Association for the Development of Education in Africa

MINISTRY OF EDUCATION
REPUBLIC OF KENYA

ADEA Inter-Country Quality Node on Mathematics and Science Education

The LEGO Foundation
www.learningthroughplay.com

REPORT on The Status of Play-Based STEM Education in Primary School Level in Africa

ADEA's Inter-Country Quality Node
on Mathematics and Science Education (ICQN-MSE)-2023

www.adeanet.org

ADEA

Association for the Development of Education in Africa (ADEA)
African Development Bank Group (AfDB),
Immeuble CCIA Plateau, Avenue Jean-Paul II
01 BP 1387, Abidjan 01 Côte d'Ivoire
Tel.: (+225) 272026 3964
Email: adea@afdb.org
Website: www.adeanet.org

Inter-Country Quality Node on Mathematics and Science Education (ICQN-MSE)
Secretariat Office, Host Institution
Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA)
P. O. Box 24214 – 00502
Karen, Nairobi – Kenya
Tel.: 020 2044406 / 0706 722697 / 0780 797648
Email: ceo@cemastea.ac.ke
Website: www.cemastea.ac.ke

Developed with the support of the LEGO Foundation

…………………………………………………..

Citation

ADEA (2023). Report on The Status of Play-Based STEM Education in Primary School Level in Africa.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADEA	Association for the Development of Education in Africa
AfDB	African Development Bank
AMU	Arab Maghreb Union
ASEI	Activity, Students, Experiments, Improvisation
AU	African Union
CEMASTEA	Centre for Mathematics, Science and Technology Education in Africa
COVID	Corona Virus Disease
EAC	East African Community
ECOWAS	Economic Community of West African States
EMIS	Education Management Information System
ESP	Education Strategic Plan
ESSP	Education and Sector Strategic Plan
GDP	Gross Domestic Product
GER	Gross Enrolment Rate
GES	Ghana Education Service
ICQN-MSE	Inter-Country Quality Node on Mathematics and Science Education
ICT	Information Communication Technology
INSET	In-Service Education and Training
IT	Information Technology
JHS	Junior High School
JICA	Japan International Cooperation Agency
KCSE	Kenya Certificate of Secondary Education
KICD	Kenya Institute of Curriculum Development
KNEC	Kenya National Examination Council
Math	Mathematics
MDG	Millennium Development Goals
MOE	Ministry of Education
MSE	Mathematics and Science Education
NCE	National Commission on Education
OECD	Organisation for Economic Co-operation and Development
PDSI	Plan, Do, See, Improve
PISA	Program for International Student Assessment
PTCs	Primary Teachers Colleges
SADC	Southern African Development Community
SDGs	Sustainable Development Goals
SEACMEQ	Southern and Eastern African Consortium for Monitoring Education Quality
SESEMAT	Secondary Science and Mathematics
SHS	Senior High School.
SMASSE	Strengthening of Mathematics and Science in Secondary Education
SSA	Sub-Sahara Africa
STEM	Science, Technology, Engineering and Mathematics
STIs	Science Technology and Innovations
TIMSS	Trends in International Mathematics and Science Study
UNEB	Uganda National Examination Board
UNESCO	United Nations Educational, Scientific and Cultural Organization.
UNICEF	United Nations Children’s Fund
UPE	Universal Primary Education
USD	United States of America Dollar
WGMSE	Working Group on Mathematics and Science Education

EXECUTIVE SUMMARY

Context

Africa is faced with myriad challenges including adverse impact of climate change against a background of a rapidly increasing population estimated at 1.2 billion. Among the challenges is that 400 million, or one in every three persons in Africa are living in extreme poverty. Meanwhile, about 226 million of the population are youth aged 15-24 years, representing about 20% of Africa's population, who are largely unemployed. This segment of the population is forecast to reach 42% by 2030. With better planning, Africa has the potential to address these perennial problems by equipping the eleven million youth joining the labour market every year with relevant Science, Technology, Engineering and Mathematics (STEM) skills, and enabling them to exploit emerging opportunities for prosperity in Africa.

The workforce in Africa is unable to fill even the existing STEM jobs due to lack of requisite STEM skills. African countries should take decisive actions to improve the quality of STEM education and accelerate equipping of youth with relevant STEM skills to take up emerging opportunities in the STEM careers. Therefore, the overall objective of this study was to establish the status of STEM education at the basic learning levels in Africa. The findings will form the basis for a policy brief for engagement with decision makers in education in Africa and development of a monitoring and evaluation framework for tracking quality of STEM at the basic learning levels.

Methodology

This study sought to establish the status of STEM education at the basic learning levels in Africa in terms of student enrolment and performance, challenges derailing achievement of quality STEM education, interventions for addressing these challenges, and the impact of the interventions on quality of STEM education. The study focused on nine countries in Africa including Angola, Botswana, Ghana, Kenya, Morocco, Namibia, Rwanda, South Africa, and Uganda. The sampling took into consideration the African Union Regional Economic and Language blocks. Focusing on the nine countries, a sample of 328 teachers of STEM subjects in public schools, school principals, and education officials considered being experts in understanding issues of STEM from their professional training and practice was surveyed. Both quantitative and qualitative data was gathered through semi-structured questionnaires and interviews administered using online platforms, and review of documents relevant to the thematic areas that were explored in this study.

Key findings

i. Enrolment and Performance in STEM education

Enrolment in STEM subjects at the secondary level has been increasing over the years in many African countries. However, the increase is mainly due to natural demographic changes and favourable policies supportive of access to basic education. Despite lack of adequate data on trends in STEM enrolment, available data on both Gross Enrolment Rate (GER) and Net Enrolment Rate (NER) at secondary school level in Africa are indicative of low access to secondary education. This has a negative spillover effect on access to STEM education at all levels in the education system. Furthermore, consistent longitudinal data on performance in STEM subjects at the secondary school level in Africa is also lacking. However, the available data points to persistent poor performance in these subjects, and disproportionately affects girls more than boys. Notably, there are no cross-country assessment programmes at the secondary school level in Africa.

ii. Challenges of achieving quality in STEM education

A range of challenges confront achievement of quality in STEM education from the basic learning levels at school level to the national level. These include inadequate teaching and learning resources and facilities, poor teacher pedagogical practices, student lack of interest in STEM subjects, relevance of STEM curriculum, and insufficient number of teachers of ***STEM*** subjects. These challenges are inter-sectional, with implications on the type of strategies that should be mounted to address them.

iii. Interventions on quality of STEM education

There are no specific strategic plans or policies on STEM education at the basic learning levels except for South Africa that has finalized one. However, within the education strategic plans are some strategies addressing the quality of STEM education, which is indicative of commitment by education authorities to address this sector. Additionally, some schools and regions had strategic plans with objectives and strategies on improvement of STEM education. . The key strategies in these plans included provision of resources and facilities, continuous teacher professional development, establishment of model schools of excellence, student mentorship programmes, recruitment of qualified staff, strengthening capacity of the Ministries of Education in quality assurance, , improving student enrolment and performance at secondary school and in tertiary institutions, and integration of ICT in education. Some interventions that were currently being implemented were reviewed and found to be: a) either national, localized in specific sub-geographies within a country, or cross-country; b) collaborations between governments and development partners for most, or sponsored by private entities, NGOs, and individual philanthropists; c) focused on multiple strategies in addressing quality of STEM education. However, these interventions were not sufficient in addressing the quality of STEM Education at the basic learning levels in Africa.

iv. Impact of interventions on quality of STEM education

Apart from donor funded interventions in STEM education, educational authorities rarely conduct impact evaluations. However, they conduct regular reviews of the education sector where issues of STEM education are included. An exception is South Africa that has a systematic impact evaluation system through an Annual National Assessment (ANA) process. Additionally, some countries including Botswana, Ghana, Morocco, and South Africa participate in the Trends in International Mathematics and Science Study (TIMSS). Meanwhile, Key Performance Indicators (KPIs) for tracking quality of STEM education were neither consistently nor adequately applied at national, regional, and school levels. Furthermore, the indicators were not precise, which could be indicative of a technical capacity gap in measurement of the quality of STEM education. The main indicators were school based test scores and results of national examinations, except for South Africa that had articulated goals and corresponding indicators that are applicable at multiple levels in the education system.

There were no specific institutions charged with quality assurance of STEM education, and department within the Ministry of Education was discharging this function However, some institutions play a role in quality assurance of STEM education, for instance, CEMASTEA in Kenya. Again, an exception was South Africa where the process of establishing a fully-fledged institution for quality assurance, the UMALUSI is in place; a strategy towards this process has been finalized. Meanwhile, there were staff with responsibility for quality assurance of STEM education, but these were not sufficient in number. Furthermore, there lacks a specific budget line for quality assurance of STEM education as the budget allocation for the department is lump sum.

Conclusion

In conclusion, the lack of adequate understanding of the status of STEM education at the basic learning levels in Africa is apparent. While it is widely acknowledged that STEM skills are fundamental for supporting technological innovations, creating jobs, and employment opportunities in STEM careers with higher earnings, African countries, unlike those in the global north, are in the nascent stages of investment in this critical sector. Meanwhile, there are hosts of multi-dimensional challenges in efforts to improve quality of STEM education in Africa, which require adoption of multi-faceted approaches in partnership with all key stakeholders in the STEM education agenda. Ultimately, African countries can confront the challenges facing STEM education and create a critical mass of youth with relevant and appropriate STEM skills for individual development and economic prosperity of the African countries. Efforts should focus on massification strategies to increase student access to opportunities in STEM education, courses, and careers. This will require rationalized and well-targeted interventions in delivery mechanism, resource mobilisation, partnerships and coordination, funding, and quality assurance.

Recommendations

The recommendations emanating from this study are:

i. Policy on STEM education at basic learning level

The national education authorities should develop a policy that will lay the ground for structured engagement in the whole spectrum of delivery of quality STEM education. Furthermore, this policy will inform strategies, mechanisms, resource mobilisation and funding models for delivery of quality of STEM education at the basic education learning levels.

ii. Review STEM curriculum

There were indications in some countries that the STEM curriculum was too broad in content coverage, that required to be review for potential scaled down while ensuring core objectives are achieved. Furthermore, the curriculum should be made relevant to the market demand with a focus on contextual realities. Additionally, STEM course books should be aligned with the curriculum.

iii. Mapping of interventions in STEM education

Education authorities should conduct mapping of on-going interventions on STEM education to document the scale of operations, focus geographies, key strategies, timelines, reach, impact, and funders. This information enables education authorities to establish existing interventions and continuously assess whether areas of need are being adequately addressed, while also consolidating emerging innovations and best practices. Furthermore, the education authorities should nurture communities of practice among the existing players and regularly convene forums for synthesis of lessons learnt from the interventions. This will enable consolidation of a repository of contextual knowledge, ensure relevance of interventions, harmonization, and coordination of efforts in this critical sector.

iv. Resource mobilisation to fund STEM education

Education authorities should provide adequate funding to support initiatives for improvement of STEM education and ensure that students are able to perform at the highest level possible. Provision of resources and facilities should be highly prioritized as this was frequently mentioned as a challenge. The resources and facilities that were mentioned more frequently were science laboratories, equipment, and chemicals, ICT infrastructure, and course books for STEM subjects.

Therefore, governments should establish more partnerships with Development Partners, Private Sector, and Foundations for technical support and funding of STEM interventions.

v. Adequate staffing of STEM teachers

To ensure quality in delivery of STEM curriculum, education authorities should ensure adequate staffing with qualified teachers of STEM subjects. Additionally, more female teachers are required in STEM to act as role models for girls and encourage increased uptake of STEM-based careers.

vi. Regular teacher professional development in STEM pedagogical practices

Sustainable models for regular capacity building of teachers of STEM subjects through different modalities should be established and sustained. Some of these models already exist in some countries including Kenya, Uganda, Zambia, and Nigeria. Meanwhile, continuous research on innovative pedagogies in STEM education should be deployed to generate insights on what is working or not working, for continuous improvement of pedagogical practices.

vii. Improve conditions of service for teachers

A recurring theme was the poor conditions of service for teachers. Strategies should be devised to attract qualified staff into STEM teaching careers, reduce teacher attrition, and improve commitment to delivery of the STEM curriculum. Meanwhile, strategies should be devised for identification and recognition of champion STEM teachers to boost teacher motivation and commitment while raising the profile of STEM education.

viii. Monitoring and Evaluation Framework for STEM education

A framework for management of quality assurance of STEM education should be developed, articulating the quality aspects, standards of performance, benchmarks, and process. Without a comprehensive framework, assessing, reporting and tracking of quality of STEM education will be elusive. Based on this framework, African countries should develop and use Key Performance Indicators for tracking progress in the quality of STEM education at multiple levels. The indicators should be aligned with specific strategies for improvement of quality of STEM education.

ix. Comparative Analysis of Trends in Performance in STEM

As part of quality assurance, countries should embark on comparative analysis of results of national assessment, cross-country assessments in the region, and international assessment, including TIMSS. This will enable governments to design targeted interventions based on evidence emerging from the assessments. Most importantly, countries in Africa should develop and implement a system for cross-country comparative studies on STEM education at the basic learning levels, particularly at the secondary school education cycle.

x. Student mentorship programmes on STEM

Student mentorship programmes should be strengthened to spark student interest in STEM. The mentorship programmes should be made comprehensive by engaging parents, experts in STEM, school leadership, teachers, and role models, particularly, female role models. Students should be encouraged to explore their talents in science and technology fairs as part of the mentorship programmes. This will make STEM education more enjoyable for the students and act as a great incentive to pursue careers in STEM.

xi. Sensitization programme for parents and communities on STEM education

Parents have a critical role in the education of their children, and, consequently in promoting STEM education. Therefore, schools, with the support of education authorities, should mount sensitisation programmes and awareness creation on STEM education for parents and guardians to secure their support in the provision of resources and facilities for STEM; and in encouraging their children to pursue STEM subjects and careers.

xii. School STEM strategy

Each school should develop a STEM strategy articulating the necessary actions to be implemented within given timelines to improve the quality of STEM education. The strategy should be developed collaboratively through a participatory process involving the students, teachers, parents, guardians, school managements, among others key stakeholders. The school level STEM strategy should articulate specific milestones, responsibilities, and resource mobilisation for delivery of identified initiatives.

xiii. Communities of practice on STEM education

Education authorities should take the lead in nurturing communities of practice on different aspects of STEM education at the basic learning levels. Given the multi-faceted nature of STEM education, governments could form a technical working group on STEM education at the basic learning level. The technical working group should guide and advice on strategies of promoting STEM education at this level, as well as address the various challenges that confront this critical sector of education.

1. INTRODUCTION

1.1 Background

Africa is faced with myriad challenges including adverse impact of climate change, increasing water scarcity, biodiversity and ecosystem loss, desertification, low resilience to natural disasters, energy crisis, health insecurity, low penetration of ICT services, and food insecurity (UN Economic Commission for Africa, 2012). On the demographic front, a key challenge in Africa has been the rapid population growth rate, currently estimated at 2.7% annual growth rate, with a population of 1.2 billion people (The World Bank, 2020). Of this population, 226 million are youth aged 15-24 years, representing about 20% of the Africa's population. This segment of the population is forecast to reach 42% by 2030 (United Nations, 2020). These youths are largely unemployed, which presents a problem of human welfare and development as it adversely affects incomes, health, education, and well-being (United Nations, 2020). Some of the adverse consequences of these demographic trends are already being felt in Africa in the form of declining standards of living, increasing unemployment rates, high poverty levels, increasing social, religious, and ethnic conflicts, low quality education, and poor health indicators (United Nations Population Fund, 2020). With an estimated eleven million young Africans joining the labour market every year for decades to come, it is critical that they are equipped with sufficient and appropriate STEM skills that are needed to exploit the emerging opportunities in this sector for prosperity of African countries (The Planet Earth Institute, 2016). In Africa, there is a large STEM skills gap between market demand and the enrolment in STEM related courses which implies a large market exists for STEM training (CEMASTEA, 2019). Therefore, a strategic response in the education sector to fill the gap in STEM skills is accelerated investment in STEM education in Africa (Formunyam, 2020).

The annual economic growth rate in Africa was projected to rise from 2.4% in 2017 to 3.5% by 2020 (World Bank, 2018; The African Exponent, 2018). However, the advent of the COVID-19 pandemic has devastated the world, with over 50 million confirmed cases, one million deaths globally; while in Africa, over one million cases, and 30,000 deaths were reported at the beginning of November 2020 (WHO, 2020). The Real GDP in Africa is projected to contract by 3.4 percent, down 7.3 percentage points from the growth projected before the outbreak of COVID-19 (African Development Bank, 2020). Therefore, the COVID-19 pandemic is not only a health crisis but will have dire economic consequences in the years to come in Africa where out of the 1.2 billion people, 400 million, or one in every three persons are already living in extreme poverty (Worldometers, 2018).

Although there is a huge potential for African countries to address the perennial problems of unemployment, poverty, and health by increasing STEM related jobs, expatriates from the developed world are currently performing most of these jobs. Most of the workforce in Africa is unable to do these jobs due to lack of the requisite skills (Jamme, 2020). For instance, infrastructure construction projects, research programmes, mining industries, control of disease pandemics such as Ebola, and the Corona Virus Disease (COVID)-19 are outsourced to expatriates and multi-nationals, which adversely affects the ability of African governments to invest in STEM skills for the future (Jamme, 2020). Against this background, African countries continue to lament about the lack of STEM workforce and high unemployment rates among the youth (ibid). However, with better planning, millions of youths in Africa could be well trained in STEM skills, creating new employment opportunities, and making great contribution to the African economy (ibid).

The African Union (AU) recognizes that STEM education at the secondary school education cycle is critical to the development of a well-equipped human capital capable of competing in increasingly science and technology-driven and knowledge-based global economies (African Union, 2015). However, the AU also acknowledges the inability of the workforce in Africa to fill the existing STEM jobs due to lack of requisite STEM skills. This raises a concern on the relevance of the current secondary school education in terms employability, technical and vocational training, and progression to tertiary education. Meanwhile, the Association for Development of Education in Africa (ADEA) has been coordinating efforts in addressing challenges of STEM education at the basic learning levels in Africa through the Inter-Country Quality Node on Mathematics and Science Education (ICQN-MSE). While these efforts are commendable, it is now time for the governments in African countries to take decisive actions to improve the quality of STEM education at the basic learning levels and accelerate equipping of youth with relevant STEM skills to take advantage of emerging opportunities in the STEM careers. These measures will guarantee sustainable opportunities for youth employment while accelerating economic growth in African countries.

1.2 Justification

STEM education is a dynamic area of discussion globally and Africa's views on why, what, how, and whose STEM education continue to be divergent. There are several STEM education initiatives implemented in African countries by various organizations that are yet to be documented for peer learning. In addition, the standards of Mathematics and Science Education in Africa remain dismal owing to various challenges stemming from mainly pedagogical leadership and practices. To strengthen these practices, there is need for countries to identify gaps that exist and formulate relevant policies to govern all levels of STEM education. Pedagogical leadership and teaching practices determine quality of Mathematics and Science Education in Africa. Several small-scale STEM education projects are being implemented in African countries, some spearheaded by development partners. There are also varied opinions on STEM education owing to regional and global perspectives on this important field. There is also a debate on whether to focus on STEM or STEAM (A stands for, 'Art and Design'). Moreover, there is need to establish a knowledge repository platform to inform STEM education in Africa. This is realizable if the on-going initiatives are determined so that the Node embarks on enhancing knowledge creation and sharing across stakeholder types and national borders for improved peer-learning practices in African countries. The situational analysis on STEM education in sample African countries will help establish a basis for developing STEM education, and a stakeholder validated framework will enhance the process of documenting national level data for peering learning.

1.3 Purpose

This situational analysis focused on the status of STEM education in Africa at the basic learning level to inform policy direction in this critical sector. The findings will be used to develop a monitoring and evaluation framework on progress in quality of STEM education in Africa and a policy brief for engagement with key stakeholders on STEM education in Africa.

1.4 Specific objectives

The specific objectives of this study were to:

a. establish trends in student enrolment and performance in STEM subjects at the secondary school education cycle in Africa;
b. establish challenges facing STEM education at the secondary school education cycle in Africa;
c. assess the interventions, including policies, strategies, and funding of STEM education at the secondary school education cycle in Africa;
d. assess the impact of interventions on STEM education at the secondary school education cycle in Africa; and
e. make recommendations for improving the quality of STEM education at secondary school education cycle in Africa

1.5 Scope

The study focused on a sample of nine countries in Africa including Angola, Botswana, Ghana, Kenya, Morocco, Namibia, Rwanda, South Africa, and Uganda. These countries were chosen taking into consideration the Africa Union regional economic and language blocks. Therefore, while Angola represented the Portuguese speaking countries, Botswana, Namibia, and South Africa represented the SADC block, as well as English speaking countries. Meanwhile, Rwanda, Kenya and Uganda represented the East African Community (EAC) block, while Ghana represented the ECOWAS, and Morocco represented both the French speaking countries and the Arab Maghreb Union (AMU) block.

