227). As a short-term remedial action, accelerated content courses are being funded by the government. In such a circumstance, the best candidates for accelerated content programmes are those teachers practising at the level below but desiring additional certification (*ibid)*. In recognition of this, the Zambia Mathematics and Science Teacher Education Programme (ZAMSTEP) was set up in 2011, to allow teachers to upgrade their professional status so that they are qualified to teach at secondary level. Overseen by the Ministry of Education, ZAMSTEP is supported by donors, including DfID, JICA, USAID and is primarily offered by the University of Zambia's School of Education, though more recently private universities have also been contracted to help strengthen the programme.

In their research on how rural sub-Saharan environments impact on teachers' ability to access in-service programmes, Buckler and Gafar (2013) conclude that school-based continuing professional development (SBCPD) programmes should be prioritised, as they do not require teachers in under-resourced settings to travel long distances or live away from home. One form of SBCPD that has been piloted across the region (for example, in Guinea, South Africa and Zambia) is Lesson Study, a Japanese concept known as *jugyokenkyu*, which 'brings together the entire teaching staff of a school to work in a sustained and focused manner on a school wide goal that all teachers have agreed is of critical importance to them' (Fernandez & Yoshida 2004, p.10 in Schwille et al. 2007, p.111).

The Ministry of Education in Zambia has embedded SBCPD into their Education Curriculum Framework and budgets in the form of its 'School Program of In-service for the Term' (SPRINT) policy. In coordination with JICA, Lesson Study has been incorporated into this policy through the 'Strengthening of Mathematics, Science and Technology Education' (SMASTE) programme since 2005 (see Figure 3.7). During this time, Japan's approach to donor aid was for 'African ownership in development and of partnership with the international community' (Mubanga 2012, p.7). The alignment of SMASTE with SPRINT allowed for ownership, sustainability and cost-effectiveness of the programme and created a direction for technical cooperation between local schools, the national ministry and the global donor agency (as demonstrated in Figure 3.8).

Figure 3.4: Framework of SMASTE Implementation. *Source: Banda 2011 in Mubanga 2012, p.8.*

Startin g year	Project Title	Focus of the Project	Target Area	Target levels	Target Subjects
2005	SMASTE School-based Continuing Professional Development Project	Implementation of Teacher Training (Introduction of Lesson Study)	Central Province	Upper Basic and High School	Science and Maths
2007	SMASTE School-based Continuing Professional Development Project Phase 2	Implementation of school based training	Central Province (Basic & High Schools)	1.Central (Basic & High school) 2.Copperbelt & North Western Provinces (Upper Basic & High Schools)	1. All Subjects 2. Science and Maths
2011	Phase 3 (under implementation)	Strengthening Teacher Performance and Skills (STEPS)	Whole Country	Selected 54 Districts in the whole Country.	1. All Subjects 2. Science and Maths

As the programme was initiated and implemented within schools, it was hoped that SMASTE would benefit more teachers than previous INSET programmes, which had required teachers to travel elsewhere with the permission of headteachers. The monthly Lesson Study cycle consisted of eight phases:

1. Setting and issue and theme
2. Preparing an experimental lesson collaboratively
3. Implementing and observing the lesson
4. Reflecting on the lesson
5. Improving the lesson plan, based on reflection
6. Implementing and observing the improved lesson
7. Reflecting on the lesson again
8. Summarizing the activities (Ministry of Education 2007, p.4 in Baba & Nakai 2009).

Figure 3.5: SMASTE project inputs from Japan and Zambia. *Source: Banda 2011 in Mubanga 2012, p.8.*

Starting year	Project Title	Project Inputs	
		Inputs From JICA	Inputs from Zambia
2005	SMASTE School-based Continuing Professional Development Project	1.Long-term expert: One(1) Technical Advisor 2.Training for education managers/teachers overseas Training (Japan: 5, Kenya:83) 3.Budget for local activities: 4.6 million yen 4.Equipment and materials: 4.5 million Yen	1. Counterpart personnel: 14 2. Budget in total: approximately 19 million yen
2007	SMASTE School-based Continuing Professional Development Project Phase 2	1. Experts • Two Long-term experts on Lesson Study and INSET Management and Coordination and Monitoring • Four Short-term experts from Kenya SMASE 2. Training for education managers/teachers overseas: total 41 persons (Japan: 11, Kenya: 17, Malaysia: 6, Technical Exchange Program with Uganda: 7 3. . Equipment and materials: 4.5 million Yen 4. Budget for local Activities 16 million Yen (23%)	1.Counterpart personnel: 115 - National level: 7 - Provincial level: 33 (3 provinces) - District level: 69 (23 Districts) - College of Education: 6 2.Budget for local activities 54.3 million Yen (77%) proportion by levels: National 7%, Province 8% District Zone and School 85%
2011	Phase 3 (under implementation)	1. Experts • Long-term experts on Lesson Study and INSET 2. Training for education managers/teachers overseas. 3. Equipment and materials 4. Budget for local Activities	1. Counterpart personnel: 115 2. Budget for local activities

In construing teachers 'as professionals, capable of critiquing and developing their own practice' (Cordingley et al. 2004), Lesson Study provides structured opportunities for teachers to reflect upon and share observations, experience and new techniques, thus promoting team spirit in schools. By highlighting the importance of teacher collaboration for professional development purposes, Lesson Study provides a concrete, continuous and cumulative teacher development programme (Schwille et al. 2007).

According to Baba and Nakai (2009), initial responses to SMASTE were overwhelmingly positive. Lesson Study was shown to have improved the quality of teaching in Central province and had a positive impact on students' performance in national examinations in Science (Banda et al. 2014). However, as the programme was rolled out nationally, it was observed that schools were increasingly regarding Lesson Study as a requirement from the Ministry or had stopped conducting the programme in the middle of term. In order to develop teachers' creativity, Lesson Study requires the school administration's understanding and support, technical input for teachers to improve their teaching skills and teamwork among the teachers within the group. However, once this programme was scaled up, schools were trapped by formal procedures and the supportive attitudes required, waned. This suggests that Lesson Study is most effective when schools take ownership of their own Lesson Study projects and are allowed to plan according to the specific needs of their schools.

In South Africa the '1+4' national programme, which was aimed at increasing teachers' knowledge in Mathematics, Science and Technology was implemented in 2015. The '1+4' programme is a weekly programme for lower secondary Mathematics teachers that splits the weekdays into one day for teacher training and the remaining four days of teaching to implement what was learnt during their training. The starting point was that Mathematics teachers required increased knowledge across all areas in the mathematics curriculum. This amounted to 23 days of intensive teacher training and discussion about the mathematics curriculum and pedagogy. This required extensive support at the provincial level and, as a result, not all provinces chose to participate in this national programme. Currently, the '1+4' programme is on hold whilst the impact of the programme is researched using pre- and post-tests for the teacher as part of the evaluation.

The University of Stellenbosch's Centre for Pedagogy (SUNCEP) is involved in a range of teacher professional development projects. For example, in the academic year 2015, they ran three programmes for about 280 in-service secondary teachers, which aimed to increase the conceptual Mathematics knowledge of participants, develop an understanding of the new Curriculum Assessment Policy Statement (CAPS) and introduce e-learning technologies for teaching and learning Mathematics. These programmes adopted a blended model with centralised face-to-face contact sessions and regular, remote lectures using the University's telematics services, which integrate satellite, mobile, web-based and video conferencing facilities. Mentoring of teachers made use of a range of social media platforms such as WhatsApp groups, Google Hangouts and Facebook. Their own informal evaluation of the programmes suggest that teachers prefer ongoing professional learning interventions to one-off courses, but that they need support and guidance throughout the intervention. They also note that teachers found the active learning approaches used in face to face sessions 'meaningful' and that teachers will not attend contact sessions unless their travelling and accommodation costs are covered. Finally, they found that it is of crucial importance to establish good professional relationships with the education district in which each teacher is located (Roberts et al. 2015a).

Both these programmes were included in the review of mathematics education interventions mentioned above (Roberts et al., 2016). In the review, the authors drew up a set of lessons learned at a variety of levels: provincial, district and school. These are too long and detailed to be included in full here, but include, for example, the requirement for 'adequate staffing of curriculum advisors' at district level and the importance of situating interventions in functional schools since 'working in dysfunctional schools is a waste of time' (*ibid*, p.66). At the level of programme design, they suggest that the plans should include realistic timeframes and clarity about who is responsible for what. In order for initiatives to be successful and bring about change, the following programme design features are seen to be vital: sustained investment and focus; communication between all stakeholders; project leadership; programme evaluation; transparent success criteria for all stakeholders; and monitoring throughout. In terms of lessons learned at the level of teachers, the report suggests that longer term initiatives with sustained and ongoing teacher support, including cycles of reflection, feedback and on-site support, tend to work well and, where possible, two or more teachers from the same school should participate in the programme. The review goes on to suggest that it is important to understand the prior knowledge of teachers, to design content of sessions accordingly, to monitor the progress of teachers and to offer incentives for teachers taking part in professional development interventions.

Widening CPD Opportunities Using New Technologies

According to Traxler (2018, p.5), 'Africa is probably, on average, characterised by the most diverse and active mobile telecoms sectors in relation to the other major regions/continents, to average incomes and to the penetration of general information and communications technology'. There are many innovative teacher professional development programmes exploiting the ubiquity of mobile phones, such as mobile training, distance education and Open Educational Resources (OERs). In Mozambique, for example, mobile phones have been integrated in pre-service teacher training across the country, through the Ministry of Education's Technology Plan for Education. In South Africa, Stellenbosch University's professional development programme described above uses a range of technologies including mobile phones within its blended learning approach and in its Advanced Certificate of Education programme it uses Moodle, which is an open-source learning management system with a mobile interface.

While mobile technologies are not intrinsically transformative of pedagogical practice, they are desired by both teachers and learners and are therefore, able to play an important, motivating role (Haßler et al. 2011). Furthermore, mobile phones can facilitate peer support among teachers, as seen in the Teaching Biology Project. Operating in Cape Town, South Africa since 2010, this project sends weekly Biology-related text messages to teachers, relating to definitions of biological processes, motivational messages and administrative messages. Teachers have responded positively to the service and indicated that they find it useful (Isaacs 2012a, p.19).

The Teacher Education in Sub-Saharan Africa (TESSA) Secondary Science Project, which is hosted by the Open University in the UK, together with African and other international partners, was initiated in 2010 in five countries in sub-Saharan Africa (Uganda, Kenya, Ghana, Zambia and Tanzania). The project provides teachers and teacher educators with a large bank of Open Educational Resources (OERs), teaching resources and handbooks, which are designed to support pedagogy courses in teacher education programmes in participating universities. Figure 3.5 outlines the various ways in which TESSA OERs have been incorporated into teacher training programmes.