To have a comprehensive overview of the status of STEM education in Africa, the study focused on four key and interrelated thematic areas. These include student enrolment and performance in STEM subjects, interventions in STEM education, impact of the interventions on STEM education, and challenges faced by STEM education at the basic learning levels in Africa.

Although the study was aimed at establishing the status of STEM education at the basic learning level in Africa, the focus was on the secondary school education cycle, which in most countries in Africa comprise of grades seven to twelve. The relatively distinct and wide range of STEM subjects that are offered in the secondary school curriculum informed the choice of the secondary school education cycle. Additionally, teachers at the secondary school education cycle tend to have more subject specialization which presents an opportunity to interrogate their experiences in these subjects.

1.6 Assumptions

The fundamental assumption in this study was that STEM education in all its dimensions was conceptualized as a developmental process which can be defined and characterised with specific attributes. These attributes include the type of content that constitute STEM education, curriculum, courses, and careers; and these are sufficiently agreeable among stakeholders in STEM education. Additionally, the key stakeholders engage in STEM education at multiple levels and their type of interactions within the STEM agenda can equally be characterized. This understanding informed the adoption of the ecological system theory as the foundation on which the study design and approaches were anchored. However, like many conceptual issues, the meaning of STEM is still in contest. This could introduce biases that can be reflected in any discourse about STEM, including the findings, and evidence gathered in this study.

1.7 Significance

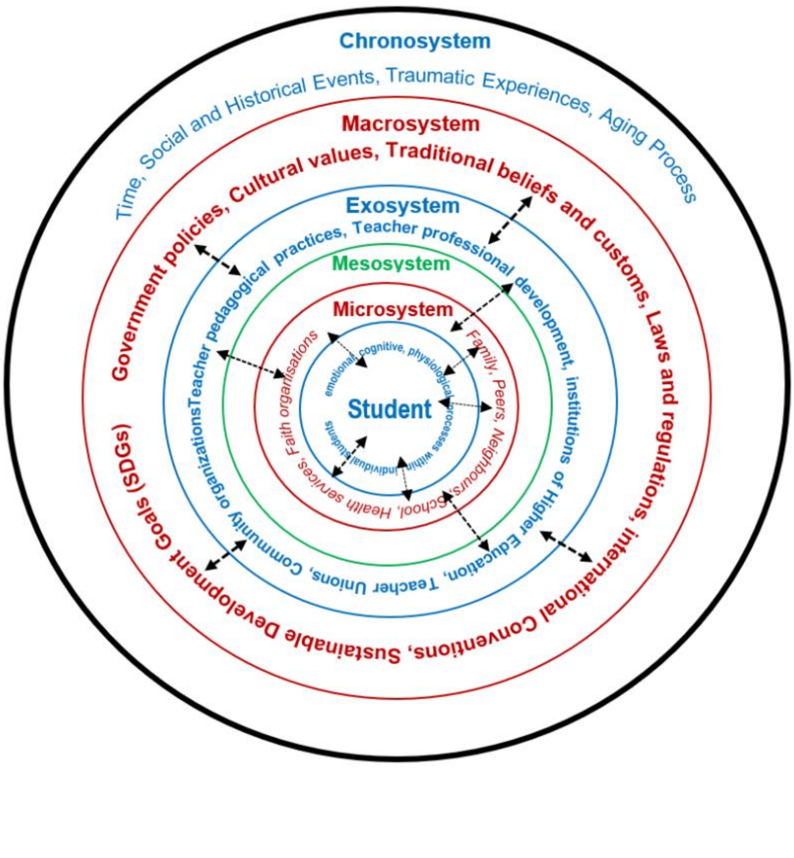
The findings from this study are applicable to a range of stakeholders. Education authorities in African countries will find them useful as a basis for catalysing action towards improvement of the quality of STEM education at the basic learning levels by referring specific findings and recommendations to their context. More importantly, planners in education will make reference to these finding in engaging with political leadership and securing their support in resource mobilisation. Equally, policy briefs that will be developed based on this study will be a key tool for engagement with leaders in education. Specifically, policy makers in education will find a basis for proposing strategies based on the evidence in this report. Meanwhile practitioners, including teachers, principals of schools, field education officials, and development partners offering technical assistance will have a reference in planning for school and regional level STEM initiatives. The planning will be based on an informed understanding of the critical factors reviewed in the study that impede the achievement of quality in STEM education. Equally, development partners supporting STEM initiatives will find the study findings useful in designing interventions. The findings will also add to the body of knowledge on STEM education in Africa, contributing to the on-going discourse in this topical issue.

1.8 Theoretical framework for the study

The situational analysis was informed by the ecological systems theory where STEM at basic education level in Africa was conceptualized as a developmental process within a microsystem, mesosystem, ecosystem, macrosystem, and chronosystem (Bronfenbrenner, 1979). This ecological model provides a framework for understanding the interconnectedness and complex interactions that occur across multiple systems in the STEM education development process among policy makers, curriculum developers, development partners, teachers, parents, and students, and other key stakeholders. In this study, student development in STEM education is anchored within the context of the system of relationships that form the student's environment. Each of the complex layers of the students' environment influence student development in STEM education. The interaction between factors in the different layers of the environment fuels the student development in STEM education, and any changes in any one layer have ripple effects throughout the other layers. Furthermore, success in transforming a system requires partnerships with key stakeholders in the population to support the process. For instance, STEM education initiatives must focus on collaborating with families in developing a shared understanding of its place in the greater society. This is because families must be comfortable with the means of supporting their children in STEM education, from helping with homework to discussing potential STEM careers. Therefore, for a comprehensive understanding of student development in STEM education, it is important that the immediate environment, as well as the interaction of the larger environment, are clearly understood. Therefore, the design, methods and approaches that were adopted in this study were anchored on the ecological systems theory.

Figure 1: Theoretical framework (adopted from Bronfenbrenner, 1979) presents the ecological system theory which illustrates the different layers of this system with the intrapersonal, interpersonal, institutional, community, and public policies that are key factors in shaping the development of STEM education in Africa.

Figure 1: Theoretical framework (adopted from Bronfenbrenner, 1979)



Microsystem: this is the layer closest and with direct contact to the student and involves all the relationships that interact directly with the student in relation to STEM education. It encompasses the relationships and interactions of a student with immediate surroundings including the family, school, neighbourhood, and peers (Bronfenbrenner, 1979; Stewart, 2000). For instance, teachers of STEM provide students with a meaningful and engaging learning environment by offering an innovative pedagogy that seeks to create an organized, coherent approach to learning science, technology, engineering, and mathematics. Meanwhile, teachers of STEM work together on lesson planning, home-school connections, and bridging STEM initiatives in the community and school. Therefore, the microsystem is characterized by a focus on the student and the interactions the student has with the environment, peers, teachers, and family. This situational analysis explored the engagement of teachers of STEM in activities that are likely to improve students' enrolment and performance in STEM. It further explored whether and how parents are engaged in supporting STEM education. Furthermore, it attempted to establish how school leadership and education authorities were supporting STEM education at the school level.

Mesosystem: this layer provides the connection between the structures of the student microsystem, for example, the connection between the teacher and parents, between the church and neighbourhood, and between peers and teachers (Bronfenbrenner, 1979; Stewart, 2000). Therefore, the mesosystem represents links between the systems that influence the student, for instance, the connection between the student's home environment, the school, and the exosystem. At this level, all of the systems directly influence the students and interact with one another. It is the complex interaction of various microsystems. This intersection includes mechanisms for integrating STEM education into various environments, including the home, school, and work. For example, there should be efforts to connect the curriculum, the school learning environment, and the home to support STEM learning. The teachers do not carry the whole burden of STEM education, and therefore parents must also encourage their children to pursue STEM activities, by increasing awareness and interest at home, and supporting co-curricular activities in STEM education. STEM initiatives outside of school can help students understand that STEM transcends the classroom. Therefore, having activities that show real-life implication of STEM can pull together the ideas presented in school and help to show how they benefit our society and even our world as a whole. Students are able to see that what they are learning now is pertinent to their future and the future of the whole world, creating an interest often lacking when learning new concepts that do not seem to carry real-world application. The mesosystem is where everything must align to support the instructional environment for all students. For example, prior to instructing students, schools must vision, plan, and provide teachers with needed materials and resources. Teachers also must be provided with training to facilitate an understanding of STEM curriculum and approaches, use of modern instructional tools and technology. Therefore, schools and teachers must prepare the learning environment. At the mesosystem level, there should be an effort to develop and/or adopt accessible curricula, instructional technologies, and instruction for all students, including those with disabilities. These efforts should build understanding across the various systems while effectively engaging students in authentic STEM education. Overall, the teacher must be committed to instruction that is conducive to learning of STEM, in terms of lesson planning, interdisciplinary collaboration, use of instructional and assistive technology, and embedded professional development.

Exosystem: this layer defines the larger social system in which the student does not function directly but represents the interconnected systems that affect the student (Bronfenbrenner, 1979). The structures in this layer impact the student STEM development by interacting with some structure in the microsystem. The student may not be directly involved at this level but does feel the positive or negative force emanating from the interactions at this level. An exosystem is where the State, regional, and community impact on STEM is important. For example, the student does not directly interact with institutions of higher education that provide support and professional development to teachers of STEM. However, the student interacts with the teacher providing the STEM instruction. Furthermore, educators alone cannot support STEM education initiatives, and for a STEM initiative to succeed, people must come together and provide supportive networks and partnerships for the initiatives. The exosystem generally reacts to cultural, economic, and social beliefs represented in the macrosystem. Within the country and regions, groups came together to discuss how to support initiatives for quality improvement of STEM education. These groups, partnerships, and networks coordinate communication, while supporting field-based design and implementation of innovations in STEM education. The communication could be done through resource persons, using online technologies in regular conference calls and periodic face-to-face meetings. Regional partnerships are the most valuable resources for supporting a STEM environment because they can leverage support for initiatives, provide a wealth of ideas, and change a community's understanding about the importance of STEM education. These partnerships can provide access to community stakeholders to pull together resources and expertise. The partners participate in activities such as providing space for professional development in STEM settings, advocacy, and outreach activities involving community members and national leaders.

Macrosystem: this layer may be considered the outermost layer in the student's environment. It comprises cultural values, customs, and laws in the society (Basham, Israel, & Maynard, 2010). The effects of larger principles defined by the macrosystem have a cascading influence throughout the interactions of all other layers. For example, if it is the belief of the culture that girls are not meant to pursue STEM careers, then culture is less likely to provide resources to support girls' engagement in STEM education. The primary focus for STEM education is to increase STEM literacy, enhance critical thinking, support higher student achievement, and prepare students for the 21st century workforce (Obama, 2009). Therefore, the macrosystem represents the cultural and political objectives that drive the educational priorities related to STEM. At the most global level, STEM education initiatives reflect the interplay of cultural, economic, and social beliefs and the political objectives that emerge from those beliefs. For example, if a country is concerned about the economy, global competitiveness, and how these are related to student achievement on STEM subjects, then it is likely that STEM education will gain higher priority in education planning and policy. Therefore, this study explored whether STEM education at the basic learning levels in Africa has been prioritised at the national education planning and policy level. With STEM education planning and policies in place, the local education systems respond by developing frameworks and mechanisms to initiate the expected changes in the system.

Chronosystem: this refers to the time frame of all the events that over time affect people throughout their life cycles including transitions, trauma, and physiological changes (Bronfenbrenner, 1979; Stewart, 2000). In this context, the chronosystem includes the dimension of time as it relates to a student's environment. Elements within this system include environmental events that occur throughout the student's life including social and historical events such as the physiological changes in a student because of the aging process. As students get older, they may react differently to environmental changes and may be able to determine how those changes influence them better. For instance, as students mature and get more exposed, they could gather more understanding, enabling them to be more focused on their future career choices.

2. LITERATURE REVIEW

2.1 Introduction to STEM education

This chapter reviews literature on STEM education at basic learning levels, with a presentation on the meaning of STEM education and a brief background on the global and regional perspectives on development of STEM education, while justifying the momentum towards a greater focus on this sector, particularly in Africa. The review will further be guided by the objectives and thematic areas in this study including a) trends in student enrolment and performance in STEM subjects; b) interventions in STEM education including policies, strategies, and funding; c) impact of interventions on STEM education; d) challenges facing STEM education; and e) recommendation for improving quality of STEM education at the secondary school education cycle in Africa.

2.1.1 Meaning of STEM education

The term STEM, which stands for the disciplines of Science, Technology, Engineering, and Mathematics (STEM) was introduced in 2001 by the National Science Foundation (NSF) of the United States of America (USA) (National Science Foundation, 2007). It refers to the education, curriculum, and careers that integrate knowledge and skills from these disciplines. STEM education was defined in the 2012 report on 'Science, Technology, Engineering, and Mathematics, (STEM) Education: A Primer', as:

"Teaching and learning in the fields of science, technology, engineering, and mathematics. It typically includes educational activities across all grade levels—from pre-school to post-doctorate—in both formal (e.g., classrooms) and informal (e.g., afterschool programs) settings" (Gonzalez & Kuenzi, 2012:1).

Findings of numerous studies on STEM education indicate that, most people, including educators and learners do not understand much about STEM education, what the acronym STEM stands for, and what subjects are offered for STEM system of education (White, 2020).

2.1.2 Overview of global perspective on STEM education

The field of STEM education gained greater focus from the 2000s in the United States when these disciplines started to be more integrated after more understanding of the strong linkage between prosperity and jobs that were increasingly based on science and technology, and the need for innovations to address emerging challenges in society (Gonzalez & Kuenzi, 2012; OECD, 2016). Despite this realisation, the performance of students in the United States in STEM disciplines was found to be low, compared to those in other countries, based on international comparative studies including the Programme for International Student Assessment (PISA) and Trends in International Mathematics and Science Study (TIMSS). Furthermore, evidence was gradually emerging that a country that does not accord greater attention to STEM education will have a poorly prepared workforce and cannot compete in the global economy (OECD, 2016). Therefore, concerted efforts to address STEM education in the United States brought together not only the academia, but also the political leadership and philanthropists, among other key stakeholders. For instance, a bipartisan congressional STEM education Caucus was formed in the USA in 2001, which noted that:

"Our knowledge-based economy is driven by constant innovation. The foundation of innovation lies in a dynamic, motivated, and well-educated workforce equipped with STEM skills" (Mansfield, 2020:5).

On the other hand, philanthropists, academia, and government agencies in the USA commissioned studies to gain a deeper understanding of what entailed STEM education, which careers had a bearing on STEM education, and how the education system could deliver a high-quality STEM integrated curriculum for the workforce of the future (Carnegie Mellon University, 2020). These initiatives had notable impacts, for instance, from 2000 to 2010 the growth in STEM jobs in the USA was at three times the rate of growth in non-STEM jobs (U.S. Department of Commerce, 2020).

At global level, STEM education has taken the centre stage in human development discourse and several international commitments recognising the place of science, technology, and innovation in sustainable economic development. Indeed, Science, Technology, and Innovations was a central theme of the United Nations seventieth session on 'Transforming our world: the 2030 Agenda for Sustainable Development' of 2015, and specifically the Sustainable Development Goals (SDGs) 1, 2, 4, 5, 7, 9, 14, and 17 (United Nations, 2015). This strong commitment at the global level is further demonstrated by the fact that over 23 Agencies, Committees, and Divisions of the United Nations have a specific focus on Science, Technology, and Innovations as a cross-cutting area in their mandates (United Nations, 2020).

Meanwhile, in the global North, the STEM agenda has expanded in other countries beyond the USA, with programmes developed in Japan, Australia, China, France, South Korea, Taiwan, and United Kingdom, among other countries, with the aim of increasing STEM skills and expanding the workforces of scientists and engineers (OECD, 2016). For instance, the European Union have recognised Science, Technology, and Innovation (STIs), as the foundation for achieving high-quality education, lifelong learning, knowledge-based society, and long-term prosperity (European Union, 2010). Towards this end, the European Union has launched several initiatives including the European Research Area (ERA) to map Europe's performance in high-tech industries, knowledge-based services, patenting, and human resources in science and technology as a strategy for strengthening technology and innovation competitiveness of Member States (European Union, 2010). The focus on STEM as a foundation for economic development is further demonstrated by the high priority placed on this sector in Japan, where both a Minister of State charged with the STI policy and a Council for Science, Technology and Innovation under a Director General are established under the Cabinet Office of the Prime Minister (Government of Japan, 2020). Therefore, globally, the commitments on STEM agenda have led to an increase in the number and scope of initiatives in this sector with the aim of preparing the workforce for the competitive global economy (Ahmed, 2016).

2.1.3 Overview of African perspective on STEM education

At the continental level, the African Union has in the Africa Agenda 2063 Framework Document for African Renaissance recognized the shortage of STEM skills in Africa (African Union, 2015). However, unlike the global North where elaborate laws, plans, legislations, policies, and strategies on STEM education at all levels in the systems have been established, African countries lack robust plans, strategies and policies on STEM education, or even clear frameworks for their implementation (Ahmed, 2016; Jamme, 2020). It is not even clear if some national leaders understand the meaning, importance, and implication of STEM education on their economies and workforce (Jamme, 2020). For instance, thousands of expatriates from the developed countries are working in high-skilled STEM jobs in Africa, while the leaders and citizens in these countries continue to complain about the lack of jobs for youth in Africa (Jamme, 2020). Therefore, there is a need for the African countries to support foundational mathematics and science as they play a critical role in the development of scientists, engineers and technologists that are the backbone of industrialisation, and economic growth (Asabere & Mereka, 2009; Jamme, 2020).

The term STEM is not yet widely understood in Africa and its implementation in education systems is currently poor even though there are many STEM programmes funded by both governments and development partners. Meanwhile, over the next decade, it is estimated that there will be thousands of job openings in Africa that will require basic STEM literacy (Ahmed, 2016). Therefore, there is need for more reflection and commitment by government and leaders in Africa on the current education policies and whether they are adequately responsive to STEM education. At the very basic level, the critical barrier in promoting STEM subjects in Africa is the limited number of people adequately qualified in these subjects.

2.1.4 *Importance of STEM education*

STEM education creates critical thinkers, increases science literacy, and enables the next generation of innovators (Engineering for Kids, 2020). There is now greater consensus that embedding mathematics, science, technology, and engineering concepts in the curriculum, will better prepare students for courses and careers in STEM fields leading to innovations of new products and services that will sustain future economies (Koketso, 2015). Furthermore, the United States Department of Commerce estimates that STEM occupations are growing at 17% annually, while other occupations are growing at 9.8%; and that STEM degree holders have higher incomes (U.S. Department of Commerce, 2020). Science, technology, engineering, and mathematics workers play a key role in the sustained growth and stability of a country's economy.

Most jobs of the future will require a basic understanding of mathematics and science. Despite these compelling facts, there lacks in Africa, an adequate understanding of the status of STEM education, and level of preparedness for implementation of comprehensive STEM education programmes (Matachi & Kosaka, 2017; The Planet Earth Institute, 2016). STEM is important because it pervades every part of our lives. Science is everywhere in the world around us. Technology is continuously expanding into every aspect of our lives. Engineering is not only the basic designs of roads, bridges, automobiles, buildings, but also tackles the challenges of the changing global weather and environmentally friendly changes to our homes. Mathematics is in every occupation, every activity we do in our lives. By exposing students to STEM and giving them opportunities to explore STEM-related concepts, they will develop a passion for it and hopefully pursue a job in a STEM field. A curriculum that is STEM-based incorporates real-life situations to help the students learn better as noted by the National Science Foundation (NSF):

> *"In the 21st century, scientific and technological innovations have become increasingly important as we face the benefits and challenges of both globalization and a knowledge-based economy. To succeed in this new information-based and highly technological society, students need to develop their capabilities in STEM to levels much beyond what was considered acceptable in the past"* (National Science Foundation, 2020:3).

STEM education in school is important to spark an interest in pursuing a STEM career in students. Better STEM education before the college level will motivate students to enrol in these courses and perhaps decide to pursue a career in related fields. Moreover, they will be more confident about their studies in general and far less likely to drop out. Meanwhile, every job includes a financial aspect, and mathematics education becomes critical for everyone. Furthermore, we live more and more in the digital age, so technology is important in all jobs, even if one were to end up in the humanities and the arts, as computer skills are now required in every career. Additionally, the world is changing rapidly, and digital technology has become a core part of our everyday lives. Advances in technology impact everything, especially the world of work where entire job sectors are emerging or disappearing, and workforces are rushing to keep up with changes. Automation and globalisation are changing the way we think about, and define, careers.

Making everyone mathematically and technologically literate is the goal of technology and engineering education and that is why it is being addressed not only at the global level but nationally as well. Teachers should never focus solely on those learners who have prospects to "succeed" in the STEM field and who are gifted. Their goal should be to make all children technologically and mathematically literate. Aside from STEM careers, STEM-related knowledge can help us learn about our environment and society. For instance, we can understand phenomena better if we understand STEM, from the weather to technology and electricity, even political trends. Therefore, studying STEM-related subjects can broaden the horizons of the mind. The key is solving problems creatively, questioning things, seeking the truth, and always being eager to explore more about how things work.

In order to be a good scientist, you need to be creative and imaginative. And while the arts and imagination are often set aside as not that important for children, it is a great thing to know that by learning STEM, a child also practices these aspects of their thinking. Good STEM education must not be boring, simplistic, and focused only on the pure facts of mathematics or science. It should be multidisciplinary, incorporating other skills and geared towards all children, so they can learn and enjoy.

Employment is becoming fluid, and people will go from having one profession to several in their working life. These may be entirely different roles, across entirely different sectors. As the world of work changes, we will need to change our skills to match. The gap between the knowledge generated in the education system and the skills demanded by employers and individuals is widening. Overcoming these limitations requires a priority focus on science, technology, engineering, and mathematics (STEM), including the development of workplace skills in STEM. Future careers will also rely heavily on ‘21st century skills’ including critical thinking, creativity, cultural awareness, collaboration, and problem-solving. When done well, STEM education complements the development of 21st century skills. It is predicted that future workers will spend more than twice as much time on job tasks requiring science, mathematics, and critical thinking than today. The importance of STEM is immeasurable because application of STEM is required in areas deemed to be non-scientific. Almost all occupations need some scientific application in order for them to thrive, for instance, accounting, machinery, stock taking. The importance of STEM education in enhancing skills for critical thinking and problem solving cannot be over-emphasised.

2.1.5 STEM subjects at Secondary Education Cycle

At basic learning level of education, different country curricula specify subjects defined under STEM education. Although the term STEM is now commonly used in educational discourse, many educators and learners can neither tell what this term stands for nor the subjects that fall under this category (White, 2014). The science subjects cover a broad area of study including physics, chemistry, earth science, space science, biochemistry, microbiology, botany, zoology, computer sciences, and civil engineering (ibid). **Table 1** presents the range of subjects that are offered in the sample nine countries.

Table 1: STEM subjects offered at secondary school education cycle in sample countries

Subject	Angola	Botswana	Ghana	Kenya	Morocco	Namibia	Rwanda	S. Africa	Uganda
Agriculture	√	√		√			√		√
Agricultural Sciences					√				
Art and Design	√	√	√	√		√		√	
Aviation Technology				√					
Biology	√	√					√	√	√
Building & Construction				√			√		√
Chemistry	√	√		√			√	√	√
Clothing and Textiles									√
Computer Studies	√	√		√			√		√
Design and Technology		√	√					√	
Domestic Science						√			
Drawing and Design				√					
Earth Sciences	√				√				
Electricity				√					

Electricity & Electronics									√
Engineering Technology							√		
Environmental Studies	√		√						
Fashion and Fabrics		√							
Fine Art	√								√
Food and Nutrition		√							√
General science									√
Health Education	√					√			√
Home Science				√			√		
ICT		√					√	√	√
Industrial Design					√				
Integrated Science	√		√						
Life Sciences					√			√	
Mathematics	√	√	√	√	√	√	√	√	√
Metalwork				√					√
Natural Science				√	√	√		√	
Physical Sciences					√			√	
Physics	√	√		√	√		√		√
Power and Energy									√
Power Mechanics				√					
Technical Drawing									√
Technology						√		√	
Woodwork				√					√
Total	12	11	5	15	8	6	10	10	18

2.1.6 Summary of STEM subjects offered

At the basic learning level of education, different countries in Africa offer relatively the same subjects in STEM education. Mathematics, for instance is universally included on every list of STEM subjects. Meanwhile there is a marked difference in the range and scope of science, and technical subjects across the countries, particularly in the technical subjects.

2.2 Enrolment and Performance in STEM education

2.2.1 Enrolment in STEM

Several comparative indicators shows that Africa still lags other regions in access to STEM education, and massification of STEM education is seen as one of the strategies to enable Africa catch up in preparation for the future (Formunyam, 2020). Additionally, it is becoming increasingly apparent that Sub-Saharan African countries have to focus on improvement in performance in Science, Technology, Engineering and Mathematics (STEM) subjects to fully benefit from the opportunities presented by a global economy that is increasingly being driven by new and advanced technologies (Bethell, 2016). Massifying STEM education in Africa will involve creating access through several strategies to increase the number of graduates in STEM courses at institutions of higher education, resulting in the growth of a more skill-intensive, and diversified African economy (ibid). In efforts to increase enrolment in general, several African countries have introduced education policies and programmes at the basic education level that have led to an increase in student enrolment at different levels of the education system (Fomunyam, 2019; Majgaard & Mingat, 2012; Tikly, et al., 2018). However, although information on general trends in enrolment is available from periodic education statistics, this is not consistently reported and, in some cases, it is missing altogether.

Table 2 presents both the Gross Enrolment Rate (GER) and Net Enrolment Rate (NER) at secondary school level for some of the sample countries which shows that there is still a challenge in achieving universal access to secondary education. This has a negative spillover effect on student enrolment in STEM courses at the secondary school level, institutions of higher education, and STEM careers. For instance, while Botswana, like several other African countries has achieved a high enrolment rate at primary school level, students' transition to higher levels of education is low, with relatively high dropout rates at transition stages (The World Bank, 2014).

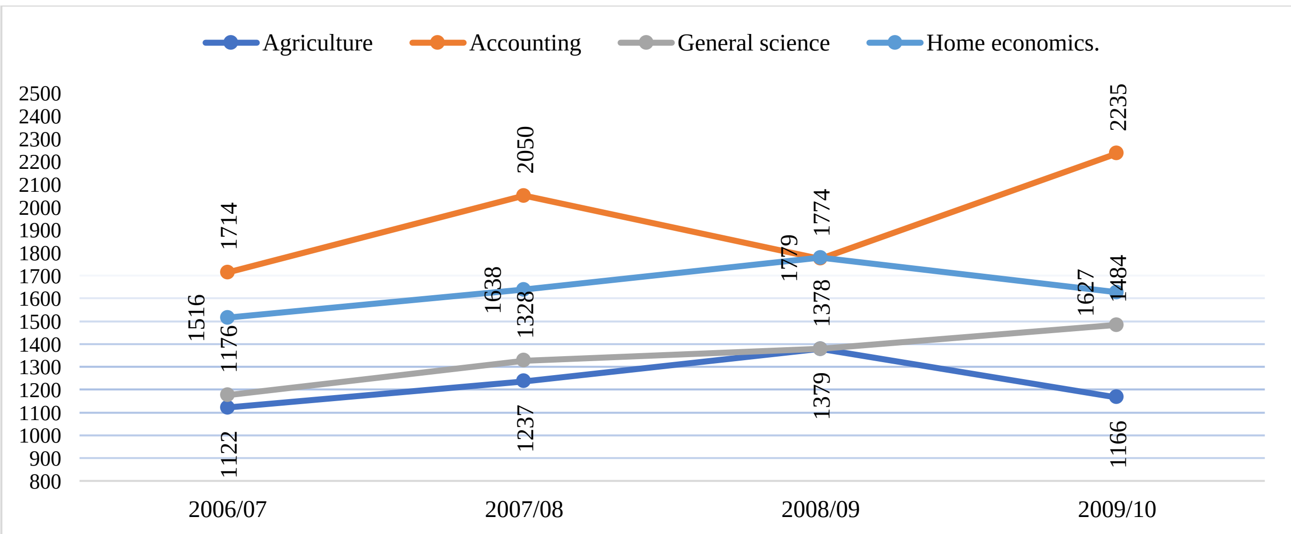
Table 2: Gross Enrolment Rate (GER) and Net Enrolment Rate (NER) at Secondary School Level

Enrolment	Angola	Botswana	Ghana	Kenya	Morocco	Namibia	Rwanda	South Africa	Uganda
GER (%)	50.7	….	74.7	70.3	81.2	….	44.3	100.5	….
Year	2016	….	2019	2018	2019	….	2019	2018	….
NER (%)	11.3	51.2	60.3	53.2	66.2	….	35.8	68.4	….
Year	2010	2017	2019	2018	2019	….	2019	2018	….

Sources: World Bank Education Statistics, UNESCO Institute of Statistics (UIS), Kenya Domestic Health Survey, UNICEF Basic Education Sector in Botswana

Specific to STEM education at the secondary school level, there is very little information that could clearly demonstrate student enrolment trends in STEM subjects in Africa. The little data that is currently available is focused on comparative analysis of access to STEM education at sub-geographies or gender within a country. For instance, a comparative analysis of enrolment in STEM by subjects in Upper West Region of Ghana between 2006 and 2010 shows no discernible change in the number of students enrolled in these subjects over the four-year period (**Figure 2**), except for minimal increments in general science and accounting (Donkor & Justice, 2016).

Figure 2: Trend in student STEM subject enrolment in Upper West Region Ghana



A study in Kenya shows that in 2005, enrolment in Arts and Humanities courses in both private and public Kenyan universities was 80% of the total enrolment, declining slightly to 78% in 2010, but was still more than 75% in 2016, which implies that only a few students were enrolled in Science, Technology, Engineering, and Mathematics (Republic of Kenya, 2018; Blom, Raza, & Kiamba, 2016). Additionally, enrolment of females in higher education is lower than males at all levels of training, especially in STEM programmes (Republic of Kenya, 2018**).** Furthermore, despite increased student enrolment at secondary school level in Kenya following the subsidized secondary education introduced in 2008, student enrolment in Physics remains low compared to Biology and Chemistry, and girls are more afflicted than boys (Omar, 2017; Mwangi, Gongera, & Thinguri, 2013). In Uganda, female students are underrepresented in STEM education, and in 2017 for instance, only a paltry 9% were enrolled in STEM courses at Makerere University (Watera, 2018).

As aforementioned, student enrolment in Universities in Sub-Saharan Africa has increased rapidly in the last two decades, for instance, in South Africa, enrolment increased from 590,000 to 938,000 from 1996 to 2011, an increase of 60% and a similar trend was noted in Kenya with a double intake of student from form four and form six in 1991 (Formunyam, 2020). However, Kigotho (2019) in Formunyam (2020:255) notes that despite an increase of 196% in student enrolment in universities in Sub-Saharan Africa between 2000 to 2015, student enrolment in STEM programmes in West Africa is still low at 9% and this needed to be increased for Africa to claim a position in the global STEM agenda.

Admittedly, there is need to identify and address factors that hinder increased student enrolment into STEM programmes in Africa. Tikly et al (2018) has identified low student attainment at secondary level in Africa as a key factor for the low enrolment at post-compulsory level. In South Africa, enrolment at the secondary level has been expanding but transition to tertiary education is low. The low enrolment in institutions of higher education has been attributed partly to the low quality of basic education, for instance, in 2017, only 55% of South Africa's learners successfully completed secondary school education (Mlachila & Moeletsi, 2019). Likewise, in Botswana, a common trend is that as girls register for courses at the senior secondary level, they drop the pure sciences and opt for the integrated sciences, which denies them an opportunity for admission into some STEM courses at institutions of higher education (Mpuchane, 2002).

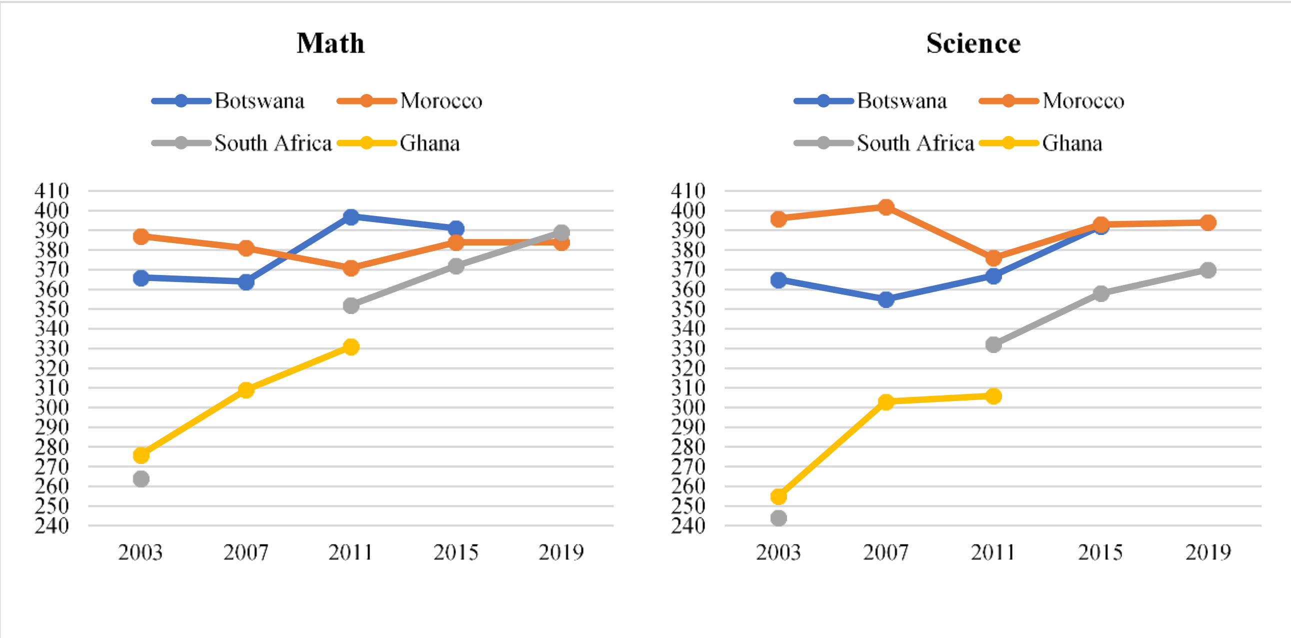
Despite the lack of sufficient data on student enrolment in STEM subjects at the basic learning levels, these trends could be illustrative of the situation in most African countries. The implications are that access to STEM education at the basic learning levels is low; secondly, countries in the region need to deploy a sustainable mechanism for conducting national comparative analysis on trends in enrolment in STEM subjects, disaggregated by relevant attributes including gender, subjects, and sub-geographies; and thirdly, this information should be disseminated widely to key stakeholders to stimulate discourse for addressing any undesirable trends that could be impending massification of STEM in the region, that may emerge from the analysis.

2.2.2 Learner Academic Achievement in STEM

Over three decades ago in 1985, Ogunniyi (1985) in Oluka (2017: 62) raised a concern on the declining performance in mathematics and science education at the basic learning level in Africa, as well as the lack of focus on applicable knowledge and skills (Oluka, 2017). This situation has persisted, without any notable changes over this span of time, and has remained a significant barrier to improved economic and social outcomes of both individuals and African countries (Oluka, 2017; Bethell, 2016). However, like student enrolment in STEM, there is insufficient data to clearly demonstrate trends in student performance in STEM in general at the basic learning levels in Africa. Despite the lack of consistent longitudinal data on performance in STEM subjects at the secondary school level in Africa, the available information points to persistent poor performance in these subjects.

Since 2003, four of the nine countries in the sample including Botswana, Ghana, Morocco, and South Africa have participated in the four yearly Trends in International Mathematics and Science Study (TIMSS) that assesses fourth and eighth grade students' achievement in mathematics and science. **Figure 3** presents the trends in TIMSS for mathematics and science at grade eight for these countries for five waves of assessment, which shows that overall, there have been marginal improvements in mathematics and science scores in TIMSS from 2003 to 2019 for some of the countries (TIMSS& PIRLS International Study Centre, 2020). However, all four countries scored below the benchmark of 500 and were all ranked in the bottom quartile in the league. For instance, in 2003, Ghana performed very poorly for the grade 8, equivalent to Junior Secondary School (JSS) assessment and was ranked in the 44th position among 45 countries that participated in the assessment. In the TIMSS 2011 science (Biology, Chemistry, Physics, and Earth Science) assessment, Ghana was again ranked in the last position 42. It is also worth noting that three of the countries have not participated consistently in all the assessments across five waves from 2003 to 2019. Aside from TIMSS, only Morocco in the sample participates in the Programme for International Student Achievement (PISA) that assesses reading, mathematics, and science competencies of 15-year-olds. Another cross-country comparative study in Africa is the Southern and Eastern Africa Consortium for Monitoring Educational Quality (SEACMEQ) that covers 16 countries and assesses literacy and numeracy at grade six. In addition, the Programme for the Analysis of Education Systems (PASEC) that assesses reading and mathematics at elementary grades covering 10 countries in Western Africa (SEACMEQ, 2020; PASEC, 2020). Notably, both SEACMEQ and PASEC focus on the primary school grades and aside from the global TIMSS and PISA, there is currently no cross-country assessment initiative at the secondary school education cycle in Africa.

Figure 3: Performance in TIMSS at Eight Grade by County



Source: IEA TIMSS and PIRLS International Study Centre (https://www.iea.nl)

The following are snapshots of performance in mathematics and science in the sample countries.

Botswana

The economy of Botswana has been performing relatively well among African countries since the 1960s to a point where Botswana has attained the upper middle-income status (The World Bank, 2019; Republic of Botswana, 2017). In the process, Botswana has created an education system with a high degree of equity in resource allocation, with resource flows to remote rural schools almost at par with urban schools, which has made it possible to sustain the economic growth (The World Bank, 2019). Furthermore, Botswana has made a steady improvement in both the 2015 and 2019 TIMSS assessments. However, the main challenge facing the education sector is low quality of education at all levels as evidenced by falling performance in national examinations and low ranking in the TIMSS international assessments (Republic of Botswana, 2015; The World Bank, 2019).

Ghana

In Ghana, results of the 2015 West African Senior Secondary Certificate Examination (WASSCE) were poor in core and elective science and mathematics subjects (Republic of Ghana, 2018). Furthermore, although performance in TIMSS has progressively improved from 2003, it is still low, and Junior Secondary School students in Ghana were found to be weak in all content areas across the STEM subjects (Mensah, Mereku, & Ameyaw, 2004). This poor performance at Junior Secondary School level poses challenges at Senior High School as there is a strong correlation between low performance at basic and senior levels in Mathematics (Abotowuro, 2015). Meanwhile, performance in general science at Basic Education Certificate of Education (BECE) for the period of 1995 to 1997 shows gender differences in favour of boys, and some of the factors that are associated with the poor performance are poverty, lack of interest in the subject, and lack of female role models in STEM (Anderson, 2006; Koketso, 2015).

Namibia

The poor performance in mathematics and science at the secondary school level starts much earlier and could be a pointer to a poor foundation in these subjects in earlier grades. Notably, student performance in mathematics has been poor particularly at the upper primary school level which needs remedial action at the foundational grades (Ilukena, Haimbodi, & Sirinji, 2018). Additionally, poor performance in mathematics and science at grade 12 in Namibia has been attributed to various factors including students' lack of interest in these subjects (Tuaundu, 2013). Olivier et al (2009) in Tuaundu (2013:2) note that Physical Science was the worst performed subject at grade 12 in Namibia in 2012, with less than 35% of Ordinary level candidates obtaining a score of 40% that is a benchmark for a pass.

Kenya

The quality of education is of concern as is evident from the consistent low scores in mathematics and science in national examinations at secondary school level (Lucas & Mbiti, 2014). The key factors for the poor performance include deficiencies in teacher ability, inadequate teaching and learning resources and facilities, and students' negative attitudes towards the subjects (Yara & Wanjohi, 2011; Mbugua, Kibet, Muthaa, & Nkonke, 2012). Meanwhile, poor attitudes towards mathematics and science, and stereotypes regarding girls' poor ability in these subjects contributes to the actual underperformance and non-selection of science subjects as electives (Awuor, 2013; Kashu, 2014). Furthermore, girls enjoy mathematics and science when the subject content is relevant and delivered in context (ibid). Existence of female role models within their context also contributes to the acceptance and valuing of science subjects (Awuor, 2013; Yara & Wanjohi, 2011).