Figure 3.6: Different types of use of TESSA materials. *Source: Open University 2016, p.9.*

Form of use of TESSA materials	**Highly structured**	**Loosely structured**	**Guided use**
Characteristics	Selection of a set of TESSA activities for all pre-service teachers to carry out	Lecturers select appropriate TESSA activities for their own course	Designated time for pre-service teachers to select TESSA activities
Teacher access to TESSA materials	New teacher books which include several TESSA sections	Website and printed TESSA sections	Website or CDs
Example	National Teachers' Institute (NTI) (Nigeria); Open University of Sudan (OUS)	University of Education, Winneba (UEW) (Ghana); Egerton University (Kenya)	University of Pretoria (UoP) (South Africa); Our Lady of Apostles (OLA) College (Ghana)

The OERs provided cover five pedagogical themes across the three science specialisms (see Figure 3.6). For each theme and context, up to six OERs are provided, which are designed to support teachers and pre-service teachers in delivering practical, meaningful activities in the science classroom, examples of which include: demonstrations; brainstorming; peer assessment; students' writing; differentiating work; risk assessment; science investigations; cross curricula links and literacy; misconceptions; and revision tools (Open University 2016, p.9). Whilst the resources do not cover the whole of the curriculum, it is envisaged that teachers will begin to incorporate these participatory teaching techniques in their general teaching practice for other parts of the curriculum.

Figure 3.7: Themes and Contexts of the TESSA Lower Secondary Science OERs. *Source: Open University 2016, p.6.*

Theme	**Biology context**	**Chemistry context**	**Physics context**
Probing children's understanding / learning	B1: Classification and adaptation	C1: Elements, compounds and mixtures	P1: Properties of matter
Making science practical	B2: Transport	C2: Acids, bases, salts	P2: Measurement
Science lived (relevant and real)	B3: Respiration	C3: Combustion	P3: Pressure
Problem solving – creativity – innovation in science	B4: Nutrition	C4: Atomic structures, chemical families and the periodic table	P4: Forces
Dealing with challenging ideas in science	B5: Cells	C5: States of matter	P5: Electricity and magnetism

Challenges in delivering quality STEM education, such as examination pressures, gendered attitudes and language of instruction, have been taken into consideration in the resource design (Stutchbury 2013, pp.4-5). Furthermore, the resources are formulated according to a template that combines both global and local content, which facilitates contextually appropriate teaching and learning practices. In light of this, the response to TESSA has been largely positive from both teachers (Stutchbury 2013; Ngman-Wara & Acquah 2015) and researchers alike, with Murphy & Wolfenden (2013, p.264) stating that 'TESSA OER specifies and models a pedagogy of mutuality for teacher and pupil learning that alters how learners are positioned and understood, that is congruent with the LCE principles found in national policies'. Nonetheless, uptake has been low, with accessibility to resources, whether hard copies or online, impeding effective implementation (Ngman-Wara & Acquah 2015).

In the Zambian context, OERs have also been introduced since 2009. They were developed in response to a project led by the NGO *iSchool.zm*, who found that integrating technology into Zambian schools was hampered by a lack of pedagogical support. Co-developed and locally contextualised by Zambian teachers and other local partners, *OER4Schools* initially supported primary school teachers in the Lusaka province, but since 2013, has been trialled as a school-wide approach across Grades 1-9. *OER4Schools* is a school-based, peer-facilitated professional learning programme that integrates the use of mobile devices, digital open educational resources and open source software to promote innovation and experimentation in the classroom. In a context characterised by difficult circumstances for schools (including shortage of finances and teaching resources, lack of or unstable electricity supply, absence of running water, safety issues) and difficult working conditions for teachers (e.g. lack of appropriate accommodation near the school, low and often delayed remuneration), the programme is structured to exploit technology tools where available, but not to be dependent on them (Hennessy et al. 2015, p.538). In order to support the active, collaborative learning of mathematics and science, materials such as professionally filmed video exemplars of interactive practices in Zambia and South Africa, have been filmed. The programme is yet to be scaled up.

The course comprises six units, which cover interactive teaching principles, group work, questioning, dialogue, Assessment for Learning and enquiry-based learning which are delivered over the course of a year, in 25 two-hour sessions. The materials have been designed to support the current Zambian curriculum, though adaptation to teachers' own purposes and settings is encouraged. According to Hennessy et al. (2015, p.545), teachers 'were found to have raised their expectations of pupils, adapted to their knowledge levels, used a range of interactive techniques, especially practical and group work, integrated technology use and collaborated with peers'. Furthermore, learners developed a deeper understanding of subject matter, were more actively engaged and were able to collaborate with one another and use digital technologies for problem solving (*ibid*).

The major challenge encountered in delivering the programme successfully, was the time commitment required by teachers to not only attend workshops, but also to study the materials and plan how best to trial the new ideas in their classrooms. However, this could be combatted if *OER4Schools* is integrated into the Zambian government's *SPRINT* framework (see above).

Clearly, digital technologies have the potential to reach teachers, who might not otherwise be able to take advantage of professional development opportunities. Given that mobile phones are used on a daily basis by almost all teachers in sub-Saharan Africa, further development of support such as the South Africa Biology example seems promising. Other approaches, enabled by the use of mobile phones, such as WhatsApp groups and access to OERs, could be further explored.

In this section on teachers, we have reported on a range of examples of initiatives aiming to improve the knowledge and expertise of teachers, for both pre and in-service teachers. Although some of them include some research element, on the whole they are not rigorously evaluated and it is almost impossible to determine the relationships between the elements of each initiative and the effect and cost, that each brings. It is notoriously difficult to 'measure' the effectiveness of initiatives of professional development for teachers, but there is some general agreement about what works well in given contexts (This is beyond the scope of this report but see, for example, Guskey & Yoon, 2009; Joubert, Back, De Geest, Hirst, & Sutherland, 2010; Orleans & Lewis, 2000; Stiles, Loucks-Horsley, Mundry, Hewson, & Love, 2009). It is recommended within this report that further research is undertaken in the context of sub-Saharan Africa.

Working Directly with Learners

While the majority of initiatives, strategies and policies under the broad theme of 'people' are concerned with teachers, there are also some initiatives that target learners directly. One such initiative is SAILI, in South Africa. This project is based on the belief that investing directly in motivated and capable students has potential for promoting Mathematics and Science education in schools. The project provides scholarships for students who have been identified at primary level as talented in Mathematics and Science, allowing them to attend good quality schools. Unlike many scholarship programmes that remove students from their local and familiar environments, SAILI identifies schools that are physically accessible and socially similar to the contexts of the students and provides support for students to attend these schools.

SAILI's website claims 'proven success' and statistics on the website demonstrate that all SAILI students passed Mathematics and Physics at school leaving level (National Senior Certificate), in comparison with the national averages of 46.3% and 50.8%, respectively. Over 500 of their past scholarship students have gone on to study at tertiary level, with 55% of these studying Engineering. However, SAILI also conducts ongoing monitoring and evaluation of their students, using school assessment data, longitudinal observation and regular contact with students, parents and school personnel. If issues arise, SAIL addresses these in a timely manner.

SAILI is a small initiative, but it provides an important example of the approach of identifying and nurturing talent adopted by, for example, the African Institute for Mathematical Sciences (AIMS) at post-graduate level. This is good for the individuals, as shown by SAILI's statistics, but it is also good for the schools and SAILI claims that there is also a positive effect on its partner schools. It suggests that the significant numbers of scholarship students in these schools raises their results and hence, their reputation, which means that good teachers are attracted to these schools and there is an ongoing cycle of improvement.

It might be that this is an approach that could be adopted more widely across all of sub-Saharan Africa as it is relatively cost-effective, but has the potential to improve the chances of many individuals, with a further knock-on effect of improving schools.

Material Resources

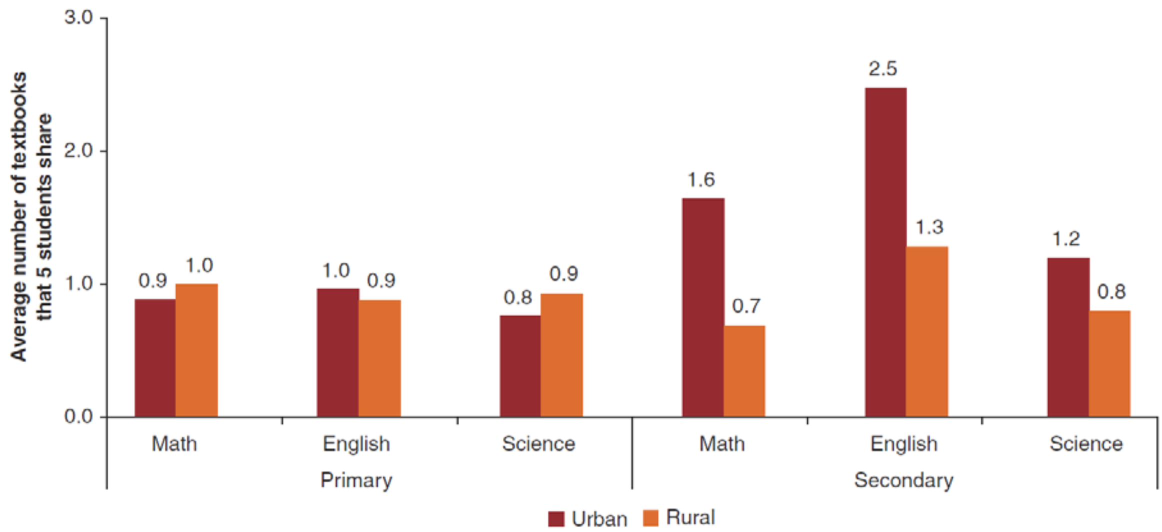
Whilst there has been a significant shift toward the adoption of competence-based curricula across sub-Saharan Africa in recent years, many challenges remain, in implementation. High student-teacher ratios and lack of textbooks and other teaching aids (particularly lab equipment and computers), hamper the implementation of constructivist approaches on the ground. As Samoff et al. (2011) suggest, in order for a pilot initiative to be scaled up successfully, the conditions (rather than the content or structure of the pilot) need to be scaled up.