South Africa

Like Botswana, South Africa has made improvements in the results of the 2015 and 2019 TIMSS assessment. Despite these achievements, the quality of education generally and STEM education specifically is an area of concern; and the low outcomes at secondary and higher learning levels were noted to begin at the primary school level of learning (Mlachila & Moeletsi, 2019). The examination outcome determines students' opportunities to continue into higher learning or entry into the world of work and poor performance in these subjects denies them life opportunities (Farley, Rose, Cavazzini, Gerard, Golubski, Robinson, & Wang, 2011).

Uganda

Despite some of the Ugandan government efforts to train mathematics and science teachers, and build modern science laboratories, students continue to attain poor performance in these subjects, and this has been linked to poor teacher pedagogical practices and lack of science equipment and apparatus (Ssempala, 2017). The number of students taking science and mathematics subjects at upper secondary remains low. For instance, the Uganda National Examination Board (UNEB) raised a concern that out of the total candidates who sat for the ordinary 'O' level examination in 2014, only 20% were offered Mathematics, 14% Physics, and 12% Biology at the advanced 'A' level (UNESCO, 2017). Girls' performance is lower than boys, for instance, in 2011, 71% of girls failed in chemistry at the ordinary level compared to 63% of the boys (ibid).

The poor performance in STEM disproportionately affects girls more than boys. Gachukia and Kabira (1991) in Koketso et al ((2015:18) asserts that females in Africa are characterised by lower performance in STEM education compared with boys. Likewise, Ottevanger et al (2007) and Martin et al (2016) in Tikly (2018: 42) note that performance in STEM education at the basic learning level demonstrates gender inequality, in favour of boys, and this is extensively manifested in many STEM classrooms across Sub-Saharan Africa. Several factors have been associated with poor performance in mathematics and science at secondary school level in Africa. These include insufficient number of teachers of mathematics and science; under-qualified teachers; teachers sense of demotivation due to lack of recognition and status; shortage of teaching and learning resources and facilities; and poor teacher pedagogical practices (Barrett, Gardner, Joubert, & Tikly, 2019; Gwaza, 2015; Komakech & Osuu, 2014). Other equally important factors include lack of parental support; lack of pedagogical support for teachers; students' and teachers' difficulties with the language of instruction; and students' poor attitude and interest in mathematics and science (Anderson, 2006; Barrett, Gardner, Joubert, & Tikly, 2019; Gwaza, 2015; Kedikilwe, 1993; Koketso, 2015; Komakech & Osuu, 2014). In efforts to improve performance in these subjects, countries in the region should embark on comparative analysis of national examinations using rationalized benchmarks to identify undesirable trends in performance that could be addressed through targeted interventions. Secondly, the countries in the region should start initiatives on cross-country assessment of mathematics and science at the secondary school level as strategy for accelerated process in achieving quality in STEM education. In addition, countries in the region should address identified challenges by designing comprehensive, targeted, and sustainable interventions to address the root causes of poor performance in these subjects.

2.3 Challenges of achieving quality in STEM education

A range of challenges confront achievement of quality in STEM education at basic learning levels in Africa. Review of documents identified systemic challenges related to teachers, students, and education managers from school leadership level to the national policy makers. The specific challenges included: a) inadequate teaching and learning resources and facilities; b) poor teacher pedagogical practices; c) student lack of interest in the subject; and d) insufficient number of teachers of STEM subjects.

2.3.1 Inadequate resources and facilities

Several studies and reports reveal that teaching and learning resources and facilities are either insufficient or lacking altogether at secondary school level in most Sub-Saharan African countries. A study in Namibia found that student academic performance in Biology at Grade 12 was affected by lack of relevant teaching and learning resources including laboratory equipment (Muyoyeta, Abah, & Denuga, 2017). The resources and facilities that were frequently mentioned as lacking or inadequate included: science laboratories, laboratory apparatus and equipment, ICT infrastructure, classroom buildings and furniture, course books, and stationery (Carr & Kemmis, 1989; Duarte, Tillostson, & Jankowski, 2018; Goel & Burton, 1996; Kahaawa, 1996). Indeed, a study on factors affecting provision of quality STEM education at the basic education level in Rwanda identified insufficient laboratory equipment as a major factor, with both teachers and students expressing this concern (Namara, 2018). The availability of textbooks influences the learning outcomes mostly in under-developed countries and given the prevalence of poor teacher pedagogical practices, adequate textbooks for learners have been found to enhance performance (Kioko, 1996; Garekwe, 1996; Republic of Ghana, 2014). Additionally, mathematics education in Sub-Saharan Africa faces shortage of textbooks which negatively affects learning since textbooks are the main and only tool for most teachers to effectively teach (Appiahene, Opoku, Akweittey, Adoba, & Kwarteng, 2014; Bethell, 2016; Republic of Ghana, 2014). Meanwhile, parents from low-income areas in Namibia like in most other African countries, are not able to offer their children essential school supplies, which negatively affects learning (Duarte, Tillostson, & Jankowski, 2018).

2.3.2 Poor teacher pedagogical practices

The second frequently identified challenge was poor teacher pedagogical practices which are due to several underlying issues including under-qualified teachers, gender stereotypes, as well as teachers' negative perception of the students' ability to learn mathematics and science. Teachers in Namibia for instance, were found to have negative perceptions and were pessimistic of the students' ability to learn mathematics concepts (Hamukwaya, 2019). Evidence also shows that teachers of mathematics, particularly male teachers lack adequate capacity in gender responsive pedagogy to the disadvantage of girls learning of this critical subject (Bethell, 2016; Tikly, et al., 2018; Kioko, 1996). For instance, teaching of mathematics was found to be gender biased in Botswana as competition was used as a strategy in the learning of mathematics, yet most girls were not comfortable competing in public (Goel & Burton, 1996; Garekwe, 1996). Negative stereotyping is also a great challenge to STEM education as it negatively influences performance by shifting an individual's focus from performing an assignment to worrying about how the performance could be linked to the group one belongs (Mukhwana, Abuya, Matanda, Omumbo, & Mabuka, 2020). For instance, some teachers were found to hold the perception that a girl who attains further education and performs extremely well in STEM subjects, specifically mathematics, will not get married because she is perceived as a non-submissive wife, thereby making some girls opt to fail to salvage their opportunities for marriage (Goel & Burton, 1996).

Despite the existence of teacher professional programmes in the region, inadequate funding implies that most of these programmes are still *ad hoc* and low in quality, and teachers lack quality professional development opportunities (Mensah, Mereku, & Ameyaw, 2004; Kashu, 2014). Meanwhile, the use of inquiry-based pedagogies that are appropriate for teaching and learning of mathematics and science has not taken root in Sub-Saharan African countries (Oluka, 2017).
Other challenges include women's general preference for non-STEM courses, overall negative attitude toward STEM, parents' expectations that fix students to certain academic courses, peer acceptance and inadequate academic preparation at lower levels (Mukhwana, Abuya, Matanda, Omumbo, & Mabuka, 2020).

2.3.3 Students lack interest in STEM

Girls were found to be highly influenced by their peers in making choices including which subjects to enrol (Goel & Burton, 1996). In most instances, girls view mathematics as difficult and masculine hence they pay little attention to the subject (Hamukwaya, 2019; Koketso, 2015; Garekwe, 1996). Evidence shows that students with elevated aspirations perform better in science and mathematics compared to those who do not have such aspirations (Mensah, Mereku, & Ameyaw, 2004). Furthermore, teachers believe that difficulties in learning mathematics are associated with a students' low interest in the subject (Hamukwaya, 2019). Therefore, student mentorship programmes could play a significant role in influencing students for higher uptake of STEM subjects and careers.

2.3.4 STEM curriculum

The relevance of the STEM curriculum has been questioned as, in some instances, there are no clear linkages in the curriculum between lower and higher levels, which results in students being inadequately prepared for the curriculum offered at higher levels (Duarte, Tillostson, & Jankowski, 2018). This was found to be the case for the Namibian mathematics curriculum which forces teachers to re-teach concepts that are covered in lower grade levels (ibid). Meanwhile, in Botswana, girls were reported to have the perception that mathematics was irrelevant to their future careers and therefore did not see the need to participate in it (Goel & Burton, 1996; Garekwe, 1996).

2.3.5 Inadequate number of STEM teachers

Many Sub-Saharan Africa countries have failed to attract adequate numbers of qualified applicants to train as teachers and those teachers who have been attracted to teach mathematics as a career receive inadequate training (Bethell, 2016). Furthermore, majority of the professional development programmes are not well developed to meet the needs of the teachers while the conditions of service have remained poor (ibid).

2.3.6 Effects of COVID-19 on STEM education

The COVID-19 pandemic has adversely affected learning globally, but the negative effect will disproportionately affect resources in poor countries, particularly in Africa. Education in Africa has not been spared as most countries closed learning institutions as a measure to prevent and slow down transmission, without alternative strategies for provision of learning (EdTech Hub, 2021). Although the full impact of COVID-19 is yet to be determined, a few studies and reports suggest major consequences. For instance, a study among teachers of STEM in Zambia revealed that closure of schools due to COVID-19 was likely to cause a drop in the pass percentage of Grade 12 secondary school students in the 2020 national examinations (Sintema, 2020) . Furthermore, a report by the European Commission indicates that COVID-19 will negatively influence both cognitive and non-cognitive skills acquisition, with long term consequences (Di Pietro, Giagi, Costa, Karpinski, & Mazza, 2020). COVID-19 has also exposed inequalities in provision of education in general. With the COVID-19 lockdowns, it became obvious that most children in Africa could not participate in remote learning due to lack of access to radios, television, computers, internet, data, and electricity (Human Rights Watch, 2020). On a positive note, COVID-19 has also accelerated adoption of remote online learning at all levels of education and has the potential to increase access (Mhlanga & Moloi, 2020). Undoubtedly, education authorities in African countries should invest more in digital literacy for both teachers and learners, and in high quality ICT infrastructure.

2.4 Interventions on quality of STEM education

All the countries in the review have education sector plans that have within them some interventions addressing the quality of STEM education. However, none of them has a stand-alone policy or plan on improvement of the quality of STEM at the basic education levels. Despite this shortcoming in lacking a specific targeted plan or policy for STEM at this level, the strategies and activities in the existing sector plans are indicative of the recognition by the respective education authorities of challenges in this sector and their commitment to address them. The following is a highlight of the key strategies and activities that are proposed in the education sector plans to improve the quality of STEM education at the basic learning levels:

i. curriculum review of the content, skills, and teaching approaches,
ii. recruitment, deployment, professional development, and retention of suitably qualified personnel in secondary STEM and ICT education sector,
iii. improvement of infrastructure in secondary schools to support STEM and ICT education,

iv. improvement of implementation of In-Service Teacher Training (INSET) for teachers of mathematics and science,
v. provision of in-service training on coaching and supervision for school head teachers,
vi. establishment of model schools of excellence in STEM,
vii. establishment of student mentorship programmes to increase uptake of STEM subjects,
viii. establishment of Science Resource Centres,
ix. strengthening the capacity of the Ministries of Education in quality assurance for mathematics and science education.

Several interventions aimed at improving the quality of STEM education are on-going and document review and online search revealed several of these interventions. Following are illustrative examples of these interventions in some of the countries in the region.

2.4.1 Botswana

Case 1

Country	Botswana
Organisation	Botswana International University of Science and Technology (BIUST)
Name of intervention	Outreach programme of the Botswana International University of Science and Technology
Goal	The overall goal is to increase students' uptake of STEM courses in tertiary institutions and STEM careers
Sponsor	Botswana International University of Science and Technology
Years	On-going initiative
Scale	National
Target groups	Secondary school students
Key activities	i. Visits by students to the Learning Arenas (Science Parks, Research Centres); ii. Feeder Chains: develop mathematics and science support chain linking primary schools, secondary schools and the BIUST. iii. Tele-conferencing: live interactive activities in solving mathematics and science problems. iv. Mentoring of primary and secondary school students. v. In-residence on-campus programme for primary and secondary school girls. vi. Enrichment residential 4-6 week on-campus residential programmes during vacations vii. National STEM Festival support; and viii. Science Circus to intensify academic readiness.

Case 2

Country	Botswana
Organisation	Steppingstone International and Design Squad Global
Name of intervention	STEM Education in Botswana: Girls Getting Geeky
Goal	The long-term goal to increase percentage of girls who complete secondary school transition to college or secure employment. By helping youth develop design process skills and apply them to different engineering challenges, the initiative addresses a gap in girls' education by training them on how to apply those tools to their own lives.
Sponsor	Multiple sponsors

Years	On-going initiative
Scale / Scope	In five centres in Botswana
Target groups	Orphaned and vulnerable girls ages 12-25
Key activities	One year, daily after-school programming, including school holidays, which includes STEM activities that foster innovation and empower girls to solve real-world problems and understand the impact of engineering in their local community and in a global context.

Case 3

Country	Botswana
Organisation	Dare to Dream Foundation
Name of intervention	Dare to Dream Foundation
Goal	The overall goal is to get young women and girls interested in STEM-preneurship, aviation, and aerospace business
Sponsor	Captain Kgomotso Phatsima, a lady commercial pilot from Botswana
Years	On-going initiative since 2008
Scale / Scope	National
Target groups	Young girls and teachers
Key activities / Strategies	Advancement of youth, women and girls in STEM, aviation and aerospace as well as entrepreneurship development through training on Coding and Robotics, Entrepreneurship, Life Skills, and Leadership Skills

Case 4

Country	Botswana
Organization	Women Engineers Botswana (WEB)
Name of intervention	Women Engineers Botswana (WEB)
Goal	Empower and engage young women in changing mindsets towards STEM as highly desirable for women
Sponsor	Bonolo Mpabanga, an Aerospace Engineer
Years	On-going initiative since 2016
Scale / Scope	National
Target groups	Women
Key activities / Strategies	Showcase women in engineering professions through a blog site, reach communities through mentorship programmes, science clubs, workshops, and panel discussions.

2.4.2 Ghana

Ghana has been implementing several initiatives to address the quality of science education with a particular focus on gender and rural/urban areas equality and equity in access to quality science education (Anderson, 2006).

Case 5

Country	Ghana
Organisation	Ministry of Education, Ghana
Name of intervention	Ghana Education Sector Strategic Plan 2018-2030
Goal	To promote quality of science education at the basic learning level
Sponsor	Republic of Ghana
Years	2018-2030
Scale	National
Key target groups	Students and Teachers
Key activities	i. providing well-equipped science laboratories to all Senior High Schools where these facilities are missing ii. analyzing data on performance trends in science and mathematics to inform implementation of future interventions, including for examination preparation iii. continuous INSET for teachers as part of the instructional calendar in integrating ICT in teaching iv. attracting mathematics and science graduates to upgrade their qualifications through a PGD and institute measures to maintain them in STEM shortage areas v. collating findings of previous research and conducting further research if required to identify reasons for low female enrolment in STEM vi. designing programmes to collaborate with women in STEM as role models for SHS girls vii. ensuring the implementation of the national policy on 60:40 admission ratio in favor of STEM

Case 6

Country	Ghana
Organisation	Ghana Association of Science Teachers (GAST)
Name of intervention	Ghana Association of Science Teachers (GAST)
Goal	To promote the quality of science education in Ghana through teacher professional development for effective teaching at the basic education level
Sponsor	Memberships and donors
Years	1956
Scale	National
Key target groups	Teachers of Science
Key activities	i. Training workshops for teachers of science content ii. Reviewing, revising, and developing resources for teaching and learning of science, including producing of textbooks for senior secondary schools that are contextually relevant and aligned to the curriculum in Ghana

Case 7

Country	Ghana
Organisation	Centre for School and Community Science and Technology Studies (SACOST)
Name of intervention	Pan-African Research and Materials Development Centre for The Promotion of Community Science and Technology in African Schools
Goal	To promote quality of science education through community science and technology in African schools
Sponsor	University of Education at Winneba, Ghana
Years	Founded 2000
Scale	National
Key target groups	Students, teachers, community members
Key activities	Linking school science and technology with the community and workplace through materials development and research

Case 8

Country	Ghana
Organisation	Ghana Robotics Academy Foundation
Name of intervention	Robotics Inspired Science Education (RiSE)
Goal	The overall goal is to develop science, engineering and technology skills in young Ghanaians
Sponsor	Multiple
Years	Ongoing since 2011
Scale / Scope	National
Target groups	Students (Secondary school & College), Youth, and Teachers
Key activities / Strategies	i. Hands-on experience building robots and programming robots to perform task including locomotion, grasping, audio and video signal, and voice recognition; ii. Students learn about teamwork, project management, problem solving, and communication skills in a stimulating setting.

Case 9

Country	Ghana
Organisation	Siemens Stiftung
Name of intervention	International education program Experimento
Goal	The overall goal is professional orientation of educators in STEM to create opportunities for the future
Sponsor	Siemens Stiftung and other Donors
Years	Ongoing since 2019
Scale / Scope	Local (Accra Ghana)
Target groups	15 Educators; 1600 children
Key activities / Strategies	Professional orientation of educators based on Ghana's national curriculum to increase basic knowledge for later career choices, enabling teachers to bridge the gap between classroom STEM lessons and professional opportunities

Case 10

Country	Ghana
Organisation	UNESCO Accra Office and Ghana Education Services
Name of intervention	STEM clinics to boost girls' participation in STEM education in Ghana
Goal	To increase girls' participation in STEM-related courses in secondary schools and higher levels of education
Sponsor	Siemens Stiftung and other Donors
Years	2016-2017
Scale / Scope	Five Districts
Target groups	Girls in Secondary Schools
Key activities / Strategies	Quarterly STEM clinics in selected districts in Ghana to sensitise girls on STEM-related careers that girls can pursue (e.g. teaching, medicine, laboratory work, or telecommunications engineering), and mentorship activities to increase girls' interest and uptake of STEM subjects through interactions with women role models to boost girls' confidence about participating in STEM-related courses, and helps to challenge the negative perceptions they may have about pursuing a career in STEM.

Case 11

Country	Ghana
Organisation	Sabre Education
Name of intervention	Quality education for kindergarten children
Goal	To nurture essential foundation skills for children to succeed in their education
Sponsor	Tullow Ghana Ltd
Years	Since 2016
Scale / Scope	Local (Six fishing communities of Western Ghana)

Target groups	4–5-year-olds Kindergarten children in six fishing communities of Western Ghana
Key activities / Strategies	i. Play-Based Pedagogy: teachers are trained to promote the development of basic STEM skills in children through a variety of fun and playful activities offered to children. ii. Water Centre: children play and explore with a variety of items in the water. iii. Nature Walk: children are taken on walks to recognise examples of natural things and man-made things. iv. Construction Centre: children practice building houses, bridges, vehicles and other items with the construction blocks. v. Numeracy (Mathematics) skills are introduced using different learning resources, for example number cards. vi. Number Talk: teacher helps children to talk about numbers in fun ways.

Case 12

Country	Ghana
Organisation	Accra Central Library
Name of intervention	STEM Study Hub
Goal	To support the city's secondary school students in their study of STEM subjects (science, technology, engineering, and maths) with a particular focus on encouraging more girls to pursue further study and careers in STEM.
Sponsor	Ghana Library Authority and Book Aid International
Years	Since 2019
Scale / Scope	Local (Accra)
Target groups	Secondary school students in Accra
Key activities / Strategies	Books donations, training librarians to strengthen their skills in supporting students in studying STEM subjects, undertaking research in the library, revising and how to tackle tricky examination questions.