In order to be truly transformative, capacity building must focus on supporting, resourcing and raising the quality of teaching and learning, rather than merely integrating new equipment and technologies (Hennessy et al. 2015). In the context of sub-Saharan Africa, where the pupil: teacher ratio was estimated at 23.1:1 in 2014 (UIS 2018) (compared with a global average of 17.4:1 (*ibid*)) and where internet penetration rates of less than 7% are found (e.g. in Burundi, Cameroon, Central African Republic, Chad, Comoros, Congo, Eritrea, Ethiopia and Somalia) (UNESCO 2015d, p.509), alternative methods for providing teachers and students with appropriate resources for quality teaching and learning in STEM and ICT are required.

Textbooks

As the primary teaching aid for teachers, textbooks are key to quality Science and Mathematics education (Bethell 2016; Read 2015). However, textbook distribution in sufficient quantity remains a challenge in sub-Saharan Africa (Bethell 2016; Verspoor 2008). Evidence suggests that textbook ratio is associated with student performance (Lee & Zuilkowski 2015; Yara & Otieno 2010) and that the desirable pupil: textbook ratio for effective learning should be less than 3:1 (Bethell 2016). However, severe textbook shortages plague education systems in the region. In Zambia, for example, the student: textbook ratio is more than 4:1 for Science and Mathematics (see Figure 3.9), with disadvantaged groups affected more severely. Fredriksen et al. (2015, pp. 19-20) identify four factors of particular relevance in contributing to textbook scarcity: large differences between countries; neglect of system costs; poor textbook planning, management, and monitoring; and poor storage and distribution systems.

Figure 3.8: Pupil-Textbook Ratio (per Five Students) in Zambia by Subject, Education Level and Urban-Rural Location. *Source: World Bank 2016, p.50.*



The TIMSS 2015 national report in South Africa (Zuze et al. 2015), found Science textbook ownership amongst Grade 9 learners ranged from 45% in KwaZulu-Natal and 65% in the Eastern Cape, to 87% in the Western Cape. It is clear that the availability of resources is critical to equity in educational reforms (Ramnarain 2011).

However, a 2011 South African initiative to address the problem of textbook provision has produced workbooks for all learners in Grades 1 to 9 in key subject areas, including Mathematics. The workbooks provide worksheets and activities to reinforce mathematics skills and lesson plans for teachers. These are distributed to 100% of schools. In an evaluation of the workbook scheme, Outhred et al. (2013) found that workbooks were generally seen in a positive light, with the majority of schools using the workbooks every day. The workbooks were also positively viewed by parents, who reported that children used the workbooks for homework and that, in some cases, they used the workbooks themselves, to learn the content their children were learning.

Improving the provision of textbooks alone is not enough, however; the quality of textbook is also important (Bethell 2016). Common criticisms of STEM and ICT education in sub-Saharan Africa include the low quality of textbooks, which are often out-of-date with curriculum reforms (Ramnarain & Chanetsa 2016; Ramnarain & Padayachee 2015), do not reflect local context (Verspoor 2008) or do not integrate indigenous knowledge sufficiently well. Further, there exists some debate about the level and complexity of scientific and technical language used in textbooks for STEM subjects (Antia, 2018). While there are strong arguments for using everyday language in the interests of readability, it is generally considered important to introduce students to the scientific and technical language they will need to respond to examination questions and to participate generally in the wider scientific community (October, 2002; Wababa, 2010). Increasingly, textbooks offer guidance for teachers and, although there is some variation in the quality of this guidance, it is generally seen to be of value (Akyeampong, Lussier, Pryor, & Westbrook, 2013).

Referring again to the workbook scheme in South Africa, the report by Outhred et al. (2013) found that the workbooks were generally seen as 'quality textbooks', with assessors of the workbooks reporting that the workbook assessment tasks are fit for purpose. However, teachers reported that the workbooks are not aligned to the work schedule and some reported that the exercises were not challenging enough. More recently, the National Educational Evaluation and Development Unit in South Africa has been conducting analyses of all the workbooks but their report on workbooks is not yet available.

A concern in most countries in sub-Saharan Africa is the language of teaching and learning, which is frequently not the home language of students. There is a growing literature on the importance of the link between language of instruction and student performance in STEM and ICT (Arthur 2001; Atweh & Clarkson 2001; Brock-Utne 2012; Chitera 2012; Coyle 2007; Howie et al. 2008; Pearson 2013; Prophet & Badede 2009; Wellington & Osborne 2001). Whilst textbooks, learning support materials and assessments in STEM & ICT subjects (as well as other academic subjects) are generally produced in English, teachers and students often make use of African languages in order to convey and establish the meaning of content (Verspoor 2008; Wababa 2010). The lack of coherence between learning materials and classroom practice, and the subsequent codeswitching that occurs, can cause confusion and prevent students from fully engaging with the content (Probyn 2006). Discussions in the students' first language are extremely valuable for eliciting prior knowledge and connecting concepts to real-life situations. However, more structured support is required in order to translate this knowledge into the medium of instruction so that these students are not disadvantaged in assessments.

In an attempt to address this concern, the Language Supportive Teaching and Textbooks (LSTT) project in Tanzania aims to support learners making the transition from using Kiswahili at primary school to using English as the medium of instruction, at secondary level. The Tanzania Institute of Education, which is responsible for the curriculum, has worked together with two universities in Tanzania and another in the UK to develop a Mathematics and Biology textbook, both of which use simple language, vocabulary lists and images in order to make the content language accessible and meaningful. By integrating language learning with subject learning, student engagement in interactive learning processes improved, as did their ability to write about Biology in English (Barrett et al., forthcoming). Phase 2 of the LSTT project, which began in 2016, is focussing on supporting teacher educators to develop and practice language-supportive pedagogy.

Both the South African workbook scheme and the Tanzanian initiative provide examples of approaches to addressing concerns about textbooks. There is no evaluation yet of the Tanzanian textbooks, and irrespective of the quality of the workbooks, the fact that the South African Department of Basic Education appears to want to quality assure the workbooks should be seen in a positive light. Overall the workbook initiative is promising and could provide an example of a way forward for other countries in sub-Saharan Africa.

Science Laboratories

The lack of resources in secondary schools is a particular challenge in the natural sciences, where laboratory work and hands-on experimentation, which are highly resource intensive, are required. In a context where infrastructure and resource provision are often funded by school fees, rurality and low socio-economic status affect students' access to specialist science equipment.

Providing students with the opportunity for hands-on training, introducing them to science in a more practical manner and providing access to laboratories and specialist science teaching materials has been shown to stimulate students' interest in Science and promote careers in STEM fields (UNESCO 2017b, p.67). However, since lab equipment, specialised chemicals for experiments and other teaching aids for the sciences are expensive to procure, distribute and maintain, many students do not reap the benefits of practical experimentation in their classes. As such, countries in the region (for example Botswana, Rwanda, South Africa and Zimbabwe) are experimenting with different models, such as low-cost science kit distribution or concentrating resources in regional or school level Centres of Excellence (Gado 2005; Hattingh & Rogan 2007; Ngololo et al. 2012; Semali & Mehta 2012). In Zimbabwe, for example, the Ministry of Education distributed the Zim-Sci kit to all secondary schools in 2014. The kit costs about $1000 and contains enough materials for students to conduct an experiment in pairs every week for four years. Both students and teachers are provided with instruction manuals and training is delivered through radio and audiocassettes (Verspoor 2008).

In a study involving 2299 elementary school students in the US, it was revealed that the systematic implementation of science kits was 'successful in some contexts at enhancing student understanding, as measured by application-based content questions' (Dickerson et al. 2006). This suggests that science kits have the potential to not only improve student attainment, but also their conceptual understanding of scientific theories. Furthermore, by allowing teachers without access to a laboratory to perform demonstrations in their class, teachers' pedagogical skills, conceptual understanding and experimental skills have been shown to improve through the use of low-cost science kits (Kriek & Grayson 2009).

In South Africa, where curriculum reforms have placed greater emphasis on practical skills in the science classroom, these low-cost kits constitute a small step towards the goal of conducting open science investigations (Ramnarain 2011). Designed to fit into an average sized lunchbox, these kits allow teachers to model the stages in a science investigation, by means of demonstrations, which may then be built upon by students in their own experiments (see Figure 3.10). In a context where resources are often funded by students themselves and therefore, unevenly distributed; where some schools have access to well-equipped laboratories and others have no specialist science equipment at all, the provision of low-cost science kits may be considered as a stepping-stone towards greater equity in science education (*ibid*). With reference to Rogan and Grayson's (2003) 'zone of feasible innovation', Ramnarain (2011) argues that science kits can aid effective curriculum implementation by allowing teachers to proceed just ahead of current practice.

Figure 3.9: Profile of Practical Work. *Source: Ramnarain 2011.*

Level	Types of science practical work
1	Teacher uses classroom demonstrations to help develop concepts.
2	Teacher uses demonstrations to promote a limited form of inquiry. Some learners assist in planning and performing the experiment. Learners communicate data using graphs and tables.
3	Teacher designs practical work. Learners perform 'guided discovery' type practical in small groups. Learners write a scientific report in which they justify their conclusions in terms of the data collected.
4	Learners design and do their own 'open' investigations. Learners reflect on the quality of the design and data collected and make improvements when and where necessary. Learners can interpret data in support of competing theories or explanations.

Science kits and other low-cost alternatives are not a substitute for laboratories. They are, however, affordable and they provide learners and teachers with some of the types of experimentation required for effective learning in Science. Further, they have the potential to inspire teachers to think beyond the problems of lack of proper laboratories, towards affordable and sustainable alternatives. In contexts where teachers may feel unable to teach Science in the way they may want to, investigating the low cost solutions used in, for example South Africa and Zimbabwe, may have some value.

A final point related to experimentation and laboratories is about assistants in the laboratory. In most successful education systems, it is commonplace for an assistant to help the teacher prepare equipment, demonstrate experiments and generally support the teacher. Not only does their presence help in the technical and logistical aspects of running hands-on activities in the classroom, but it also frequently offers the teacher psychological support. It appears that in most sub-Saharan school contexts, laboratory assistants are not employed (Ottevanger et al., 2007). Our recommendation would be for education systems in sub-Saharan Africa to explore possibilities of developing a high quality cadre of teaching assistants.

Building ICT Capacity in Schools

In terms of the provision of hardware and software, there has been ongoing and sustained investment in ICT in sub-Saharan Africa, with a wide range of educational ICT projects at various levels, from school to pan-national. The emphasis has largely been on the provision of new technologies in educational environments, which had thus far been resource-poor (Wallet 2015), and, as Isaacs (2012, p.11) suggests, 'The dominant view seemed to be that ICT itself would catalyse the much-needed changes in the education system.' However, as suggested above and as argued by Wallet (2015), this technocentric approach to educational reform was doomed to failure without significant strategic efforts to train teachers to use ICT effectively to support teaching and learning.