2.4.3 Kenya

Case 13

Country	Kenya
Organisation	Ministry of Education
Name of intervention	National Education Sector Strategic Plan 2018-2022
Goal	Provision of quality STEM education
Sponsor	Republic of Kenya
Years	2018-2022
Scale	National
Key target groups	Students and Teachers
Key activities	Support ability of teachers in secondary education to enhance quality of education in the country

Case 14

Country	Kenya
Organisation	Centre for Mathematics, Science, and Technology Education in Africa (CEMASTEA)
Name of intervention	Strengthening of Mathematics and Science in Education (SMASE) programme
Goal	Strengthening the quality of mathematics and science education at basic education level in Kenya
Sponsor	Republic of Kenya (supported by JICA from 1998 to 2013)
Years	1998 on-going
Scale	National
Key target groups	Students and Teachers
Key activities	i. introduce a learner-centred teaching and learning approach that transforms lesson delivery from teacher-centred to learner-centred through the 'ASEI-PDSI approach'. ii. research in innovative teaching and learning of mathematics and science education iii. development of INSET content and materials iv. provision of training to primary and secondary school teachers in programmes v. monitoring and evaluation of INSET activities and classroom practices in the country

Case 15

Country	Kenya
Organisation	Ministry of Education and the Government of Ireland through its Embassy in Kenya
Name of intervention	Young Scientists Kenya (YSK)
Goal	To promote students' pursuits of careers in science, technology, engineering and Mathematics (STEM)
Sponsor	BLAZE by Safaricom and other partners
Years	On-going
Scale / Scope	National
Target groups	Secondary school students
Key activities / Strategies	i. National Science and Technology Exhibition. ii. Outreach and mentoring of students; career guidance and counselling, inquiry-based learning experiences coding, robotics, virtual reality. iii. Bootcamp on commercialization, entrepreneurship training, intellectual property and trademarking, pitching and presentation mentoring

Case16

Country	Kenya
Organisation	iLabAfrica, Strathmore University
Name of intervention	i. Google RISE Awards, ICT Skills for 10,000 Kenyan Rural Girls. ii. Internet Society Grant in Enhancing Teaching ICT Skills; and iii. Open Day and Computer Science Competitions for Girls.
Goal	To increase girls' uptake of STEM courses and careers

Sponsor	Google and other partners
Years	From 2010
Scale / Scope	Local (selected districts and schools)
Target groups	Students, teachers, head teachers
Key activities / Strategies	i. promoting computer science education among marginalized girls 12-18 years. ii. workshops for students on computer and leadership skills, teachers on ICT integration in teaching and learning, and sensitising head teachers on investment in ICT infrastructure. iii. open day and competition on computing skills for high school girls enrolled in computer studies.

Case 17

Country	Kenya
Organisation	Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA)
Name of intervention	STEM model schools programme
Goal	To promote Science, Technology, Engineering, and Mathematics (STEM) Education in basic education in Kenya
Sponsor	Ministry of Education
Years	2017 and ongoing
Scale / Scope	National programme in target secondary schools
Target groups	Target secondary schools
Key activities / Strategies	i. establishment of the STEM Model School programme in 102 public secondary schools. ii. introduction of Robotics science as a strategy for enhancing students' creativity, critical thinking, problem solving, communication and collaboration in preparation for the competency-based curriculum. iii. promoting inviting school climate with focus on people, process, policies, programmes and place. iv. supporting students' innovations. v. creation of Maker Spaces in the STEM Model schools. vi. provision of STEM resources and facilities to STEM model schools.

Case 18

Country	Kenya
Organisation	STEM Education Inc is a Colorado non-profit Corporation
Name of intervention	Promoting and establishing the next generation of Science, Technology, Engineering, and Math (STEM) leaders for the 21st Century
Goal	To empower children and young adults with the knowledge and resources needed to inspire an early passion for science, technology, engineering, and math and computer science (STEM+CS)
Sponsor	Multiple
Years	2011 ongoing
Scale / Scope	Kenya,
Target groups	Students (pre-school, primary, secondary)

Key activities / Strategies	Through our after-school STEM+CS clubs, children are introduced to engineering and computer science using "kid friendly" materials which engage the child's interest immediately. Stimulating creativity, perseverance, and technological skills, at all levels, we learn to work as a "team" through robotics challenges. The concept of competition going hand in hand with efforts to see others succeed permeates every aspect of the learning environment, reinforcing life skills of "pursuit with cooperation".

Case 19

Country	Kenya
Organisation	Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA)
Name of intervention	Strengthening of Mathematics and Science in Secondary Education (SMASSE) Project in Kenya
Goal	Improvement of mathematics and science education through In-service Training (INSET) for teachers
Sponsor	Japan International Cooperation Agency
Years	1998-2013
Scale / Scope	National
Target groups	Students, STEM teachers in secondary and primary schools, education managers
Key activities / Strategies	Teacher Professional Development and Establishment of INSET system

2.4.4 Uganda

Case 20

Country	Uganda
Organisation	Ministry of Education and Sports (MoES)
Name of intervention	Uganda Education and Sports Sector Strategic Plan (ESSP) 2018-2020
Goal	Delivery of quality STEM education in Uganda
Sponsor	Republic of Uganda
Years	2017-2020
Scale	National
Key target groups	Teachers and students in secondary schools
Key activities	i. Training of teachers to qualify for teaching of STEM subjects and demand more attention on STEM education ii. Improving guidance and counselling in schools for the benefit of learners

Case 21

Country	Uganda
Organisation	Ministry of Education and Sports (MoES)
Name of intervention	The Secondary Science and Mathematics (SESEMAT) programme

Goal	To strengthen quality of science and mathematics education through improvement of teaching of science and mathematics in Uganda
Sponsor	Japan International Cooperation Agency (JICA) and Republic of Uganda
Years	2005 and on-going as national STEM programme under Ministry of Education and Sports
Scale	National
Key target groups	Teachers and over 2,500 are reached annually
Key activities	In-service training of teachers of mathematics and science, accompanied with mentorship sessions throughout the year

Case 22

Country	Uganda
Organisation	Uganda Communication Commission (UCC)
Name of intervention	Provision of ICT infrastructure to schools under the Uganda Communications Development Fund policy 2010-2015
Goal	To strengthen quality of science and mathematics education through improvement of teaching of science and mathematics in Uganda
Sponsor	Japan International Cooperation Agency (JICA) and Republic of Uganda
Years	2010-2015
Scale	Local (underserved areas) reaching 500 schools (100 each year for five years)
Key target groups	Students and teachers
Key activities	Provision of ICT laboratories in 500 schools located in under areas of Uganda

Case 23

Country	Uganda
Organisation	Ministry of Education and Sports
Name of intervention	Uganda Post-Primary Education & Training Expansion and Improvement Project
Goal	To improve teaching and learning of science and technical subjects in secondary schools and TVET institutions
Sponsor	African Development Bank (AfDB)
Years	2009 on-going
Scale	Local
Key target groups	Students in secondary schools and TVET institutions
Key activities	Provision of infrastructure for STEM education through rehabilitation and expansion of facilities at Secondary Schools and Business Technical and Vocational Education and Training (BTVET) Institutions

Case 24

Country	Uganda
Organisation	Forum for African Women Educationalist (FAWE)
Name of intervention	Promoting Science, Technology, Engineering and Mathematics (STEM) amongst girls in Uganda for equitable and sustainable development
Goal	To improve participation and performance of girls in STEM subjects
Sponsor	Dubai Cares
Years	2016-2019
Scale / Scope	Local (40 schools from Central, Western, Northern, and Eastern regions of Uganda)
Target groups	Girls in Secondary Schools and their Teachers
Key activities / Strategies	Improving teaching and learning practices by advancing pedagogical methodologies utilized in mathematics, science, engineering, and technology learning as well as promoting educational excellence in STEM amongst girls in Uganda's secondary schools.

2.4.5 Rwanda

Case 25

Country	Rwanda
Organisation	Ministry of Education
Name of intervention	Education Sector Strategic Plan 2018-2024
Goal	To improve the quality of STEM education in Rwanda
Sponsor	Republic of Rwanda
Years	2018-2024
Scale	National
Key target groups	Teachers and students
Key activities	i. ICT Curriculum development by streamlining digital content ii. use of ICT through smart classrooms iii. support careers guidance and counselling focusing on STEM education at early secondary school levels iv. introduction of global micro-science experiments, robotics and artificial intelligence v. promote hands-on science education enabling students in primary and secondary schools' opportunities to engage in practical work in physics, chemistry and biology

2.4.6 Cross-Country

Case 26

Country	Africa (with Head Quarters in Kenya)
Organisation	Centre for Mathematics, Science, and Technology Education in Africa (CEMASTEA)
Name of intervention	Strengthening of Mathematics and Science in Education (SMASE) programme in Africa
Goal	Strengthening the quality of mathematics and science education at basic education level in Africa
Sponsor	Members Countries with supported by JICA
Years	1998 on-going
Scale	Cross-Country
Key target groups	Students, Teachers, Educators, Education Mangers
Key activities	i. Research in innovative education ii. Development of INSET content and materials iii. Provision of training to primary and secondary school teachers in programmes tailored to individual country needs iv. Networking v. Collaboration with partners and stakeholders vi. Monitoring and Evaluation of INSET activities and classroom practices in member countries

Case 27

Country	14 countries in sub-Saharan Africa: Botswana, Côte d'Ivoire, Gabon, Ghana, Ivory Coast, Kenya, Mauritius, Nigeria, Senegal, South Africa, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe. HQs in Accra Ghana
Organisation	Junior Achievement (JA) Africa, HQs in Accra, Ghana
Name of intervention	Sparking youth interest in careers in Science, Technology, Engineering, and Mathematics (SySTEM)
Goal	To promote among students Africa interest in STEM courses and careers by: i. improving perceptions and interest in pursuing STEM education and related careers. ii. increasing knowledge of STEM disciplines, and their interconnectivity. iii. improving students' ability to apply innovative learning methods. iv. increasing knowledge and ability to acquire and apply transferable professional and personal skills
Sponsor	Multiple
Years	Since 1970
Scale / Scope	Sub-Sahara Africa (Affiliated to the Global JA established in 1919)
Target groups	Student and youth
Key activities / Strategies	JA Africa implements a 12-week programme aimed at raising awareness of, and interest in STEM career opportunities through workshops, hands-on activities, and field trips where students are challenged to think like STEM professionals and brainstorm how STEM can make a difference in people's lives. The programme comprises six stages divided into eleven sessions and one field trip.

2.4.7 Summary of the interventions

The key characteristics of these interventions are:

a) some are national in scope, while others are localized in specific sub-geographies within a country, while still others are cross-country interventions.
b) government and development partners are joint sponsors for most of the interventions; however, some interventions are led through the initiatives of private entities and individual philanthropists.
c) most of the government interventions for improvement of STEM education are embedded within national education sector plans.
d) most of the interventions have focused on multiple strategies to address the root causes of low quality of STEM education in Africa including teacher professional development, provision of teaching and learning resources and facilities, and student mentorships on STEM education.
e) while some interventions have documented results, it was a challenge to ascertain the reach and impact of most of these interventions.

It was noted that the interventions presented are just a snapshot of many interventions that could be going on. Hence countries in the region with support of ADEA should embark on a mapping exercise to establish the full range, scope, and scale of past and current interventions as a strategy for drawing comprehensive lessons and best practices in improving the quality of STEM education at the basic learning level.

2.5 Impact of interventions on quality of STEM education

2.5.1 Overview

Apart from evaluation of donor funded interventions in STEM education, educational authorities in the sample countries rarely conduct impact evaluations. However, they do conduct regular education reviews quarterly, semi-annually, and annually. Some of these reviews are part of the reporting process of the education authorities while others are special reviews when there are notable challenges or changes in global trends in education, for instance assessment of progress towards meeting international commitments, including the Sustainable Development Goals (SDGs). However, there are no regular stand-alone reviews focusing on STEM education, and any such review is normally within the general review of the education sector.

2.5.2 Key performance indicators in STEM education

Aside from the general indicators for overall quality of education and efficiency of the education system including access, participation, repetition, dropouts, and performance in national examinations, few countries have made a deliberate focus on key performance indicators for the quality of STEM education (The World Bank, 2019). However, South Africa is an exception as it has made attempts to clearly articulate indicators for mathematics and science in the Action Plan to 2019; Towards Realisation of Schooling 2030 (Republic of South Africa, 2015). The following are select indicators from the South Africa Action Plan:

- Indicator 5: Number of Grade 12 learners passing mathematics,
- Indicator 6: Number of Grade 12 learners passing physical science,
- Indicator 9: Average Grade 9 mathematics score obtained in TIMSS

Likewise, Rwanda has identified some key performance indicators in the Rwanda Vision 2050 policy document. These indicators include, a) percentage of graduates in STEM related programmes with a target of 44% in 2035 and 50% in 2050, and b) percentage of students' enrolment in TVET as proportion of total students in basic education with a target of 60% by 2050 (Republic of Rwanda, 2015). Meanwhile, in efforts to improve performance in mathematics and science in Namibia, some of the proposed strategies are to develop and use performance indicators (Tuaundu, 2013). Furthermore, it has been proposed that the agencies within Ministries of Education in the region responsible for national assessments should ensure that they provide teachers of mathematics and science with concrete examples of student performance at different achievement levels (Bethell, 2016). Additionally, education authorities are also encouraged to ensure that national examination boards put in place comprehensive feedback systems to supply schools, teachers, and other practitioners with both qualitative and quantitative information on student performance in mathematics and science (Bethell, 2016). Overall, the authorities in the Ministries of Education in Africa should develop comprehensive indicators focusing on STEM education and aligned with specific strategies for improvement of quality of STEM education.

2.5.3 Improvements in teaching and learning

Despite the lack of comprehensive and consistent evaluation of the impact of interventions in STEM education at the basic learning levels in Africa, there are some illustrative examples of small-scale studies that have revealed progress in achieving quality in this sector. For instance, the 'ASEI-PDSI approach' was found effective in building teachers' confidence and ability in delivery of lessons, nurturing student positive attitude towards mathematics and science, and improving test scores in these subjects (Mutisya, 2010; Mwangi & Atina, 2016; Katiambo, Wasike, & Mutsotso, 2019; Matachi & Kosaka, 2017). In Uganda, the Secondary Science and Mathematics (SESEMAT) programme significantly improved teachers and student's attitudes towards science and mathematics; performance of students in the national examinations; and adoption of practical teaching among mathematics and science teachers (Komakech & Osuu, 2014). Furthermore, the SESEMAT programme strategies including school-based teacher initiatives and lesson study have been adopted by teachers and have greatly enhanced teachers' knowledge and practices, while improving classroom practices, and students' achievement in science (Manyiraho, Atibuni, Olema, & Wamakote, 2020; Kariisa, 2015). In Ghana, reporting on an outreach intervention that targeted high school students, Yawson et al (2016) noted significant improvements in students' attitude towards science, science careers, and scientists (Yawson, et al., 2016).

2.5.4 Improvement in INSET system for teachers of STEM

Aside from the impact observed in improved teacher pedagogical practices, learning, and student achievement in mathematics and science, some of the interventions have contributed in the development of sustainable systems for continuous teacher professional development. In Kenya, implementation of the SMASSE project led to the establishment of an INSET system for teachers of mathematics and science, with a fully-fledged and public funded national institution, the Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA) (Matachi & Kosaka, 2017; CEMASTEA, 2019; Republic of Kenya, 2018). This structural improvement in the education system has enabled the delivery of continuous professional development with quality not only for teachers of mathematics and science, but also for education managers across the country, including the education quality assurance and standards officers. Riding on the lessons learnt in Kenya, 12 other African countries including Burkina Faso, Ethiopia, Ghana, Malawi, Mozambique, Niger, Nigeria, Rwanda, Senegal, Uganda, South Africa, and Zambia launched similar mathematics and science improvement programmes, and five of them including Ghana, Niger, Nigeria, Uganda, and Zambia have since established sustained INSET programmes under the Ministries of Education (Matachi & Kosaka, 2017). These developments imply that with strategic focus, it is possible to plan and implement sustainable STEM education improvement programmes at the basic learning levels in Africa.

From the fore going, there is evidence of impact of interventions on STEM education in terms of improved teacher pedagogical practices, student positive attitude and interest towards STEM subjects, and improved student achievement in these subjects. Furthermore, evidence is available at the system level in terms of establishment of a sustainable INSET system for professional development of educators in mathematics and science. This achievement should form the basis for more deliberate focus on comprehensive improvement of quality of STEM education at the basic learning levels, founded on a sound policy and strategies to accelerate student uptake of STEM subjects and careers.

2.6 Recommendations for achieving quality in STEM education

Various studies and reports have recommended several strategies in improving quality of STEM education at the basic learning levels. The following are some of the key recommendations.

2.6.1 Science and Technology fairs and excursions

The STEM interventions should include student exposure initiatives through external educational opportunities to spark student interest and develop a passion for STEM subjects (Duarte, Tillostson, & Jankowski, 2018). Additionally, initiatives on students' attachments in enterprises should be implemented where students can physically see and feel the practical application of STEM in the real world (Blom, Raza, & Kiamba, 2016; Republic of Kenya, 2018).

2.6.2 More funding for STEM education

Governments should establish national assessment programmes where these are lacking, and plan for participation in regional, and international assessment such as TIMSS as this will enable governments to design targeted interventions based on evidence emerging from the assessment (PASEC, 2020; SEACMEQ, 2020; TIMSS& PIRLS International Study Centre, 2020; Mensah, Mereku, & Ameyaw, 2004). Meanwhile, education authorities in those countries in Africa that are already participating in TIMSS should continue to support participation in TIMSS, (Mensah, Mereku, & Ameyaw, 2004). Furthermore, education authorities in African countries should provide adequate funding to support initiatives for improvement of science and mathematics education in the primary and secondary schools to ensure that students are able to perform at the highest level possible (Mensah, Mereku, & Ameyaw, 2004).

2.6.3 Student mentorship programmes on STEM

Student mentorship programmes at an early age was proposed as a solution to addressing the challenge of low interest in STEM subjects (Awuor, 2013; Katiambo, Wasike, & Mutsotso, 2019; Yara & Wanjohi, 2011). Evans and Popova (2016) cited in Mlachila et al (2019:46) assert that training of teacher plays a major role in the performance of students and that students excel better when they are taught with blended interventions. Meanwhile continuous research on STEM teaching methods, student experiences, and teacher experiences will generate insights on what is working or not (Duarte, Tillostson, & Jankowski, 2018). There should be adequate exposure of STEM teachers to creative and innovative teaching strategies that encourage the involvement of the learner (Mensah, Mereku, & Ameyaw, 2004).

3. DESIGN AND METHODOLOGY

3.1 Study design

The methods and approaches adopted in this study were informed by the nature, purpose, objectives, and expected deliverables of the study. STEM education is a relatively new concept, not only in Africa but globally. Furthermore, little is currently known about the status of initiatives in STEM education at the basic learning levels in Africa as there are relatively few studies done in this area. Therefore, the exploratory research design was adopted in gathering information from targets groups who are more likely to have a better understanding of this subject matter to ensure efficiency in implementation of the study. Additionally, both qualitative and quantitative approaches were adopted in gathering information to ensure both depth and breadth of the information that was gathered on the status of STEM education at the basic learning levels in Africa. The specific approaches that were adopted included:

a) Desk review of relevant reports, policies, education sector plans, and research studies on STEM education in Africa.
b) Document analysis of country profile reports on the status of STEM in the nine target countries.
c) Survey through questionnaires of educators including teachers of STEM at basic education, and education officials at local and national levels with responsibility on STEM education; and,
d) Interviews with senior education officials in the respective countries. Therefore, respective tools were developed for gathering data from these target groups and these are described in sub-section 3.4.

3.2 Target groups

The choice of the target groups was informed by the need to reach the right people with information on the STEM education in Africa based on their training and professional practice in the education sector. Therefore, the key target groups in this study were teachers of STEM subjects in secondary schools, education officials at the local levels in charge of teacher support and education quality assurance, and education officials at the national level in charge of policy formulation and education management. Another key target group were students of STEM at basic education level. However, this category was not reached directly, but information on enrolment in STEM and performance in national examinations was reviewed to get an understanding of both participation and performance in STEM education.

3.3 Sample

The number and distribution of countries participating in the study was decided by ADEA based on the criteria of regional economic blocks in Africa and national languages. Therefore, the final nine countries (Angola, Botswana, Ghana, Kenya, Morocco, Namibia, Rwanda, South Africa, and Uganda) are representative of the five economic blocks in Africa, and the respective languages. Meanwhile, in each country, 90 teachers of STEM subjects, 30 principals of secondary schools, 20 education officials at the local levels and 2 senior education officials at the national level were targeted. Only public secondary school teachers and principals were targeted in this study. Therefore, in each country 142 participants were targeted for survey, and a total sample of 1,278 was the planned sample to be reached through questionnaires and interviews. **Table 3** presented the planned and achieved sample in this study. The study ensured equal participation of both male and female participants in each country. Specific to the teachers, effort was made to ensure that the sample in each country considered the STEM subjects offered at basic education level. This strategy ensured that the perspectives and experiences of the diverse teachers of STEM subjects were captured.