Providing computers, monitors, servers and other peripherals, often in computer laboratories, is expensive, and these devices need to be stored securely and properly maintained, which means there is an ongoing cost. However, the development and deployment of mobile technologies has the potential to reduce costs, improve quality and increase access to educational opportunities (Wright & Reju 2012; Adeoye 2015) as previously argued, because almost all teachers have these devices as do many of their students. In a context where access to mobile phones and network coverage cannot be guaranteed, however, it is important that planning to use them in the teaching of STEM and ICT exploits these technology tools, where available, but does not depend on them (Hennessy et al. 2015, p.538).

In terms of teaching and learning with ICT, whether with computers, mobile phones or other devices such as television and radio, it is generally agreed that teachers need some knowledge and understanding of the role of the ICTs and their own role. They also need to understand how to use the ICTs and, importantly, how technology can contribute to their students' learning. This relates to the discussion above, about the importance of professional development for teachers, but the discussion also covers a variety of initiatives that can provide learning opportunities for STEM and ICT students in schools.

One approach is to provide content. In South Africa, for example, the Department for Basic Education has established two education broadcasting channels to support learners in Grades 7 to 12 in a range of subjects, including Mathematics and Science. The content is developed by an NGO called 'Mindset' and consists of videos, which are aligned to the curriculum, and which teach difficult concepts in carefully scaffolded ways. The videos include experiments and demonstrations and are able to show students how the concepts they are being taught relate to life outside the classroom. In Science this can be particularly powerful when students do not have access to laboratories, as they are still able to gain some experience of experimentation. Further, while the videos cannot, and should not, replace teachers, they do expose the learners to new and different teaching styles. The Mindset Teach video project has been evaluated by Nicoleau and Sackman (2017), who found the videos to be good value for money and that the extensive reach of the organisation, which broadcasts to over 2.5 million households and over 1500 individual schools and resource centres, Nicoleau and Sackman (2017, p.89) suggests that the videos model 'behaviours and practices that make for good teaching'.

E-classroom is a second initiative from South Africa, which provides content. It was established in 2012 'in response to a clear and desperate need for high quality educational content and supplies' (Roberts et al. 2016). E-classroom is a website that provides content, aligned to curriculum, for teachers, learners and parents. They report that 'to cater for some of the shortages, highlighted by Equal Education and the Global Competitiveness Report, E-Classroom has secured the licensing rights for a 'Virtual Science Laboratory', which can be licensed to schools.' However, access to the content on the website is not free and there currently appears to be no evaluation of the quality of the content.

Provision of content is perhaps the most straightforward use of ICTs for teaching and learning in STEM and ICT. Another South African initiative, greenshootsedu.co.za, provides an example of a website that not only offers content, but also provides an interactive environment, in which students learn about mathematical concepts and enter their answers to mathematics questions designed to check and assess their understanding. The power of ICT is first, in providing real-time feedback to the learners and second, in providing teachers with learner analytics. The website provides some evaluation of the Maths Curriculum Online (MCO), suggesting that its use increases learners' confidence and teachers' enthusiasm for teaching. It further appears that students perform better in mathematics than previously. A comment from an evaluation report states that Etilab is positive, in that it suggests that there have been real changes to teaching and learning: 'The sustained and widespread change to practice, as reported by teachers between 2016 and 2017, is encouraging in light of the many failed education reform initiatives that have been attempted in the past two decades in South Africa. As teachers indicate, the effect this is having on learners is no longer limited to MCO but is affecting the in-class learning of Mathematics and general perceptions to Maths in schools' (Green Shoots 2018).

Another approach is to use mobile phones for teaching and learning. There is growing literature investigating the potential of so-called mobile learning, otherwise known as m-learning in developed contexts (Aker et al. 2011; O'Hagan 2013; Ramnarain & Moosa 2017; Roberts et al. 2015; Traxler 2018; Vadachalam & Chimbo 2017). Preliminary evidence suggests that the introduction of mobile technologies in the classroom can act as 'a catalyst for change in teaching and learning styles' (Chigona et al. 2014, p.1) and provide 'unparalleled access to information, raising the quality of education and enhancing learning outcomes worldwide' (O'Hagan 2013, p.55).

The integration of mobile technologies in education has been particularly evident in South Africa, whose White Paper on e-Learning states that 'ICTs, when successfully integrated into teaching and learning, can advance higher-order thinking skills such as comprehension, reasoning, problem solving and creative thinking and enhance employability' (Department of Education 2004, p.14). Secondary STEM and ICT m-learning initiatives in South Africa include the MobilEd project, Dr. Math and the Nokia Mobile Mathematics Mobile Service (see below for details). According to Vadachalam & Chimbo (2017), these initiatives have shown that mobile phones are effective tools for teaching and learning in schools and also provide learner support with or without a teacher in the classroom, as indicated by the spike in usage of the Dr. Math app during the 2011 teacher strike.

The Nokia Mobile Mathematics (MoMath) project was initiated in 2007, with the objective of improving the mathematics performance of Grade 10 learners in South Africa by providing access to curriculum-aligned mathematics content. By 2011, the number of subscribers had increased to 25,000 learners, 500 teachers and 172 schools in 4 provinces (Isaacs 2012a, p.20). In order to implement MoMath effectively in the classroom, teachers receive a 2-day orientation training session, taught by project team members and teachers involved in the pilot phase of the project. A curriculum advisor from the LEA provides further support. 79% of the teachers who were trained reported (both immediately afterwards and 6 months later) that the training course equipped them with everything they needed to know about the project (*ibid*).

The service contributes to strengthening pedagogical practice, as it provides OERs that can be used in the classroom, even if the students do not have mobile phones. In addition, teachers can make use of the tests to develop ad hoc examinations, thus providing an opportunity for formative assessment. By the end of the second term of using the service, most teachers agreed that the project has a significant impact on their students' attitudes toward mathematics, as well as on their own roles as Maths teachers (*ibid*). According to O'Hagan (2013), 82% of login activity takes place outside school hours and, as such, the service has evolved to primarily support independent, after-school work. As well as hosting competitions, quizzes and peer-learning based on lessons, the site also allows teachers to assign and monitor homework. Such m-learning services have been suggested as a time-effective and inexpensive way to measure uptake, completion and performance rates on homework activity and extension activities (Roberts et al. 2015, p.10).

In Tanzania, the BridgeIT project has used mobile phones to deliver curriculum-centred visual content in Mathematics, Science and Life Skills classrooms across 150 schools in Tanzania, reaching 1021 teacher and 60,540 learners within three years (Isaacs 2012a, p.16). The project is funded by USAID and has been developed and implemented by the International Youth Foundation, in close partnership with the Tanzania Ministry of Education and Vocational Training, as well as the Forum for African Women Educationalists, Nokia and the Pearson Foundation. Through BridgeIT – or *Elimu kwa Teknolojia* – teachers have access to a digital catalogue of 151 unique Mathematics and Science lessons and 32 Life Skills lessons, which include 4-7minute long videos on topics such as human biology, geometry and HIV/AIDS. Teachers are able to download these videos, which are produced locally and stored on the server of a local mobile network operator, using their mobile phones and then project them to students by connecting to a television. Reportedly, students have shown improved motivation and better test results as a result of the project, as they are able to easily view diagrams and images, which help them to grasp the subject and better understand complex concepts (*ibid*). Ramnarain and Moosa's (2017) study supports the view that ICT integration has much to contribute in strengthening the quality of teaching and learning. They found that simulations using technology were found to be effective in addressing misconceptions, regarding the field of electricity circuits, held by Grade 10 learners from underperforming schools.

These examples relate to the teaching and learning of Mathematics and Science using ICTs. However, in countries, where versions of Computer Science, Computer Studies or ICT are taught, there are further considerations in terms of building ICT capacity and strengthen ICT education. One consideration is that ICT is usually seen as an 'add-on' in teaching Mathematics and Science, whereas in the teaching of ICT, computers are essential. A second consideration is that because ICT is a relatively new subject, it is unlikely that many education systems will have enough teachers of the subject who are properly trained to teach ICT.

In response to the first of these challenges, the Zambian Information and Communication Technology Authority (ZICTA) was established, which supports increased access to computers through the donation of ICT equipment and the training of teachers. There is a deliberate policy to build and strengthen micro-labs and lead the rolling out and implementation of SMART Zambia. In one example, the University of Zambia, which is working with ZICTA, the Zambian government and companies in China on the 'Thin Client Systems' computer assembly initiative, procure computer parts, assemble them and then set up school mainframes to feed dummy computers in classrooms.

It may be that a more holistic approach is needed. Various Centres of Excellence have been established in order to facilitate the collaborative efforts required to strengthen ICT education. The ICT in Education Coordinator of Ghana observed that 'The sea of ICT is so wide that no single entity can do the fishing; it requires partners to do this successfully and effectively. Partnership is influenced by: hardware acquisition; software acquisition; connectivity; training; maintenance and technical support; monitoring and evaluation. Partner with both global and local companies to help with the above' (Awuku 2011, p.294). Bainton et al. (2016b, p.20) recommend Centres of Excellence as having the potential ‘to create a mutually supportive environment that nurtures high impact as well as playing a key role in modelling and initiating system wide transformation’. Another example of a more holistic approach is Operation Phakisa in South Africa which is a presidential initiative established in 2014, and designed to fast track implementation according to the priorities of the National Development Plan (National Planning Commission, 2011). Initially, this operation focused on environmental affairs and health, but since 2015 has begun work on mining and education. The roll-out plan for the delivery of curriculum through ICT includes a costed implementation plan for all schools; professional development for teachers and administrators; a written change management plan for ICT integration; and a monitoring and evaluation plan to include indicators for successful ICT use.

Examples of initiatives which focus on the processes of collaboration, in order to strengthen ICT education include the Ghana-India Kofi Annan Centre of Excellence in ICT. The centre, in partnership with the Finatrade Foundation, Microsoft, Intel, Cisco, Into IT, NIIT and IPMC, the Ministry of Communications, NITA and GICTED, is training over 100 ICT tutors from 44 senior secondary schools, in Ruby programming language (Farrell & Isaacs 2007).

Clearly, the provision of ICT capacity is complex. It relates to hardware and software, where it seems the most promising examples of widespread and sustainable solutions lie, in the use of mobile phones. It also relates to learning with ICTs, where perhaps the most straightforward and affordable solutions lie in the provision of content, although the quality of such content may not always be assured. Some of the more powerful solutions involve students interacting with technology in ways which provide them with immediate formative feedback, but this requires the learner to be online and tends not to be free. Finally, it relates to learning about ICTs (for example, Computer Studies), where the requirements are so challenging that it seems that collaborative efforts between a range of partners may provide a way forward.

Conclusion

Initiatives and strategies for addressing issues in secondary STEM and ICT education should aim to be coherent, feasible and practical, and address inclusion. The questions below arise from the discussion above and are presented again, as questions, for inclusion in the diagnostic framework.

Relevance and Coherence:

- Are STEM and ICT curricula relevant to the backgrounds and experiences of students and teachers?
- Are approaches to initial teacher education and continuing professional development coherent and relevant to the work of STEM and ICT teachers?
- Are schools equipped with appropriate resources for teaching STEM and ICT?

Feasibility:

- Is it possible to teach all the curriculum content in the time available?
- Is it possible to carry out all the hand-on practical work expected in the curriculum?
- Are there policies specifically targeted at attracting more teachers into STEM and ICT education? What evidence is there that they will be successful?
- To what extent are schools able to provide appropriate access to laboratories for students?
- Is it possible to provide textbooks in STEM and ICT subjects for all students?

Inclusion:

- Do STEM and ICT curricula recognise that students may have very different starting points when entering secondary school? Are they appropriate for the cognitive and linguistic level of all learners?
- Are approaches to teaching STEM and ICT subjects specifically targeted at improving learning outcomes for girls?

- Do initial teacher education and continuing professional development take into account the different needs of prospective or practising teachers? Do they recognise the specific needs of teachers in rural areas?
- To what extent are disadvantaged schools helped to improve their material resources?

Chapter 4: Identifying Data Gaps for Quality Assurance

The World Bank report argues that, while educational systems around the world and especially in low and middle-income countries, such as all the countries in SSA, report on enrolment, numbers of schools, numbers of teachers, teacher salaries and so on, it is rare to find that these countries report on learning. This allows governments to ignore the poor quality of education and means that parents are unaware of the quality of education their children are receiving. For example, a study based in Kenya found that although two-thirds of parents appeared to be satisfied with the country's education, fewer than half their children could pass basic tests of proficiency in literacy or numeracy (Pritchett et al. 2013).

Data on learning can be used in education in formative ways, to monitor performance by schools, teachers, districts and systems. Assessment data on the performance of individual students, for example, can provide information about the progress and attainment of these students. Although one of the key uses of such data is to decide which candidates will be admitted to particular schools, courses or universities (Bethell 2016), data is also frequently used for purposes of improving education systems and student outcomes. In some jurisdictions, student assessment data is analysed in detail by teachers and is then used to inform teacher interventions (Datnow & Hubbard 2015; Marsh & Farrell 2015). Student assessment data can also be used more widely to advise teachers on where to place their emphasis in teaching (Bethell 2016; Van der Berg 2015). Other data, such as information about teacher performance, can be used to advise schools, districts and larger jurisdictions on where they need to target support.

A key use of data, however, is to help develop an understanding of learning outcomes (student performance) within and across countries, which in turn informs decisions for and about education:

"…one of the main aims of conducting national assessments or participating in international assessments is to provide information on a country's educational outcomes, which in turn assists policy-makers and other stakeholders in the education system in making policy and resourcing decisions for improvement" (Best et al. 2013, p.8).

Data on Student Performance

International Assessments

Student performance data *across* countries is gathered through international large-scale assessments and regional large-scale assessments. These assessments collect information not only about student outcomes but also about teachers and schools, which provides opportunities, amongst other things, for exploring correlations between student outcomes and contextual factors (for example, see Howie 2003).

Large scale testing as listed below has been shown to have a positive impact on schools and teachers (e.g. league tables, staffing decisions) and learning outcomes (Clarke 2012) and although there are arguments that these tests are too expensive for low and middle-income countries, in fact the cost has been shown to be one of the least expensive of all innovations in educational reform (Clarke 2012). Frequently this data kick-starts reforms and reviews. Following the publications of results in large scale testing in Mauritius in 1999, for example, the country began an overhaul of their education system, beginning with a review of their master plan (Kulpoo 1998).

Current relevant large scale international and regional tests include:

- Trends in International Mathematics and Science Study (TIMSS) is conducted every four years on Grade 4 and Grade 8 students. Only three SSA countries have taken part (Botswana, Ghana and South Africa), with the most recent study conducted in 2015.

- Programme for International Student Assessment (PISA) is conducted every three years on 15-year-old students and focuses on reading literacy, mathematical literacy and scientific literacy. The most recent study was in 2015. The only SSA country to take part is Mauritius. Zambia is taking part in the current round of PISA-D, which is designed for developing countries.
- Southern African Consortium for Measurement of Educational Quality (SACMEQ) is conducted at five or six-year intervals, on students in Grade 6 and focuses on reading and mathematics. The most recent study was in 2012 and 16 countries in SSA **took** part;
- Programme for the Analysis of CONFEMEN Education Systems (PASEC) is conducted at four-year intervals on students at the beginning and end of primary school (and proposed at the end of basic education in 2016). The test focuses on mathematics and reading in French. The most recent study was in 2014, when ten countries in SSA took part.

As can be seen from this list, data from countries in SSA is scarce and, participation in international studies is limited to a very few countries. This is perhaps to be expected, as low income countries tend not to take part in international studies, partly because the reporting of outcomes results can cause 'international embarrassment and humiliation' (Kamens & Benavot 2011, p. 286). More countries take part in regional assessments, which is in line with the trends reported by Kamens and Benvot (2011)[1].

It appears that the PASEC and SACMEQ regional tests have been useful to countries in sub-Saharan Africa but, as suggested above, the larger tests such as PISA may not be appropriate. It may be that it is worth pursuing the regional approach, whilst exploring the potential of emerging initiatives such as PISA for development.

National Assessments

Student performance data *within* countries is collected through national assessment and it appears that the data collected is widely used to inform education policies. For example, in a systemic review of 54 studies, Best et al. (2013) showed that policies including reform of the curriculum, textbook revision, allocation of resources, teacher education and many others, were influenced by national assessments. Their study also found that national policies regarding curriculum, performance standards and assessment are most frequently reviewed and reformed in the light of assessment data.

In a report about mathematics education in SSA, the World Bank produced a comprehensive account of the data they collected and how it is used, (Bethell 2016). Bethell reports that fourteen countries in SSA have developed the capacity to conduct national tests and have repeated these assessments at least once. Most of these countries measure student performance in Mathematics and Language in Grades 1 to 6, but not at secondary level, and they are, therefore, beyond the scope of this report.

However, Ethiopia, Malawi, Mauritius, Namibia the Gambia, Uganda and South Africa also conduct national assessments at lower secondary level. All of these assess at least Mathematics, and some assess Science as well. Ethiopia, for example, assesses Biology, Chemistry and Physics while Mauritius assesses the three sciences and Computer Studies. All the countries taking part, including South Africa from 2018, (see below for further information) conduct the tests on samples of students. While some have been criticised for the sampling methods used and for the quality of the tests themselves, these assessments do provide policy makers with evidence of students' learning or their failure to learn in Mathematics and sometimes in other STEM subjects.

All these assessments provide snapshots of students' performance. They do not, however, supply data about the performance of a cohort of students over time but, Thomas et al. argue (2013), that this sort of longitudinal data allows the calculation of 'value-added' measures, which in turn can

[1] However, it appears that neither the proposed 2016 SACMEQ study nor the 2016 PASEC studies took place, although there is no available information in the public domain as to why.

demonstrate what schools, and the education system as a whole, are adding to the achievement of students.

Systemic Testing in South Africa

In South Africa, Annual National Assessments, which assess all students' performance in Literacy and Numeracy at Grades 3, 6, and 9, were introduced in 2012. By 2014, all primary students from Grades 1 to 6 and those in Grade 9 took the tests. These standardised tests provided item by item analysis of data from all learners, potentially providing teachers and schools with valuable information about the relative performance of individuals, classes, schools, districts and provinces and the whole country (Dhlamini 2016). Further, diagnostic reports were produced, providing information about, for example, achievement in specific mathematical topic areas, areas of weakness and strength and guidance for remedial action. Figures 4.1 and 4.2 below provide examples relating to the Grade 9 assessment, taken from the 2014 diagnostic report for Mathematics (Department of Basic Education, 2014). The data from the tests was disaggregated by socio-economic quintile and by gender, providing useful information for districts and provinces.

Figure 4.1: ANA Areas of Weakness and Strength. *Source: Department of Basic Education 2014, p.51.*

AREAS OF WEAKNESS	AREAS OF STRENGTH
Learner responses showed weaknesses in the following areas: • Circumference and area of a circle; • Perimeter and area of a trapezium; • Congruency and similarity deductions; • Angles opposite equal sides of a triangle; • Lowest Common Multiple; • Square root and Cube root; • Direct and indirect proportion; • Terminology and definitions in geometry; • Factorisation; • Multiplication of fractions; • Determination of the gradient and the equation of a straight line; • Squaring of binomials; • Products of binomials; • Quadratic equations;	Questions on the following areas were reasonably well answered: • Writing out in scientific notation; • Finding the ratio of a given quantity; and, • Completing a number sequence.

Figure 4.2: ANA Remediation Guidance. *Source: Department of Basic Education 2014, p.57.*

Remediation

Ensure that learners understand the difference between simplifying $\frac{x^2-4x}{x^2-2x-8}$ and $\frac{(x^2)(-4x)}{(x^2)(-2x)(-8)}$. Clarify that in $\frac{x^2-4x}{x^2-2x-8}$ the numerator has 2 terms and the denominator has 3 terms. Dividing by x^2 or $-2x$ is not allowed. However in $\frac{(x^2)(-4x)}{(x^2)(-2x)(-8)}$ dividing by the factors x^2 and/or $-2x$ is allowed because the numerator and the denominator each contain only one term.

The ANAs tests and findings represented a concerted effort to gather data on student performance in order to improve educational outcomes, though there was some criticism of the purpose, quality and consistency of the tests and about what they revealed about student learning (Spaull 2014; Van der Berg 2015). In 2015, the tests were boycotted by the powerful teaching unions because they placed a burden on teachers and, according to some, were of little value to the South African student. The results, which were used to 'name and shame' teachers and schools (Gerber 2017), are to be replaced by a National Integrated Assessment Framework (NIAF) which will test a sample of learners from Grades 3, 6 and 9, every three years. The first cycle is due to start in 2018.