Table 3: Sample

Target	Status	ANG	BW	GH	KEN	MAR	NAM	RW	SAR	UGX	Total
Teacher	Planned	90	90	90	90	90	90	90	90	90	810
	Achieved	3	27	32	42	0	17	48	16	10	195
	RR (%)	3%	30%	36%	47%	0%	19%	53%	18%	11%	24%
Principal	Planned	30	30	30	30	30	30	30	30	30	270
	Achieved	0	13	10	16	0	3	20	2	1	65
	RR (%)	0%	43%	33%	53%	0%	10%	67%	7%	3%	24%
Local Education Official	Planned	20	20	20	20	20	20	20	20	20	180
	Achieved	0	9	10	15	0	0	5	7	0	46
	RR (%)	0%	45%	50%	75%	0%	0%	25%	35%	0%	26%
Senior Education Officials	Planned	2	2	2	2	2	2	2	2	2	18
	Achieved	3	1	2	2	0	2	2	2	3	17
	RR (%)	150%	50%	100%	100%	0%	100%	100%	100%	150%	94%
Country Reports	Planned	1	1	1	1	1	1	1	1	1	9
	Achieved	0	1	0	1	0	1	1	1	0	5
	RR (%)	0%	100%	0%	100%	0%	100%	100%	100%	0%	56%
	Planned	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**143**	**1287**
Total	**Achieved**	**6**	**51**	**54**	**76**	**0**	**23**	**76**	**28**	**14**	**328**
	RR (%)	**4%**	**36%**	**38%**	**53%**	**0%**	**16%**	**53%**	**20%**	**10%**	**29%**

The overall response rate was 29% which closely aligns with observed trends in online survey responses which on average are about 29% for primary data. Meanwhile, although Morocco was one of the sampled countries, the education authorities declined to participate in the primary data collection and hence the study utilized secondary data gathered through review of documents. The relatively lower response rate was mainly because data collection in three countries (Angola, Namibia and Uganda), was not adequate due to logistical issues. Additionally, data was not collected from school principals and local education officials in Uganda, education officials in Namibia, due to logistical reasons including lack of email addresses and phone contacts. In Angola, only the interviews for senior education officers were successfully conducted. However, a lot of qualitative data was collected in the eight countries that participated which was considered sufficient in understanding the issues and trends in the thematic areas that were explored in this study. Furthermore, the data was collected from teachers of STEM and education managers, who were knowledgeable on issues of STEM education based on their training and professional experience. Additionally, the response rate from interviews and country reports was high, and a lot of information was gathered through these approaches. Admittedly, the main challenge was noted in the survey through the online platform as most respondents may not have had access to internet connectivity because over 30% of the emails either bounced or were not opened. However, despite the lower response rate, the information gathered was considered sufficient to draw accurate conclusions and make respective recommendations.

3.4 Data collection tools

3.4.1 Content of tools

Based on the objectives of this study, the issues to be explored fell under seven thematic areas: a) enrolment of students in STEM subjects; b) performance of students in STEM subjects; c) challenges facing STEM education; d) interventions for improvement of STEM education; e) policies on STEM education; f) funding of STEM education, and g) impact of interventions on STEM education. In gathering information on these thematic areas, four key tools were adopted including: a country report template (Annex A), questionnaire for teachers (Annex B), questionnaire for school principals (Annex C), questionnaire for local education officials (Annex D), interview guide for senior education official at Ministry of Education Headquarters (Annex E), and document review guide (Annex F). **Table 4** presents the matrix that guided in development of the respective tools. The use of multiple tools to gather data from a cross section of respondents are meant for triangulation of both the source and methods in data collection to improve on the accuracy of information gathered.

Table 4: Matrix for development of tools

Thematic area	Key questions	Target/source	Tool
1: Student enrolment and performance in STEM subjects	What is the trend in enrolment in STEM subjects at the basic education level and are there gender, subject areas, regional differences? What is the trend in performance in STEM subjects at basic education level and are there gender, subject areas, regional differences? What are the existing mechanisms for monitoring the quality of STEM education?	i. Education reports ii. Senior Education Officials iii. Teachers iv. Local education officials	i. Document guide ii. Country profile report template iii. Interview guide iv. Questionnaire
2: Interventions, policies, strategies and funding of STEM education	What are the current interventions for improvement of STEM education, are they national interventions, what specific areas of focus? What issues of STEM educations are addressed in the current policies and education plans? What is the proportion of the nation budget and education sector budget that is allocated to the STEM at basic education level?	i. Education reports ii. Senior Education Officials iii. Teachers iv. Local education officials v. Document review	i. Document guide ii. Country profile report template iii. Interview guide iv. Questionnaire
3: Impact of interventions on STEM education	What are the impacts of the interventions for improvement of STEM education? What are the existing mechanisms for monitoring and evaluation of improvements in STEM education?	i. Education reports ii. Senior Education Officials iii. Teachers iv. Local education officials v. Document review	i. Document guide ii. Country profile report template iii. Interview guide iv. Questionnaire
4: Challenges facing STEM education	What are the economic, socio-cultural, policy, and institutional challenges facing STEM education?	i. Education reports ii. Senior Education Officials iii. Teachers iv. Local education officials	i. Document guide ii. Country profile report template iii. Interview guide iv. Questionnaire
5: What recommendations are proposed for improvement of STEM education?	What do the different targets consider to be the remedies for the challenges confronting STEM education at basic learning levels in Africa?	i. Education reports ii. Senior Education Officials iii. Teachers iv. Local education officials	i. Document guide ii. Country profile report template iii. Interview guide iv. Questionnaire

3.4.2 Validity and reliability of the tools

The tools were developed by the consultant and reviewed by the ADEA technical team to ensure that they were valid and could be used in collection of accurate information on the thematic areas that were identified for this study. Meanwhile, triangulation of both the source and methods in data collection was an additional measure to ensure that the information gathered was accurate for drawing valid conclusions and making appropriate recommendations.

3.5 Field data collection

i. Negotiating Entry

The overall management of the study lay with the ADEA Coordinator for the ICQN on Mathematics and Science Education (ICQN-MSE). Therefore, the Coordinator used the existing communication protocols and mechanisms in the ADEA establishment and led in sharing information and briefings about the study with respective authorities in the Ministries of Education in the target countries. The coordinator also led in sharing an overview with the Country Focal Persons on the operational aspects of the study including timelines for the study, and logistical considerations. Furthermore, the Coordinator through the Country Focal Person ensured that the relevant informed consent was granted for data collection from the identified study participants. Given the current situation presented by the COVID-19 pandemic, online technologies including Zoom, SurveyMonkey, email, and WhatsApp, were utilized in gathering the required information. For this strategy to be effective, the consultant collaborated with the ADEA Coordinator for the ICQN-MSE and country focal persons in the management of the data collection process.

ii. Coordination of data collection at country level

The ADEA Coordinator for ICQN-MSE liaised with the Ministry of Education in each of the target countries to appoint a focal person at the headquarters who managed the process of data collection at the country level. Given the broad thematic areas and the strategic nature of this study, the focal person was appointed by the Minister for Education and was a senior education official at the level of Director of Education or equivalent status. Involvement of the country focal persons ensured participation and contribution of critical stakeholders in this study and enhanced relevance in the findings and final report. The specific roles of the country focal person in the study were:

a. preparation of the country report on the status of STEM education based on a template that was shared.
b. selection of two (one male and one female) senior education officials at the Ministry of Education headquarters for interview by the consultant, providing their contacts (telephone, email, skype address) and booking appointments for the interviews.
c. selection of 30 public secondary schools and 30 principals of these schools across the country to respond to the principals' questionnaire on the status of STEM education in their schools. The country focal person was expected as much as possible to ensure regional and gender representativeness in the country during the selection of the schools and principals and guidelines for this process were shared (Annex 3).
d. selection of 90 (45 male and 45 female) teachers of STEM from the 30 secondary schools while ensuring gender balance. The country focal person ensured a balance in gender and STEM subjects as indicated in the guidelines for data collection (Annex 3)
e. selection of 20 (10 Male and 10 female) local education officials draw from regions / counties / districts / provinces in the country, to respond to the questionnaire on the status of STEM education at the basic learning level; and local education officials from the same regions as the teachers and schools.
f. providing the consultant with the current education policy in general and policies on mathematics and science education, current education sector plan and any other relevant education sector reports on mathematics and science education.

g. providing the email addresses, mobile phone numbers, and Skype ID (where possible) for selected senior education officials, principals of secondary schools, teachers of STEM, and local education officials as specified in the guideline for data collection.

iii. Field data collection

Teacher and education officials' surveys: The questionnaires that were used in teacher, principals, and local education officials' surveys were digitalized in SurveyMonkey and shared as a link through the email addresses or phone contacts of the respondents. This strategy was meant to maximize on the response rate. Further to mitigating the COVID-19 pandemic by ensuring social distancing, the online data collection was anticipated to be faster and cost efficient. It was expected that the questionnaire would take a maximum of 20 minutes to complete. It was anticipated a total of 1,080 teachers and 180 education officials would be reached through the questionnaire.

Interviews: interviews were conducted with senior officials in the Ministry of Education headquarters on the seven themes identified in this study. The country focal person had selected the two senior officials at the ministry of education headquarters for the interviews and shared their email addresses, mobile phone numbers and skype addresses. Additionally, the country focal person supported in booking appointments for the interviews, while the consultants shared Zoom links with the respective officials. The identified officials had a role in quality assurance, policy formulation or interventions in STEM education. The interviews were planned to take a maximum of one hour through Zoom and were recorded for transcription to ensure all the gathered information was documented. A schedule was developed on the interview dates and shared with the country focal person for interview appointment with the identified senior education officials.

Desk review: relevant and current policy documents, education sector plans, education reports, research and evaluation studies that are relevant to mathematics and science education were identified through searches on the internet. The key words used in the search were a combination of '***mathematics*** and ***science education*** in ***Afric***a' and '***STEM education*** in ***Africa'***. The documents that were gathered were further reviewed using the criteria of a '***STEM education at the basic learning level in Africa'***. Meanwhile the country focal persons shared or referred the consultant to existing policies, education sector plans and reports that are relevant to STEM education. Through this process, 103 documents were gathered and reviewed using a document guide developed for this purpose.

Country Profile Report: The country focal person prepared and shared a brief country profile report on the seven thematic areas using a template shared by the consultant.

Quality Assurance: Guidelines (Annex 3) on the process of data collection at the country level which was used for the induction of the Country Focal Person as well as serve as a guide in the data collection process at the country level. The guide articulated both the process and key considerations to ensure quality data collection. Meanwhile, the ADEA technical team reviewed progress in implementation of the study at key milestones to ensure quality of deliverables.

3.6 Data analysis and report writing

The quantitative data was summarized through descriptive statistics in terms of frequencies, percentages, and means using both MS Excel and SPSS version 22 to establish any emerging trends in the status of STEM education at the basic learning levels and any unique occurrences. The findings were presented in Tables and Graphs as appropriate. Meanwhile, the qualitative information from the interviews was recorded and transcribed to ensure that during the qualitative analysis all relevant information was documented. Both the transcriptions and qualitative data from the open responses in the survey were subjected to qualitative analysis through content analysis. This involved coding of the textual responses using key words and establishing themes, with supporting narratives from the information. The responses from multiple respondents and target groups were subjected to comparative analysis to establish any notable and significant divergences or convergences in trends and patterns in the identified themes. Additionally, verbatim excerpts from the interviews and open responses were isolated and used to reinforce observed trends from the analysis for clarity in interpreting the findings. The findings were presented in tables, figures, and narratives as appropriate. Meanwhile the findings were subjected to further analytical review to identify gaps between the observed status in the seven thematic areas, and the expectations as defined in policy documents and education plans. This enabled an understanding of the existing gaps to inform development of the monitoring and evaluation framework and respective policy briefs.

3.7 Stakeholders' validation workshop

The draft report, alongside the draft monitoring and evaluation framework were shared with ADEA for review and feedback. After incorporation of the feedback, the final report was presented to stakeholders through a webinar for validation and feedback. Upon validation of the final report and the monitoring and evaluation framework, the policy briefs were developed.

3.8 Policy briefs

The policy briefs articulated the actions required at country level in order to improve the quality of STEM education at the basic learning levels in Africa, including the mechanisms for monitoring progress in this critical sub-sector.

3.9 Deliverables

a. An action plan showing project activity, timelines, and expected deliverables
b. A situational analysis report on STEM education in Africa
c. A monitoring and evaluation framework on STEM education in Africa
d. A stakeholder validation workshop report detailing list of participants and resolutions
e. Two policy briefs based on the findings of the survey

4. FINDINGS

4.1 Introduction

This section presents both quantitative and qualitative findings based on data that was gathered through survey of teachers of STEM subjects, principals of secondary schools, education officials, and interviews with senior education officials in the sample countries. The findings are presented thematically based on the key themes that were the focus of the situational analysis including: student enrolment and performance in STEM subjects, interventions focused on improvement of quality of STEM education and their impact, challenges encountered in attempts to achieve quality of STEM education in Africa, and recommendations on how to address these challenges. Findings on each of these thematic areas are presented and an attempt made to triangulate by source by weaving the findings from the different target groups into a coherent whole, while highlighting any divergencies and concurrences. Meanwhile, where data was sufficient, comparisons were made across the countries to highlight any contextual issues that may emerge. The quantitative findings are mainly descriptive in the form of percentages, frequencies, means, and sum totals, and are presented in tables and graphs as appropriate, accompanied with relevant narrative description of any observed trends that could be indicative of the status of STEM education in Africa, based on the themes that were explored in this study. While the quantitative findings provided breadth in the trend and range of issues, the qualitative findings supplemented with depth of issues, enabling deeper understanding of the observed trends while allowing for divergence and concurrences in issues, patterns, and trends. Meanwhile, where gaps were identified in the available data, this was noted and highlighted in form of suggestions and recommendations.

4.2 Background

Table 5 presents the demographic profile of the respondents which shows that over one third of the respondents were female, and 95% had at least an undergraduate qualification. All the teachers were STEM teachers with about one third having mathematics as their first teaching subject, while the others were teachers of science and technical subjects. However, 66% of the school principals and 36% of the local education officials were not specialists in STEM subjects.

Table 5: Demographic profile of survey respondents

Characteristic		Principal (n=65)		Teacher (n=185)		Edn official (n=36)	
		n	%	N	%	n	%
Sex	*Male*	36	55%	127	69%	22	61%
	Female	29	45%	58	31%	14	39%
Age	*25 or less*	0	0%	6	3%	0	0%
	26-30	0	0%	13	7%	0	0%
	31-35	0	0%	52	28%	0	0%
	36-40	6	9%	45	24%	0	0%
	41-45	13	20%	34	18%	5	14%
	46-50	12	18%	16	9%	12	33%
	51-55	16	25%	16	9%	14	39%
	56 or more	18	28%	3	2%	5	14%
Qualifications	*Ordinary secondary*	0	0%	1	1%	0	0%
	Advanced secondary	1	2%	2	1%	0	0%

	Diploma college	2	3%	19	10%	0	0%
	Undergraduate	32	49%	135	73%	10	28%
	Masters+	30	46%	28	15%	26	72%
Country	*Botswana*	13	20%	27	15%	8	22%
	Ghana	10	15%	32	17%	6	17%
	Kenya	16	25%	42	23%	13	36%
	Namibia	3	5%	17	9%	0	0%
	Rwanda	20	31%	45	24%	2	6%
	South Africa	2	3%	16	9%	7	19%
	Uganda	1	2%	6	3%	0	0%
Teaching subject	*Mathematics*	4	6%	58	31%	7	19%
	Physics	0	0%	21	11%	3	8%
	Chemistry	1	2%	33	18%	3	8%
	Physical Sciences	0	0%	4	2%	0	0%
	Biology	8	12%	31	17%	6	17%
	Natural Science	0	0%	1	1%	0	0%
	Integrated science	0	0%	3	2%	0	0%
	Agriculture	1	2%	5	3%	1	3%
	Computer science	1	2%	13	7%	0	0%
	Woodwork	0	0%	1	1%	0	0%
	Metalwork	0	0%	1	1%	0	0%
	Building & construction	0	0%	1	1%	0	0%
	Electricity	0	0%	3	2%	1	3%
	Drawing & design	0	0%	1	1%	0	0%
	Art & design	1	2%	1	1%	0	0%
	Technology	0	0%	1	1%	2	6%
	Home Science	2	3%	3	2%	0	0%
	Business studies	4	6%	4	2%	0	0%
	Social Studies	27	41%	0	0%	13	37%
	None	16	25%	0	0%	0	0%

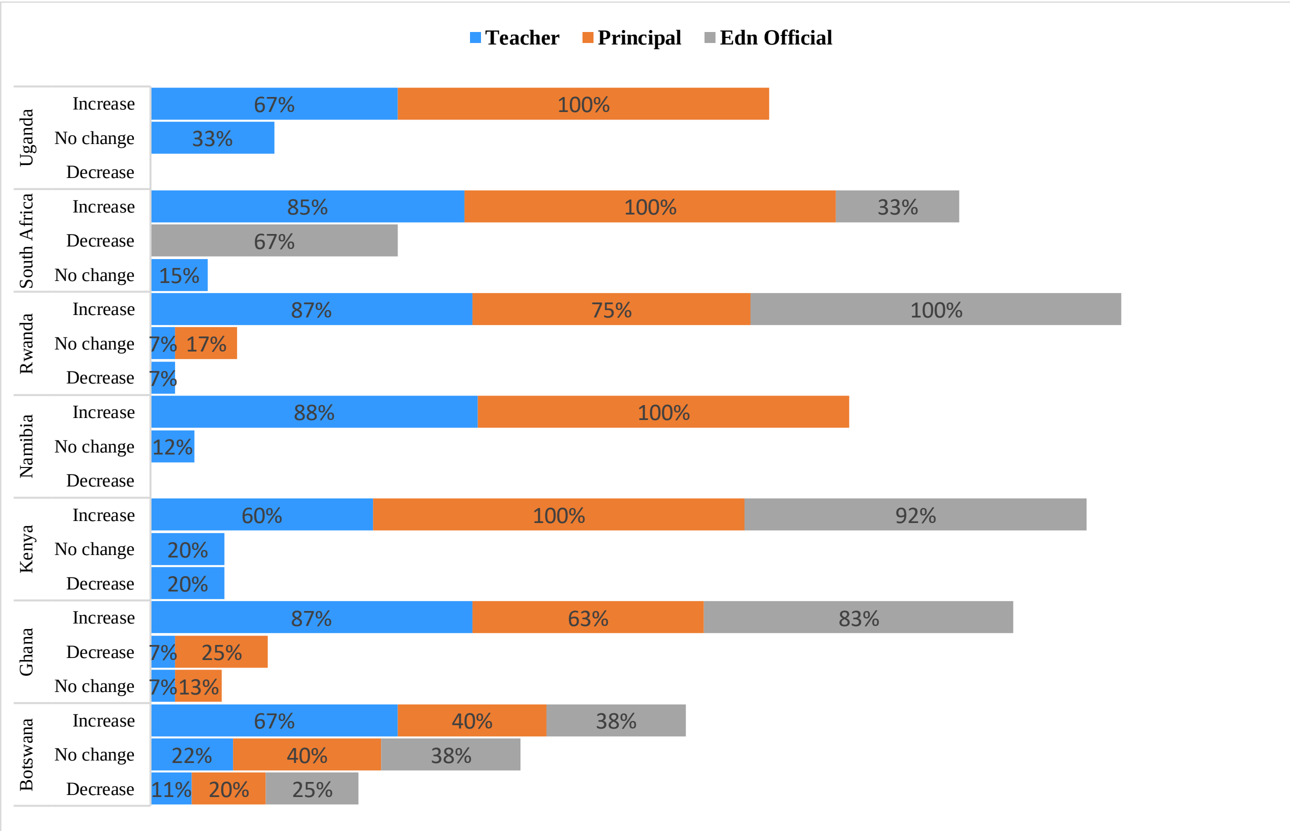
4.3 Enrolment and Performance in STEM education

In this study, enrolment of students in STEM education at the secondary school level was a key thematic area to establish whether enrolment was increasing, decreasing, or has not changed in the past three years. Information on enrolment was gathered from teachers, principals of secondary schools, and local education officials on the trends in student enrolment in STEM subjects over the last three years (2017-2019). The objective was to establish whether there was an increase, decrease or no change in student enrolment in STEM subjects, and factors that these trends could be attributed to. For teachers, information was sought on trends in enrolment for their teaching subjects, while for the principals, information was sought on trends in STEM subjects in their schools. Meanwhile, for the local education officials, information was sought on trends in enrolment in STEM subjects in their regions.

i. Trend in student enrolment in STEM at basic learning levels

Overall, the general trend shows that principals, and education officials indicated an increase in student enrolment in STEM subjects over the three years (2017-2019) for the sample countries (**Figure 4**). However, proportionately more teachers than principals and education officials in Botswana and Ghana indicated an increase in enrolment. Likewise, proportionately more principals than teachers and education officials in Kenya, Namibia, South Africa, and Uganda indicated an increase in enrolment.