The systemic testing of Mathematics and language, for Grades 3, 6 and 9 was introduced by the Western Cape Education Department (WCED) in South Africa as a supplement to the ANAs and school-based assessments. Unlike the ANAs, the systemic tests are set, administered and marked by independent service providers. They are written annually, during the last term of the academic year. During the first term of the new academic year each school receives a report which provides the pass rates and average scores of the previous year, as well as individual student performance in particular areas of language and Mathematics.

Diagnostic reports for the tests have been introduced this year (WCED 2018) providing rich opportunities for discussion at school and departmental level. Looking forward, potential lies in the use of professional learning communities for cluster work sessions to analyse teaching gaps identified in school-based assessment and systemic testing and to design interventions to address the gaps (WCED 2015). The challenge lies in identifying interventions to address these gaps at district, school and classroom level, that are favourable to teacher unions, teachers and learners (Hoadley & Muller 2016).

While the feedback of the systemic tests in the first term may be too late to improve student performance, the diagnostic reports offer prospects of large-scale intervention for formative assessment and assessment for learning. The former refers to a means of acting on areas of improvement identified in the test, and the latter is an opportunity for professional development to improve teaching and learning strategies for student performance.

The tests appear to be generally well received and the results are promising. In September 2016, the Business Day newspaper reported that: “Independent research has shown that the interventions informed by the tests have contributed significantly to improvements in results. These interventions have helped to reduce the gap between high-performing and low-performing schools by about 25%“ (Attwell 2016).

This suggests that large scale national assessments do provide valuable information at provincial or national level. For other countries in sub-Saharan Africa, wishing to better understand how, and how well their educational system is functioning, looking to the South African experience may provide some lessons. It seems important to note that if a census type assessment (such as the ANA) is to be introduced, then the implications for teachers should be carefully considered, and teacher buy-in should be secured, possibly via the unions.

Examinations

The most common national assessments take the form of formal examinations, very often compulsory tests at the end of a school cycle (Bethell 2016). In Zambia, for example, Grade 9 students take the Upper Basic School Leaving Examination, with those who pass six subjects, including English, gaining entry to High School. Interestingly, passes in Mathematics, Science and ICT are not required. In Kenya, students sit the Kenya Certificate of Primary Education (KCPE) examination at the end of eight years at primary school. Performance in this examination determines which kind of secondary school the student will be able to attend.

Clearly, these examinations provide large amounts of data, but it seems that this data is seldom analysed, disseminated or used as well as it might be. It appears that, in addition to the crucial information related to the achievement of the individual student, some examination boards provide further information, although in most cases this provision tends to be erratic and lacking in useful detail.

The South African ANA example discussed above, however, provides an example of ways in which this data could be used. A second example of potentially useful practice is taken from the West African Senior School Certificate Examination (WASSCE). This Council provides an online ‘toolkit’ with a question by question report, taken from traditional Chief Examiners’ reports from previous examinations, related to each question on the examination. For example, Figure 4.3 below reports on question 7 of the 2015 Mathematics paper and Figure 4.4 reports on question 5 from the 2015 Computer Science paper. The toolkit also provides a section entitled Weakness and Suggested Remedies, an example of which, related to Chemistry, can be seen in Figure 4.5.

Figure 4.3: WAEC General Mathematics Question. *Source: http://waeconline.org.ng/e-learning/Mathematics/maths224mq7.html*

Question 7

The table is for the relation y = px2 – 5x + q.

x	-3	-2	-1	0	1	2	3	4	5
y	21	6		-12				0	13

- (i) Use the table to find the values of p and q;
  (ii) Copy and complete the table.
- Using scales of 2 cm to 1 unit on the x-axis and 2 cm to 5 units on the y-axisdraw the graph of the relation for -3 £ x £ 5.
-
- Use the graph to find:
- y when x = 1.8;
- x when y = -8.

Observation

The Chief Examiner reported that this question was attempted by majority of the candidates. Some of the weaknesses observed from candidates who attempted this question included their inability to obtain the equation using values from the table and their inability to read from the graph.

In part (a), Candidates were expected to obtain the values for p and q by substituting two values of x and the corresponding values of y into the equation and solve simultaneously. For instance, when x = 0, y= -12. Therefore, -12 = p(0)2 – 5(0) + q. This implied that -12 = 0 + q which gave q = -12. When x = 4, y = 0 and q = -12, 0 = p(4)2 - 5(4) – 12. i.e. 0 = 16p – 32. Hence, p = 2. Therefore, the equation was y = 2x2 -5x – 12.
Candidates would then use this equation to compute the other values of y and complete the table

X	-3	-2	-1	0	1	2	3	4	5
y	21	6	-5	-12	-15	-14	-9	0	13

Using this table, they would draw the required graph

Figure 4.4: WAEC Computer Studies Question. *Source: http://waeconline.org.ng/e-learning/Computer/Comp224mq5.html).*

Question 5

1. Define algorithm.
2. State **three** characteristics of algorithm.
3. Write an algorithm for finding the average of **six** numbers when the sum of the numbers is given.

Observation

The expected answers were:

(a) An algorithm is a procedure consisting of a finite set of unambiguous rules (instructions) which specify a finite sequence of operations that provide the solution to a problem.

OR

It is a step-by-step procedure to solve a given problem.

(b) **Three characteristics of an algorithm:**

- Finite
- Effectiveness
- Unambiguous

(c) **Algorithm for finding the average of six numbers:**

1. Start
2. Get the sum of the Six numbers
3. Compute average: Average = Sum/6
4. Output the Average
5. Stop

The questions here tested Candidates' knowledge of "Programming Languages" but unfortunately, most of the candidates did not respond to the question correctly.

Figure 4.5: WAEC Chemistry Remediation (general). *Source: http://waeconline.org.ng/e-learning/Chemistry/chem324mw.html*

Chemistry Paper 3 May/June 2015

Subject Home 1A 2A 3A 1B 2B 3B

CANDIDATES' WEAKNESSES AND SUGGESTED REMEDIES

The performance of the candidates was affected by the following weaknesses:

- non-adherence to rubric;
- cancellation/alteration of the values to agree with those of their teachers;
- arithmetical errors in volume of acid used;
- averaging non-concordant titre values;
- poor mathematical skills;
- poor knowledge of S. I. units of mass concentration and molar concentration;
- test on solids instead of solutions;
- lack of knowledge of confirmatory test for carbon (IV) oxide;
- poor knowledge of laboratory set-up and names of laboratory apparatus;
- poor knowledge of solubility of gases in water;
- assigning wrongs charges to ions.

The following remedies were suggested to improve on candidates' performances, and overcome these weaknesses.

- schools should sponsor their chemistry teachers to STAN conferences;
- candidates should improve on their reading habits;
- candidates should read and understand the rubrics before responding to questions;
- candidates should be taught how to observed and record observed reactions;
- candidates should be taught how to write correct charges on cations and anions, when carrying out specific chemical tests.

While there is scope for improvement in the detailed content of this provision, both in terms of the questions and answers and particularly in terms of the remedial advice, this approach could be useful to teachers and students and might serve as a model for other examination agencies in SSA.

Examinations are of course not the only way to assess the knowledge and skills of students. Zambia is experimenting with a 'Trade Test' for ICT in secondary schools, which is still in its pilot phase. It seems that the goal is to penetrate all secondary schools (Grade 9 and above) in line with the Government policy of ensuring that practical subjects such as Computer Studies, Metalwork, Woodwork and Bricklaying (both theory and practical components) are rolled out to, and are accessible in all secondary schools. For this test, students are tested on their proficiency in the use of spreadsheets, word processing, database management and presentation tools. According to a consultant in the country, the test has been well received by students and teachers because students will receive a separate practical qualification from TEVETA, in addition to the academic certificate from the Examinations Council of Zambia (ECZ).

One concern related to within-country examinations is the quality of the examination itself. Bethell (2016) points out that there is often a mismatch between the examination and the curriculum, and that some examinations are simply 'not fit for purpose'. While this chapter concerns the gathering and using of data, and while the quality assurance of examinations is probably outside of the scope of the chapter, this issue is possibly worth considering to end this section on student assessments.

UMALUSI is the Council for Quality Assurance for General and Further Education in South Africa. Examinations, such as the Grade 12 National Senior Certificate (NSC), are moderated and quality assured by UMALUSI. After the students sit, for example, the Grade 12 Mathematics examination, the quality of the examination papers is also quality assured locally, by the Association for Mathematics Education of South Africa (AMESA), and internationally, by Cambridge Assessment International Education and then reported on to the National Department of Education. An alternative to the NSC is the IEB NSC, which is an internationally benchmarked qualification, equivalent to Cambridge AS level, and regulated by the South African National Department of Education.

As pointed out above, there are useful and important ways in which examination data can be used to help improve teaching and learning in STEM and ICT subjects. It would seem important for national examination authorities to provide reports detailing where students appeared to have difficulties, and perhaps to provide examples of good responses. This sort of report could also feed into the quality assurance of the examination itself and might provide some insights into where to put resources which would support teachers. If the majority of students are unable to answer a specific question, for example, targeted guidance on teaching that topic could be provided for teachers. Crucially, however, teachers and students should be made aware of the reports and advised how best to take advantage of them. Finally, it could be useful for countries wishing to implement vocational and practical education to consider developing trade tests, such as the Zambian example above.

Data on Teacher Performance and Skills

Collecting data on teacher performance is deeply problematic (e.g. see Elliott 2015). First, it is notoriously difficult to measure, and therefore collect data on their performance and skills (Firestone 2014). Some of the assessments mentioned above (e.g. SACMEQ and TIMSS) collect data on teachers' knowledge and attitudes, in addition to the data collected about students. This is not the same, however, as teacher performance. Secondly, there is resistance amongst teachers to the idea of collecting such data, especially since it can be used for purposes of appraisal and related rewards or sanctions (Ballou & Springer 2015).

Despite some professional reservations, there is clearly a need to monitor both individual teachers and the teaching workforce as a whole. In terms of monitoring the performance of individual teachers, two approaches are commonly used: observation of teachers in their classrooms and performance of their students. This second approach is a proxy, but is generally regarded as valid (Ballou & Springer 2015). As far as observation of teachers in their classrooms is concerned, common practice internationally, is for this to happen at the school level where 'Classroom observations …. are used almost universally to judge competence' (Cohen & Goldhaber 2016, p. 9) . However, the practice is fraught with difficulties, largely because it is highly subjective (*ibid*) and, as the CDE report from South Africa found, 'Classroom observation is the main source of evidence for measuring performance, but it is not without its challenges' (The Centre for Development and Enterprise 2015).

In some cases, observation of teachers is undertaken by outside agencies. In Zambia, for example, the Ministry of General Education has a Directorate of Teacher's Education and Specialised Services (TESS) which conducts quality assurance and carries out inspections in schools. After their initial teacher training, teachers are only confirmed as qualified teachers once they have been observed teaching in class, and their performance found satisfactory. This same organisation visits schools to inspect lessons and monitor the professional conduct of teachers. What happens to the data collected in this way is unclear and in general, the data generated by both these approaches is not collected at country level. However, one of the country specialists consulted by the team who prepared this report, reported that 'TCZ assessments will increasingly provide data on teacher performance and professional conduct'.

In the area of monitoring, Zambia is also developing a Teacher Competence Framework drafted by the Teaching Council of Zambia (TCZ), for teachers and teacher educators. This framework is primarily aimed at improving teacher quality.

In South Africa, teachers are assessed internally within their schools as part of the 'Integrated Quality Management System' (IQMS) which is mandatory in all schools. According to their documentation, one aspect of this teacher assessment, entitled 'Developmental Appraisal', appraises individual teachers in a 'transparent manner', aims to determine 'educator competence' and identify areas of strength and weakness, leading to the development of programmes for individual development. A second aspect, known as 'Performance Measurement' aims to evaluate individuals for salary and grade progression, affirmation of appointments and rewards and incentives. Interview data from teachers, collected as part of the study, suggests that provided there is buy-in from all stakeholders, performance measurement can be a useful tool.

The IQMS documentation (Department of Basic Education South Africa, 2004) explains what happens to the various forms involved in the process. The evaluation forms relating to individual teachers, for example, are filed in their personal file in the school, whereas the summative report is filed in the school's profile file (also in the school). Some data, in the form of a 'summative evaluation' is submitted to the District Office, which then produces a 'composite schedule' to submit to the Provincial Office who, in turn, use this data to determine salary progression for teachers. It is not clear whether, or how the data is used in other ways and for other purposes.

As suggested above, collecting data on teacher performance is problematic, but the examples from Zambia and South Africa provide some potentially promising approaches, as seen in the Zambian aim of using a framework to improve quality, and the South African aim of ensuring transparency. However, there are also lessons to be learned in terms of reducing paperwork and gaining teacher and school commitment to the process.

Data on School Level Resources

Many countries in SSA do not have reliable data on the school level resources required to deliver STEM and ICT education, including, for example, laboratory equipment, textbooks, state and quality of chemicals and computer hardware/software, reliability of running water, electricity and internet provision. The UNESCO report on ICT in Education in SSA states that, 'The most significant obstacle in measuring ICT in education in sub-Saharan Africa is the lack of systematic data collection. Several countries do not currently carry out data collections, while others are in their infancy' (Wallet 2015, p.8).

South Africa, however, provides an exception. This country regularly collects such data, which is reported in the 'NEIMS' reports. The 2018 report (Department of Basic Education 2018), for example, provided data concerning the provision of sanitation facilities, the supply of water, electricity, fencing and security, sports facilities, communication facilities (which includes numbers of computers used for teaching and learning), laboratories and libraries. Figures 4.6 and 4.7 below show these statistics for the communication facilities and laboratories.

Figure 4.6: NEIMS Statistics on Communication Facilities, Disaggregated by Province. *Source: Department of Basic Education 2018.*

COMMUNICATION FACILITIES

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

NEIMS
National Education Infrastructure Management System

Communication Source Facilities

17/01/18

Site Type : Ordinary Operational Schools

Table 11

		Communication Systems Available								Without Communication Systems	
Province Name	Number of Sites	Cell Network	Landline	Fax	Two way radio	Internet Connectivity for Teaching and Learning	Internet Connectivity for Administrative Purposes	Public Call box	Intercom	Total	%
Eastern Cape	5393	5255	1293	1057	38	562	1053	414	279	73	1.36
Free State	1166	1111	878	829	29	303	386	446	58	6	0.51
Gauteng	2070	1760	1866	1744	130	1329	1438	992	494	0	0.00
KwaZulu Natal	5840	5645	2455	1829	55	536	998	658	242	52	0.89
Limpopo	3834	3785	888	543	5	144	306	156	35	23	0.60
Mpumalanga	1715	1642	933	655	3	74	110	130	3	13	0.76
North West	1467	1441	639	553	9	271	640	138	95	3	0.20
Northern Cape	541	509	420	390	12	208	377	94	114	0	0.00
Western Cape	1445	1061	1410	1339	95	1248	1267	708	133	0	0.00
Total	**23471**	**22209**	**10782**	**8939**	**374**	**4675**	**6574**	**3736**	**1453**	**170**	**0.49**

One site can have more than one type of communication

Figure 4.7: NEIMS Statistics on Laboratories, Disaggregated by Province. *Source: Department of Basic Education 2018.*

LABORATORIES

basic education
Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

NEIMS
National Education Infrastructure Management System

Laboratory Source Facilities

17/01/18

Table 8

Site Type : Ordinary Operational Schools

Province Name	Number of Sites	With Laboratory	% With Laboratory	Without Laboratory	% Without Laboratory
Eastern Cape	5393	370	6.90	4994	66.78
Free State	1166	327	28.04	839	71.96
Gauteng	2070	690	33.33	1380	66.67
KwaZulu Natal	5840	667	11.42	5173	88.58
Limpopo	3834	667	11.42	5173	88.58
Mpumalanga	1715	212	12.36	1503	87.64
North West	1467	288	19.63	1179	80.37
Northern Cape	541	108	19.96	433	80.04
Western Cape	1445	480	33.22	965	66.78
Total	**23471**	**3809**	**18.98**	**20071**	**81.02**

Data concerning school-level resources is collected by SACMEQ and the latest of these studies was conducted in 2014. However, this data relates to primary schools, as it reports on students in Grade 6, so is outside the scope of this paper.

The UIS report (Wallet 2015) emphasises that data related to ICT deployment is scarce and states that collecting more, and better-quality data is a priority. It also states, however, that as an organisation the UIS will provide help:

> *'To complement national efforts, the UIS is committed to support countries in establishing the appropriate national-level mechanisms and processes for reporting data. In particular, data on device type, deployment patterns and other key aspects will be important to help shape policymaking as ICT expands across African education systems. Given the advocacy work of the Broadband Commission and its role in development, data on bandwidth in schools will also be in high demand and important for policymakers'* (Broadband Commission 2013, p.20).

The NEIMS reports from South Africa suggest one approach to collecting school-level data. Whether or not they are collecting the right sort of data, and how this data is used once it is collected, is not clear. However, if, as Wallet (2015) suggests, it is important to collect the data, other countries in sub-Saharan Africa might consider following the example of South Africa, at least as a starting point.

Data on Success of Policies and Initiatives

Although the literature showcases a wide range of innovative programmes being implemented as a means of addressing challenges in the delivery of quality STEM and ICT secondary education for all, it appears that there are frequently gaps between policy or strategy and the reality of practice on the ground. For example: 'It is evident that there is a gap between teacher education policy and practice in Anglophone West Africa. Most teacher education policies are "add-on," meaning that they were formulated as part of a larger national policy framework for basic, secondary and tertiary education' (Colley 2014).

This example demonstrates an attempt to collect evidence on the success of teacher education policies and their implementation, and there are many similar examples in the research literature. However, these examples generally refer to smaller initiatives, research projects and the like. It is less common to find evaluations which might provide evidence of gaps between policies and practice, of country-wide, government-led policies and initiatives. Overall, it seems, a rigorous and accessible evidence base on what works to improve STEM and ICT education in various contexts is lacking.

The South African government, however, provides some examples of initiatives that aim to develop a rigorous and accessible set of data on what works. For example, the National Education Evaluation Development Unit (NEEDU), for example, is an independent institution that systematically identifies the factors and inhibitors of school improvement in schools, districts, provincial education departments and the national education department, in order to achieve a national system of quality education. It has a cross-cutting approach, working with all stakeholders in five-year cycles, for example, it might address teaching and learning in rural schools (Department of Basic Education 2013a). NEEDU reports directly to the Minister of Education.

In a recent NEEDU evaluation *Schools that Work II* (NEEDU 2017), best practices were identified in successful and improving schools. The National Senior Certificate (NSC) was used to identify successful schools from different socio-economic backgrounds across all the provinces. Recommendations related to school, district and education departments were made, which assert that:

- Sharing successes should be an integral part of the work of an improving school. There are aspects in every teacher's work and every school's work which reflect the best practice which others can learn from.
- Schools need to foster a collaborative culture among teachers that puts student learning first and turns a teacher's best practice into a school-wide best practice.
- If school improvement planning is to make an impact on the standards achieved by learners, then effective planning processes must be at the heart of the school, and drive its development.

- Individual parts of the district need to strategically co-ordinate their work better so that they operate in concert with one another, as opposed to working in separate silos or in competition for limited district resources.
- In addition to setting the expectation of data-driven decision-making, districts need to take responsibility for collecting data, analysing it and using it effectively to support learning.
- In pursuit of quality education, districts need to take deliberate steps to reduce the amount of time circuit managers spend on operational or administrative issues and monitoring schools' compliance, and shift their focus toward improving teaching and learning in schools.
- A standard must be set, regarding the number of teaching days in each term that cannot be exceeded through attendance at workshops, union meetings, memorial services, sporting events or cultural activities.

Other examples from South Africa include the 2013 report of the investigation into the implantation of Mathematics, Science and Technology (Department of Basic Education 2013b) and the report on the 'Funza Lushaka' bursary programme (see Chapter 3 for more details), which aimed to attract high-achieving students into the teaching profession (Lewin et al. 2016).

This chapter is concerned with gaps between data and practice, and the point here is that although many countries in sub-Saharan Africa do not appear to recognise a need to fill the gaps, it could be argued that South Africa is demonstrating the will to do so, and perhaps provides a model for other countries in the region to follow.

Conclusion

This chapter, identifying gaps for quality assurance in secondary STEM and ICT education, aimed to highlight the sorts of data that countries might be expected to collect. This data would be useful at various levels (national, provincial etc) to pinpoint problem areas and, in some cases, begin to suggest approaches for remediation. Taking the perspective that policies and initiatives need to be coherent, feasible and inclusive, the questions here are designed to diagnose where the gaps are in data collection. The following questions arise from the discussion previously presented and are presented in question form to facilitate their inclusion in the diagnostic framework.

Relevance and Coherence:

- Is information about teachers' and students' perceptions about the STEM and ICT curricula collected?
- Are the curricula quality assured for internal coherence and coherence across the whole of STEM and ICT?
- Is it appropriate to take part in international or regional assessments (such as TIMSS, PASEC)?
- Is it appropriate to develop national assessments, including assessments that make use of pupil level longitudinal data?
- What data is important to collect about the quantity and quality of STEM and ICT teachers?
- Is data collected about STEM and ICT teachers necessary, reliable and appropriate?
- Is data about school level resources collected at local, regional and national level?
- Is the information collected about school level resources necessary, relevant and appropriate?