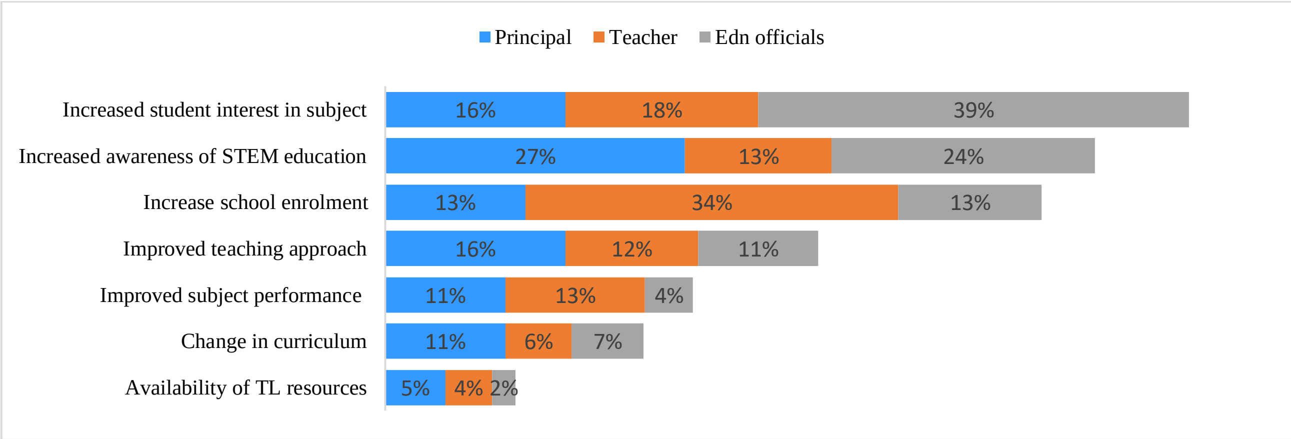
Figure 4: Trend in student enrolment in STEM subjects



ii. Reasons for increase in STEM subject enrolment

Proportionately more teachers attributed the increased student enrolment in STEM subjects to the increasing overall school enrolment, while school principals attributed it more to increased awareness of STEM education, and the education officials indicated it had more to do with increased student interest in the subject (**Figure 5**). These key reasons could reflect the demographic changes in the region as well as favourable policies that countries in the region have adopted as strategies to increase access to basic education, including the free secondary education, and the 100% primary to secondary school transition policies. Furthermore, teaching approaches and improved student performance in the subjects, were other factors associated with increased enrolment particularly for the optional STEM subjects. Apparently, availability of teaching and learning resources was not frequently mentioned as a reason for increased enrolment in STEM subjects. Overall, it is more likely that increasing enrolment in STEM subjects could be attributed more to demographic changes and favourable policies for accessing education in the region.

Figure 5: Reasons for increase in STEM subject enrolment



The following are some illustrative excerpts explaining the increased student enrolment in the STEM subjects:

[Improved subject performance]

"Compared to the previous years, the number of students in STEM subjects has slightly increased due to the improved performance in STEM subjects in National examinations".

Principal, Rwanda

[Increased awareness of STEM education]

"I think that the change is due to the mind set change among learners and implies they are goal oriented in choosing STEM subjects basing on what they want to become in future"

"Following many sensitizations, girls have already understood that they are also capable, they can study Sciences and Mathematics like boys".

Principal, Rwanda

"Science subjects especially mathematics and physical science were believed to be difficult by many students but after I started teaching these subjects, students were performing and that attracted more learners to science field of study".

Teacher, Rwanda

[Increased student interest in the subject]

"The enrolment has increased because students have liked the subject and enjoy learning due to variant teaching approaches".

Teacher, Kenya

[Improved teaching approach]

"Learners are enjoying the new methodology we are using to teach science subject eg pbb. Teaching is now Lerner based and this has made learners to encourage their peers to do science subject".

Teacher, Kenya

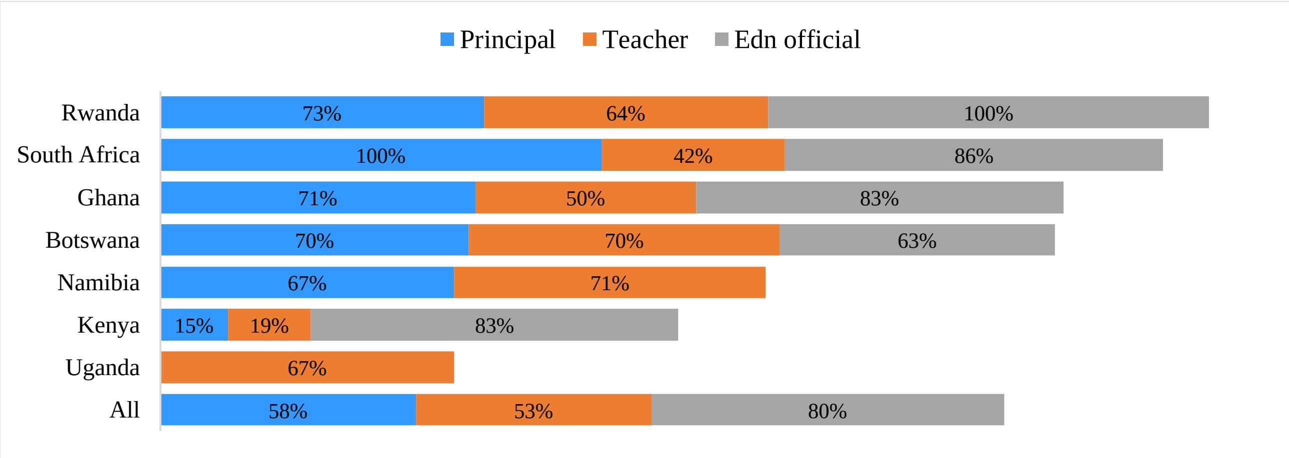
"The increased enrolment of recent is due to quality of our training and progress of our graduates in the job market particularly those who are self-employed. Ghanaians are now gradually appreciating technical and vocational training".

Principal, Ghana

iii. Gender differences in student enrolment in STEM subjects

Overall, teachers, principals, and education officials indicated there were gender differences in STEM enrolment in the schools with proportionately more education officials than principals and teachers having this understanding (**Figure 6**). This could imply that there could be gender differences between schools in a region that may not be apparent to teachers and principals within some schools or there could be more awareness of gender issues among education officials than the principals and teachers. However, there were differences across countries with proportionately more respondents in Rwanda and South Africa indicating existence of gender differences in student enrolment in STEM subjects, and this could again reflect the level of awareness of gender issues among respondents in these countries probably due to higher profile of gender initiatives in these countries. Additionally, a higher proportion of teachers in South Africa indicated existence of gender differences in student enrolment in STEM subjects.

Figure 6: Gender Differences in STEM enrolment



iv. Trend in student performance in STEM education at basic education levels

Overall, proportionately more teachers, principals, and education officials indicated improvement than decline in student performance in STEM subjects over the three years (2017-2019), except for Botswana where more indicated a decline in performance (**Figure 7**). Proportionately more principals than teachers of STEM indicated an improvement except for Rwanda where proportionately more teachers than principals indicated an improvement in performance. Overall, proportionately more teachers in Botswana indicated a decline in student performance in STEM subjects over this period.

The main reasons for improved student performance in the STEM subjects were improved teaching approaches, increased student interest in the subject, and improved student performance (**Figure 8**). Notably, the reasons for improved student performance could be reinforcing, for instance improved teaching approach could contribute to increased student interest in the subject, resulting in improved performance in the subject, which perpetuates a cycle of improved performance. The other key reasons for improved student performance in the subjects include availability of teaching and learning resources, improved teacher subject content mastery, and school improvement programmes.

Figure 7: Trend in student performance in STEM subjects

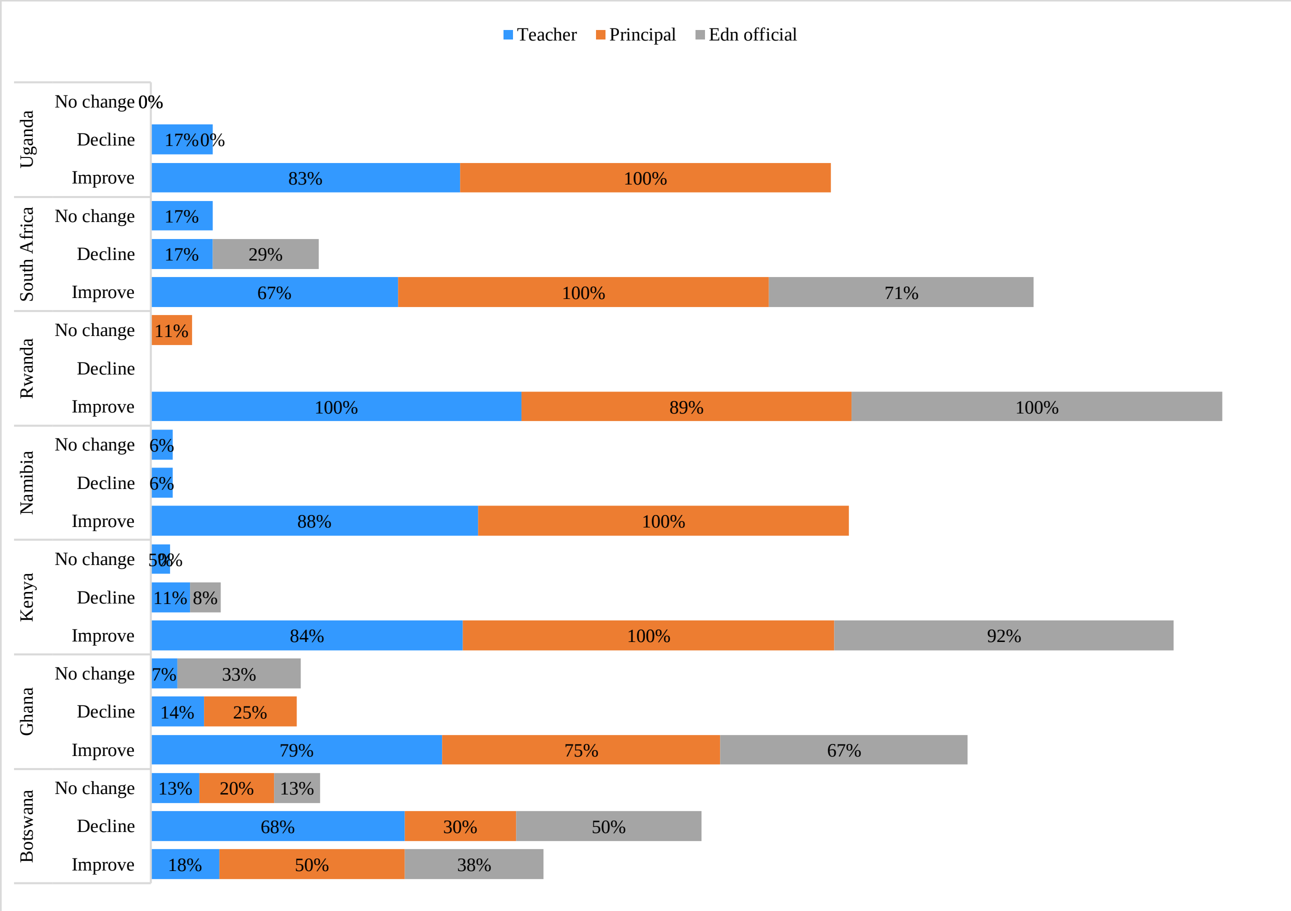
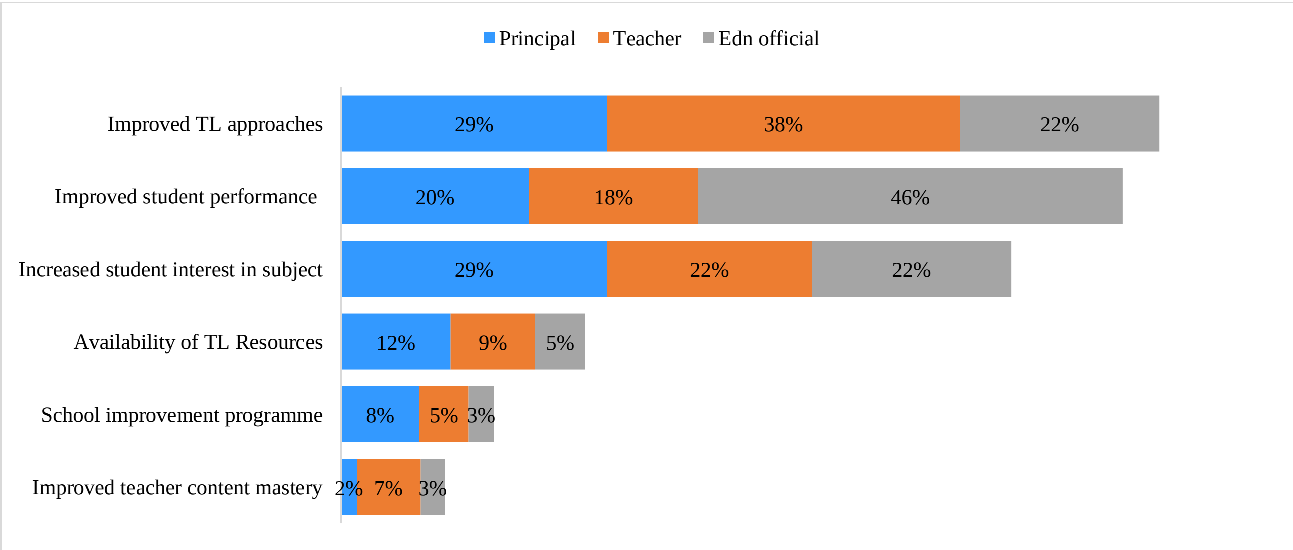


Figure 8: Reasons for improved performance in STEM subjects



The following are illustrative excerpts of the reasons for improved student performance in the STEM subjects.

[Improved teaching approach]

"I have been trained by AIMS on different teaching strategies to use while teaching science subjects, and I also attended to different webinars where I had a chance to converse with different professionals on different topics such as making teaching and learning environment more enjoyable, common mistakes done by teachers that make students lose interest in studying, teaching and mentorship relationship, evaluation and assessment, etc. In short, I improved the way I used to teach by making my lesson more enjoyable and by integrating technology in my class".

Teacher, Kigali City, Rwanda

"Teaching using wide range of technology in class. Technology brings the outside world in to the classroom. Showing videos, pictures, etc of what is happening in real world opens the students mind and hence brings performance"

Teacher, Kavango West, Namibia

[Improved student performance]

I teach the candidate classes so that from the national examination results, students' performance had increased. And others work under the motivation of the previous high performances.

Teacher, Rwanda

"It is due to different student performance results from national examination that shows a good progress, for example, in the biology, the performance rate had increased about 40%".

Teacher, Rwanda

[School improvement programme]

Headmaster and his assistants have put a lot of monitoring mechanisms in place to check teacher absenteeism

[Increased student motivation and improved teaching approach]

"This is due to improved commitment and attitude of the learners in taking the subject. This has been facilitated by improved methods of teaching brought about by teachers embracing PowerPoint lesson delivery and other School Education Quality Improvement Programme (SEQUIP), in which programme I am one of the lead coordinators".

Teacher, Kakamega, Kenya

"The performance has increased due to how I teach and assess the science subjects and according to how I encourage the students to love science subjects".

[Availability of TL resources]

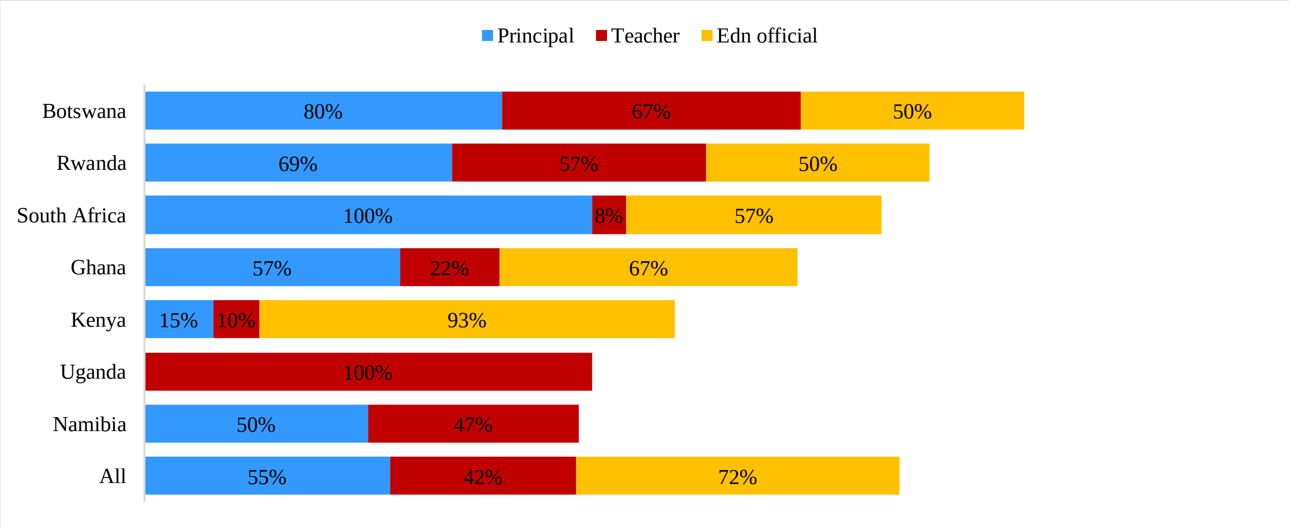
"Students understanding of the concepts has improved significantly. Availability of learning aids and internet has contributed to improved performance too".

Omusati Region, Namibia

v. Gender differences in student performance in STEM subjects

Similar to the trend observed in enrolment, teachers, principals, and education officials indicated there were gender differences in student performance in STEM subjects (**Figure 9**). Comparing the percentage point difference in proportion of teachers, principals, and education officials on gender differences in enrolment and performance, the general trend is a higher proportion of all respondents indicated differences in enrolment than in performance. These percentage point differences in those who indicated gender differences between enrolment and performance were 13%, 3%, and 8% for teachers, principals, and education officials, respectively. This finding could imply that given a chance to access STEM subjects, for both boys and girls the gap in performance is narrower and could be easier to close. There were differences across countries, for instance, Botswana had the highest proportion of respondents indicating existence of gender differences while Kenya had the least. Meanwhile, proportionately more education officials than principals and teachers reported gender differences. Furthermore, teachers were the least likely to report existence of gender differences in student performance in STEM subjects, and this could again be a pointer to less understanding of gender issues among teachers than principals and education officials. Additionally, proportionately more education officials in Kenya, principals in South Africa, and teachers in Botswana reported the existence of gender differences in student performance. These disparities across and within countries in reporting on gender disparities could be an indication of differences in local contexts, understanding of gender issues, and level of analysis of gender disaggregated data within schools, regions, and the country.