Feasibility:

- Is it feasible to determine teachers' and students' views on the curriculum?
- Is it feasible to quality assure STEM and ICT curricula?
- Is it possible to conduct national assessments?
- Is it feasible and practical to produce detailed examiners' reports on national examinations?
- Is it feasible to collect data about teachers' performance in sensitive, but practical ways?
- Is it feasible to collect data about school resources in methodical and systematic ways?

Inclusion:

- Is there data available about numbers of disadvantaged groups participating in STEM and ICT?
- Is data collected about the number of disadvantaged teachers?
- Is data available about school-level resources and equipment designed to enable disadvantaged or disabled students to participate in STEM and ICT?

Chapter 5: Conclusion and Diagnostic Framework for Sustainable STEM & ICT Education

The report has summarised previous work identifying challenges to the implementation of an inclusive, good quality secondary STEM and ICT education. The focus of the present study, however, has been to begin to identify what can be done to overcome these challenges. The report underlines the importance for countries to develop national strategies to support STEM and ICT education. A feature of successful STEM and ICT education strategy in other parts of the world is the proactive and strategic role of governments in identifying areas for intervention, linked to development priorities. The diagnostic framework below is intended to inform the development of such a strategy. At a general level, strategy needs to address the following key issues identified in the report.

Firstly, there is a need to develop the relevance and coherence of interventions. Interventions are often highly fragmented. Many have been introduced by donors and NGOs and have operated in a piecemeal fashion. Governments need to ensure that existing interventions clearly articulate with existing policies including national development visions, TVET policies, education sector development plans and policies, science and technology policies and gender policies as well as with relevant regional and global agendas and initiatives, including the Sustainable Development Goals and the African Union's *Agenda 2063*. This requires a systemic approach, focusing on coherence between different elements of the education and training system including curriculum, assessment and teacher education. At the heart of successful strategy is the need to improve the quality of the STEM and ICT teaching force. A key priority is improving the preparation and continuing professional development of teachers, both in terms of subject knowledge and in subject specific pedagogy. Strategies need to identify means to attract and retain good quality STEM and ICT teachers.

Secondly, national strategies need to be feasible. A problem with many of the strategies reviewed and a barrier to effective scale up of potentially successful interventions, is the disjuncture between the demands of new strategies and interventions on the one hand, and the difficulties of implementation, given the realities faced by African education systems, on the other hand. The report has summarised previous work that identifies a range of challenges associated with STEM and ICT education in SSA such as inappropriate or outdated curricula, a lack of qualified teachers, pupils unprepared for learning, natural disasters, language policies and lack of resources. There is a need to ensure that attempts to change curriculum and assessment practices start from a realistic appraisal of, amongst other things, enrolments, resources, the professional capability of teachers and of learner performance at the end of primary school. Plans need to be sufficiently detailed to take account of local realities as well as the demands of already over-crowded curricula and high stakes assessments. The use of ICTs to improve learning outcomes also requires careful planning, as discussed in Chapter Three. As was also suggested in Chapter Three, strategies need to consider an incremental approach to expanding access to interventions.

Thirdly, as argued in Chapter Two, national strategies need to be more inclusive if they are to expand the pool of secondary school graduates with the STEM and ICT skills necessary to support sustainable economic and human development and to contribute towards environmental protection. Baseline assessments for strategies need to properly identify different starting points for diverse groups of learners. Policies targeted at specific groups, such as those focused on gender, also need to take account of the complex intersectionalities between gender, socio-economic background and language, for example. Schools should be given appropriate support to adapt initiatives to their own realities and teachers need to be adequately prepared to teach learners from increasingly diverse backgrounds. A more targeted approach to the allocation of resources and infrastructure to support STEM and ICT, focusing on disadvantaged schools, can increase inclusion.

Closely related to the need for a more strategic approach, is the need to close the evidence gap, as was argued in Chapter Four. The report has highlighted the issue of a lack of robust evidence on which to develop and implement strategies aimed at improving learning outcomes in STEM and ICT education. In particular, the report has identified the need for more rigorous evaluation of interventions, with a focus on what works in raising learning outcomes for all in difficult delivery contexts, in Africa. Linked to this is the availability of assessment data that can track learner progress over time as a means to better understand the long-term impact of change on diverse groups of learners, including girls and other disadvantaged groups. At classroom level, a more effective use of formative assessment can assist in the implementation process through identifying and overcoming barriers to effective learning.

Governments also need to put in place more robust means of evaluating the performance of STEM and ICT teachers as a key means of monitoring the quality of STEM and ICT education. This is a notoriously difficult policy to implement, but some examples of successful practice were provided in Chapter Four. As has been suggested, an important consideration in the success of strategies aimed at monitoring teacher quality is achieving clarity over the necessity, reliability and appropriateness of the data collected. Harnessing the views of teachers on the STEM and ICT curricula is also vital for ensuring the relevance and feasibility of changes to curricula. Harnessing the views of learners is vital for assessing the degree of student engagement. Another area for careful monitoring is in terms of the level of resources and infrastructure to support STEM and ICT. It is important from an equity point of view, to measure how resources are distributed between schools serving more, and less advantaged learners.

At all levels of the system, a key consideration is not just the availability of appropriate data, but the capacity to use data to inform policy and practice. Finally, and closely related to the above, is the need to develop capacity within African governments to commission and undertake relevant research into successful practice in STEM and ICT education which can inform policy and practice. Many African governments currently lack this capacity which increases dependence on outside expertise and on the use of evidence conducted in contexts that may be quite different from national realities.

The diagnostic framework below summarises the key issues identified in the report, in the form of questions that are of relevance for policy makers. Based on the detailed discussion in earlier chapters, they are intended as a starting point for developing national strategy in the area of STEM and ICT education. They are not intended to be exhaustive. Between them, the questions cover the issues arising from this report, which strategy needs to address in the areas of curriculum and assessment, people and material resources. The questions are organised in relation to the three cross-cutting themes outlined in Chapter One, of Relevance and Coherence, Feasibility and Inclusion.

The issues are presented in the form of questions for two main reasons. The first of these is the provisional nature of identifying successful practice. Even in the case study countries of South Africa and Zambia, and for the reasons identified in Chapter Four, evidence relating to the success of initiatives is emergent. Secondly, no two countries are alike, and leading and managing complex change necessarily involves an iterative process of evidence-led problem solving, if ideas borrowed from elsewhere are to be applied appropriately in different contexts. Developing initial questions is intended to inform such a problem-based approach to strategy development and questions will necessarily be further refined and developed in the process.

Finally, it will be observed that many of the underlying issues and challenges that the questions flag up, resonate beyond secondary school STEM and ICT education. They relate to the relevance and coherence, feasibility and inclusiveness of the education system as a whole. In this sense, the framework is intended to make a positive contribution to thinking about wider processes of reforming secondary school education in Africa, in the context of the MCF SEA study.

Domain	Questions		
	Relevance and coherence	Feasibility	Inclusion
Curriculum & Assessment	Do STEM and ICT education policies articulate with national development vision, TVET policies, education sector development plans and policies, science and technology policies and gender policies? How well do the STEM and ICT education policies align with global trends in policy? Do ICT policies set out a plan for using digital technologies to improve learning? To what extent does STEM and ICT education address issues of environmental sustainability? Are STEM and ICT curricula relevant to the backgrounds and experiences of students and teachers? Are the curricula quality assured for internal coherence and coherence across the whole of STEM and ICT? Is it appropriate to take part in international or regional assessments (such as TIMSS, PASEC)?	Do STEM and ICT education policies and plans start from a realistic baseline assessment of enrolments, resources, professional capabilities of teachers and performance at the end of primary level? How detailed are plans to improve STEM education and policy? Are plans for monitoring and evaluation embedded within national plans? Are realistic budgets drawn up and sources of funding identified? Is an incremental approach taken to expanding access to interventions in the field of STEM and ICT? Is it possible to teach all the curriculum content in the time available? Is it possible to carry out all the hand-on practical work expected by the curriculum? Is it feasible to quality assure STEM and ICT curricula?	Do baseline assessments identify different starting points for diverse groups of learners? Do gender strategies acknowledge and target intersectionalities of disadvantage? Do policies include plans for students who did not achieve expected learning outcomes at the end of primary education? What autonomy and support do schools serving disadvantaged learners have, to adapt curricula and pedagogy to suit their learners? Do STEM and ICT curricula recognise that students may have very different starting points when entering secondary school? Are they appropriate for the cognitive and linguistic level of all learners? Are approaches to teaching STEM and ICT subjects specifically targeted at improving learning outcomes for girls? Is data available regarding the number of disadvantaged groups participating in STEM and ICT?

	Is it appropriate to develop national assessments, including assessments that make use of pupil level longitudinal data? Do curricula take account of teachers' and students' experiences? Are assessments well aligned with the curriculum? Do assessments capture the spirit of the curriculum?	Is it possible to conduct national assessments? Is it feasible and practical to produce detailed examiners' reports on national examinations?	
People	Are approaches to initial teacher education and continuing professional development coherent and relevant to the work of STEM and ICT teachers? Are there policies specifically targeted at attracting more teachers into STEM and ICT education? What evidence is there that they will be successful? What data is important to collect regarding the quantity and quality of STEM and ICT teachers? Is the data collected about STEM and ICT teachers necessary, reliable and appropriate? Is information about teachers' and students' perceptions about the STEM and ICT curricula collected?	Is it feasible to collect data about teachers' performance in sensitive but practical ways? Is it feasible to determine teachers' and students' views on the curriculum?	Do initial teacher education and continuing professional development take into account the different needs of prospective or practising teachers? Do they recognise the specific needs of teachers in rural areas? Is data collected about the number of disadvantaged teachers involved in delivering STEM and ICT?
Material resources	Are schools equipped with appropriate resources for teaching STEM and ICT?	To what extent are schools able to provide appropriate access to laboratories for students?	To what extent are disadvantaged schools helped to improve their material resources?

	Is data about school level resources collected at the local, regional and national level? Is the information collected about school level resources necessary, relevant and appropriate?	Is it possible to provide textbooks in STEM and ICT subjects for all students? Is it feasible to collect data about school resources in methodical and systematic ways?	Is data about school-level resources and equipment, designed to enable disadvantaged or disabled students to participate in STEM and ICT, available?

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