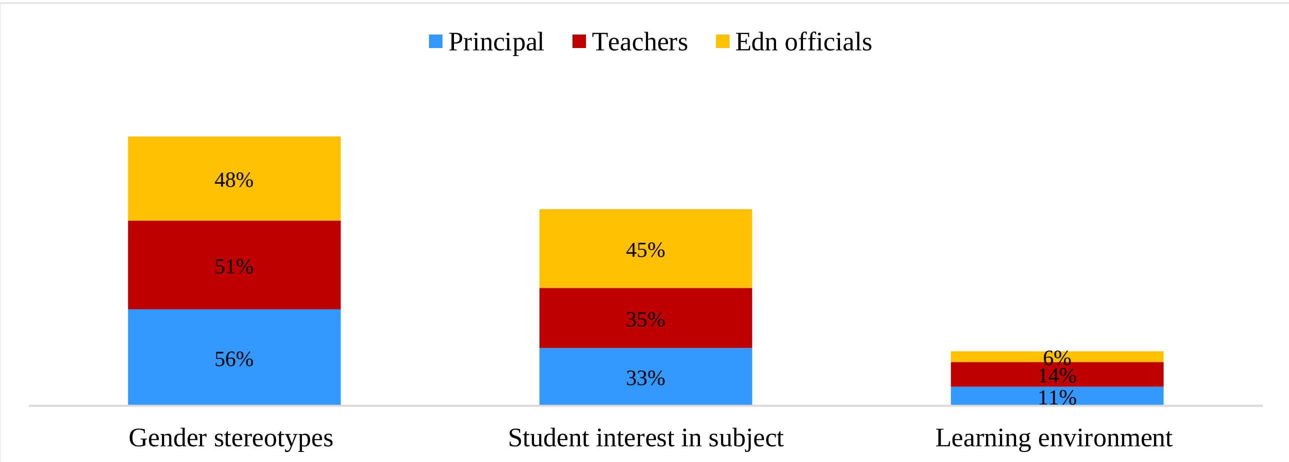
Figure 9: Gender differences in student performance in STEM subjects



vi. Reasons for gender differences in student performance in STEM subjects

The key reason mentioned by teachers, principals, and education officials for differences in gender performance in the STEM subjects in their schools was gender stereotypes (**Figure 10**). Other reasons were student interest in the subject and the learning environment. While these reasons are well known in gender literature, they have been persistent, and this calls for deliberate strategies for sustained mainstreaming of gender in the STEM education agenda.

Figure 10: Reasons for gender differences in student performance in STEM subjects

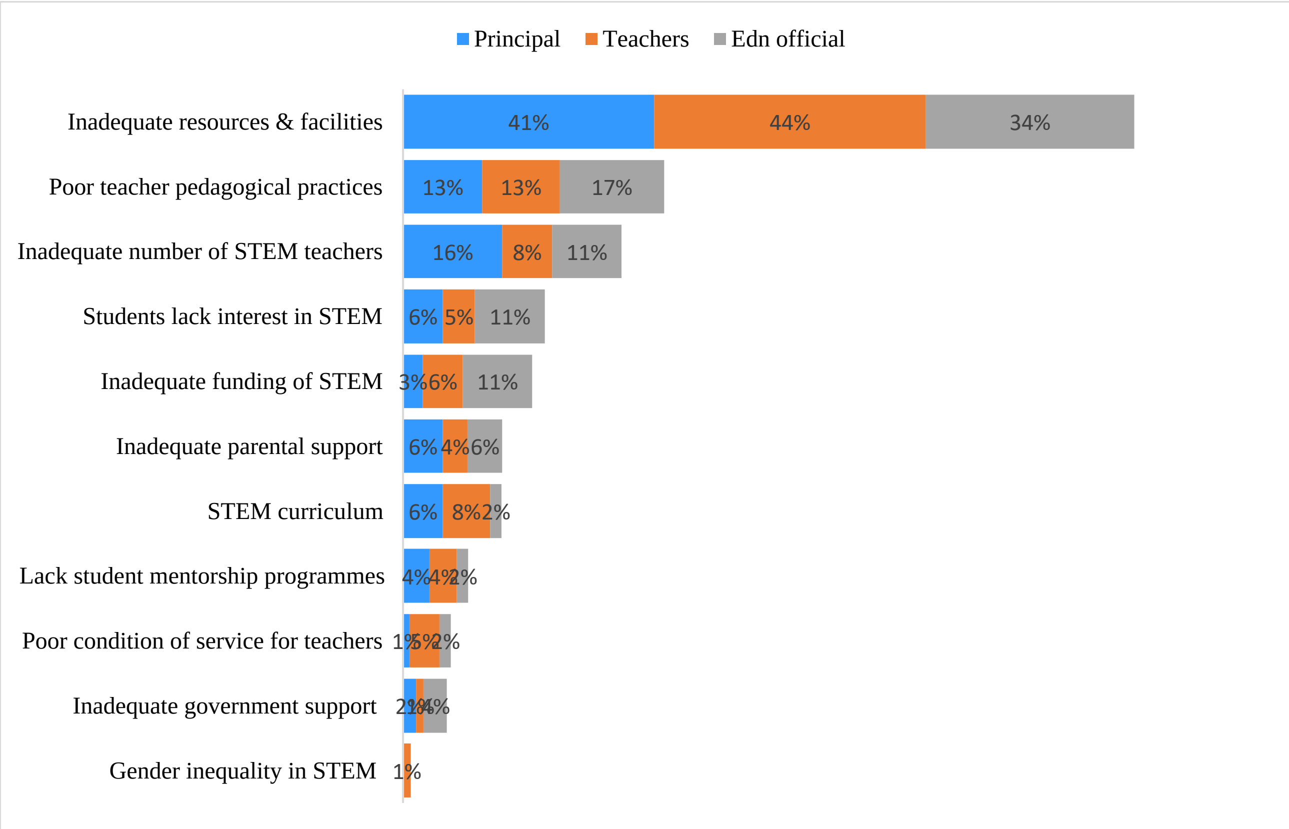


4.4 Challenges in achieving quality in STEM education

Teachers, principals, and local education officials

The teachers of STEM, principals of secondary schools, and local education officials identified the challenges that impede achievement of quality in STEM in their subjects, schools, region, respectively. The information was gathered through open ended questions, and therefore, these were subjected to content analysis by categorizing them into emerging themes. The categories were subjected to frequency analysis and categorized into eleven challenges presented in **Figure 11,** which shows that the main challenge is inadequate resources and facilities for teaching and learning of STEM which accounted for over half of the challenges. The challenges related to teachers were poor pedagogical practices, inadequate number of teachers, and poor conditions of service, which collectively accounted for about a third of the challenges.

Figure 11: Challenges in achieving quality STEM education



The challenges are explored and described as presented by the respondents.

4.4.1 Teachers and School Principals' perspectives

i. Inadequate resources and facilities

The main issues here were the lack of teaching and learning resources and facilities including laboratories, equipment, computers, chemicals and reagents, textbooks, internet connectivity. The key issue here is that critical resources and facilities for teaching and learning of STEM were either lacking or inadequate. Additionally, high student enrolment aggravated the situation.

Lack of laboratory equipment and chemicals for practical lessons. This has often resulted in slight unhealthy relationship between teachers and the various STEM teachers especially during WASSCE. Leadership thinking has always been that teachers are demanding too much money for laboratory facilities.

Teacher, Ghana

ii. Inadequate school leadership support

The key issue that emerged is lack of school-level recognition of champion teachers who were excelling in promotion of STEM education.

iii. Gender inequality in STEM

Issues under gender inequality were about gender stereotypes and the few female teachers in this category of the teaching force.

[Inequalities in STEM]

Although STEM is a major driver of the nation's job market, the disparity between genders and minorities leaves a lot to be desired.

Teacher, South Province, Rwanda

iv. Inadequate government support

The issues under this category were lack of supervision and monitoring by the Ministry of Education which led to lack of an accountability system that directly links teacher performance to their students' achievement. This leads to a bit of *laisse faire* and less commitment on the part of the teachers. Hence many students are dropping or opting out of some science subjects where they had a choice to do this.

v. Inadequate parental support

The commitment of the parents to support their children's education in general and STEM in particular was of concern to the teachers. For instance, parents were not ready to provide stationery, textbooks, notebooks for their children where this was required.

vi. Inadequate funding of STEM

It was indicated that offering STEM subjects in a school is expensive due to the resources and facilities that are required, and without adequate funding this become a challenge. Additionally, inadequate funding meant that schools are not able to support student and teacher participation in some key STEM activities including science and technology fairs, as well as forums for professional development for teachers in order to improve their pedagogical practices.

vii. Poor conditions of service for teachers

Poor conditions and terms of service for teachers was indicated as a challenge that led many to quit teaching for other career opportunities. Specifically, the remuneration of teachers was a recurrent theme across the board, with indications that they are not able to meet their basic needs and cannot therefore concentrate fully on teaching but had to explore other opportunities including micro-enterprises to make ends meet. The following are illustrative excerpts on this challenge:

[Low teacher salaries]

Experienced persons with expertise quit teaching career every year for job hunting where they can be paid a salary that can at least help them afford good standard life.

Teacher, Rwanda

viii. STEM curriculum

The STEM curriculum was indicated as being broad, while time was insufficient to deliver the curriculum as expected. Others indicated that some content was outdated, and some textbooks had content errors. Still others felt that the STEM curriculum does not prepare students for the job market. Furthermore, students lacked a strong foundation in STEM at the elementary levels which they could build upon at the secondary school education cycle.

ix. Inadequate number of STEM teachers

A recurrent theme emerging on staffing in STEM was the heavy teaching load for teachers of STEM. Admittedly, the average teaching load for a teacher was 13.6 hours per week. Therefore, the under-staffing in the STEM subjects could be the main reason contributing to the heavy teaching load. Another related issue was the high enrolment which means that STEM teachers are handling many learners which may compromise the quality of teaching and learning. As noted elsewhere, the high attrition among teachers of STEM makes students give up on pursuing these subjects and consequently, affecting careers choices in STEM.

x. Students lack interest in STEM

Apathy and lack of interest towards STEM subjects among students, particularly girls, was reported. Furthermore, lack of role models and mentorship programmes meant that learners do not get adequate information about STEM Education and careers. There are also traditional cultural beliefs where the STEM subjects are taken to be difficult, and this culture could be perpetuated by some teachers further aggravating learner's enrolment and performance in these subjects. All these dynamics contribute to students' lack of interest and motivation to study STEM subjects.

One of the challenges has to do with students' interest in my subject area, building and construction and woodwork as it is perceived that if you are not too good academically you can pursue these technical subjects.

Teacher, Ghana

xi. Poor teacher pedagogical practices

Teachers of STEM indicated that there were inadequate opportunities to participate in STEM forums where they could improve their pedagogical practices given rapid development in technologies that have an implication on how the STEM curriculum is implemented. This is due to the fact that these programmes are not available or where they exist, teacher participation is restricted due to lack of funding and time to access them. Furthermore, where these programmes exist, they are not regular or well-structured to meet the needs of the teachers but are rather *ad hoc* with little relevance for improvement of quality of STEM education. As a result, poor pedagogical practices are prevalent among teachers of STEM.

4.4.2 Senior Education Officials' perspective

What are the key challenges in achieving quality in STEM education at the basic learning level in your country?

Interviews with the senior education officials generated the following challenges in achieving quality STEM education at the basic learning levels:

i. Inadequate resources and facilities

One of the frequently mentioned challenges was inadequate resources and facilities for teaching and learning of STEM subjects. These resources and facilities ranged from science laboratories to equipment, chemicals, computers, internet connectivity, and course books.

ii. Lack of a policy on STEM Education

Aside from South Africa, which has a Mathematics, Science, and Technology Strategy under the Department of Basic Education, all the other countries lack strategy or policy specific to the STEM education at the basic learning levels. However, some strategies on STEM are embedded within the education sector plans of these countries, but these are not comprehensive enough to adequately address the STEM education agenda

iii. Inadequate funding of STEM

Across the sample countries, inadequate funding of STEM education at all levels was a frequent theme that emerged from the interviews. Funding is reported to be inadequate for construction of science laboratories, provision of equipment, and other necessary resources and facilities for teaching and learning of STEM subjects. In some instance, there are plans and strategies developed on improvement of STEM education, but these cannot be implemented due to lack of funds.

iv. Poor condition of service for teachers

In most instances, teachers of STEM subjects were said to have low satisfaction with their teaching jobs largely because of poor terms and conditions of service. These teachers feel that they handle a heavy teaching load relative to those of other subjects due to the time it takes to prepare for practical activities in these subjects. The situation is further aggravated by situations where they lack sufficient resources and facilities for teaching their subjects.

v. Inadequate STEM specialists at Ministry of Education

The senior education officials indicated that they lack sufficient STEM subject matter specialists at the headquarters who could be in charge of coordination of implementation and evaluation of quality improvement programmes for STEM education.

vi. Inadequate number of teachers of STEM subjects

It was frequent mentioned that the number of teachers of STEM subjects was inadequate, and this could be one of the contributing factors to heavy teaching loads and low satisfaction of the teachers in these subjects. Furthermore, inadequate number of teachers and the consequent heavy teaching loads could relegate the teachers to poor pedagogical practices when they lack sufficient time for preparation for teaching.

vii. Students lack interest in STEM

The poor attitude of some students towards STEM subjects was another frequent theme and could be a pointer to many underlying issues. For instances, stereotypes about the presumed difficulty level of these subjects accompanied with poor pedagogical practices could cement the poor attitudes and consequent lack of interest in learning these subjects.

viii. Low number of students in STEM courses at tertiary institutions

The number of students, particularly girls, who proceed to take STEM courses in Tertiary Institutions was indicated as low. Furthermore, some students, initially admitted for STEM courses at Tertiary level drop out or opt for humanity courses. These practices continue to perpetuate the low enrolment in institutions of higher learning. However, it should also be noted that the intake capacity into STEM courses in Tertiary Institutions is still low in some of the countries.

ix. Poor teacher pedagogical practices

It emerged that most teachers of STEM subjects face the challenge of poor pedagogical practices, which was attributed to inadequate initial training and few opportunities for professional development once they have joined the teaching force.

4.5 Interventions targeting quality of STEM education at basic learning level

Information was gathered from teachers, principals, local education officials, and senior education officials on the activities, strategies, mechanism, policies, plans, and budget allocations on interventions targeting quality of STEM education. The teachers and principals and local education officials were required to indicate their participation in forums or workshops at, within, outside the schools, and online focused on improvement of quality of STEM education in their schools. They were also required to indicate how often they participate in the forums, type of issues addressed, the usefulness of these forums in improving the quality of STEM education, and who offers the support to enable them participate in these forums. The local education officials were required to indicate whether they organize forums or workshops for teachers of STEM and whether they participate in these forums, including those offered through online platforms. They were also required to indicate the type of issues addressed, how often they participate, and who supports the forums. Meanwhile, the senior education officials were required to indicate the priorities and strategies of the education authorities in improving the quality of STEM education. The following sub-sections present both the quantitative and qualitative findings on the information gathered regarding interventions targeting improvement of STEM education at the basic learning levels.

4.5.1 Participation in forums for quality improvement of STEM education

The teachers, principals, and education officials indicated whether they have participated in forums focusing on STEM subjects, within school, outside school, and online. Additionally, they were required to indicate how often they have participated in these forums, which issues were discussed, and whether these forums were useful in improving the quality of STEM education in their schools. They also indicated who supported their participation in these forums. Finally, they shared their experiences in using online technologies for participating in STEM forums. The typical questions used in gathering this information from teachers were as follows:

i. do you participate in forums / meetings/ discussions in your school that focus on quality of STEM education in your school?
ii. how often do you participate in the forums / meetings / discussions that focus on STEM education in your school?

- *iii. what are the issues that you normally cover with teacher in the forums / meetings / discussions on STEM education in your school?*
- *iv. how useful do you find these forums / meetings / discussions in improving the quality of STEM education in your school?*
- *v. have you used any online technologies (e.g., Zoom, Skype, WhatsApp, Webinars, Facebook, etc.) to participate in a forum aimed at improving the quality of STEM subjects?*
- *vi. how effective was the online technology that you used to participate in a forum aimed at improving the quality of STEM subjects?*
- *vii. what were the key challenges encountered in using the online technology to participate in any forum aimed at improving the quality of STEM subjects?*

Figure 12 shows that overall, a higher proportion of teachers were participating in forums on STEM education, particularly within the school than outside the school. However, there were differences across countries. For instance, a higher proportion of teachers in Kenya, Uganda and Ghana were more likely to participate in school-based forums, while those in Botswana and Namibia were least likely to participate in these forums. Additionally, teachers in Kenya and Uganda were also more likely to participate in outside school STEM forums, while those in Ghana, South Africa, and Botswana were the least likely to participate in outside school STEM forums. Furthermore, teachers in Kenya, Uganda, and South Africa were more likely to participate in online forums on STEM issues while those from Botswana and Ghana were the least likely to participate. The differences in participation in STEM forums across countries could be associated with the existence of STEM programmes for teachers within and outside schools, teacher sensitization on these programmes, and their ability to participate or access these forums including availability of devices and internet connectivity for online programmes.

Figure 12: Teachers' participation in STEM forums

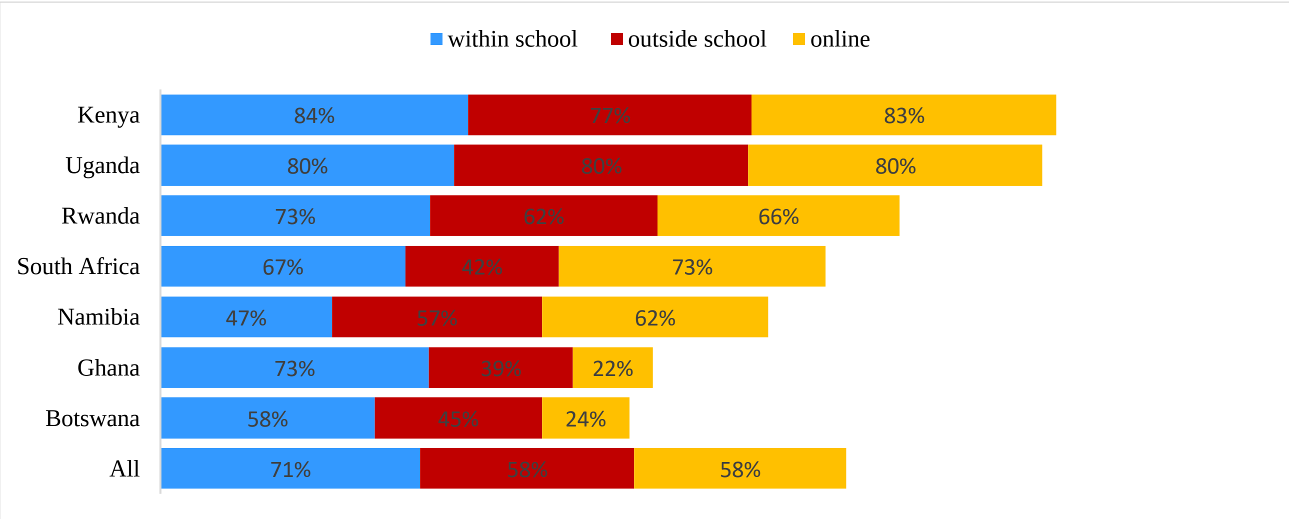
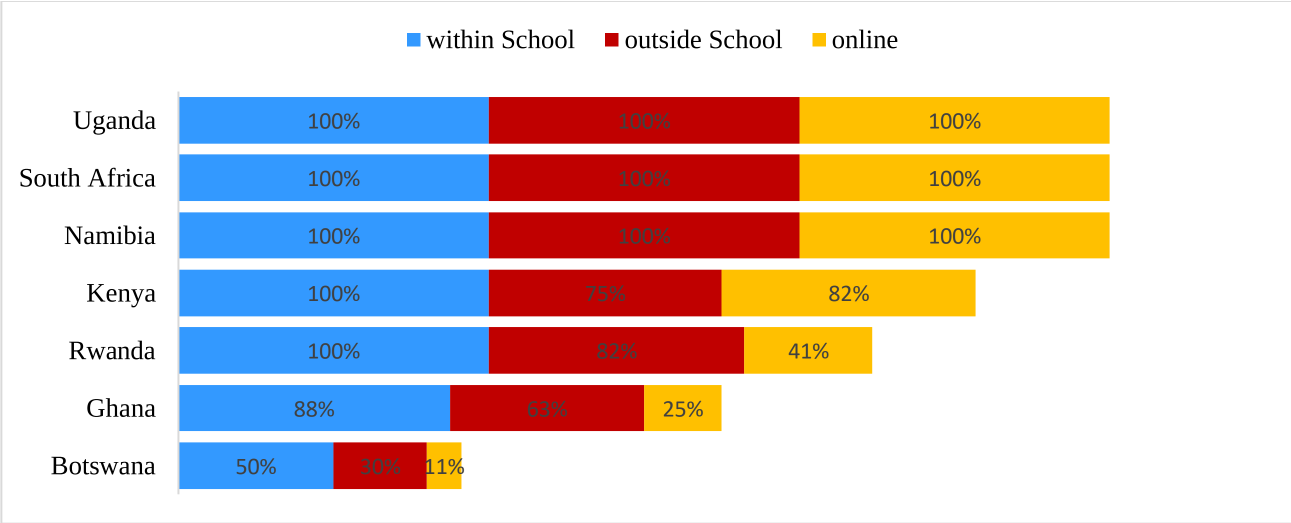


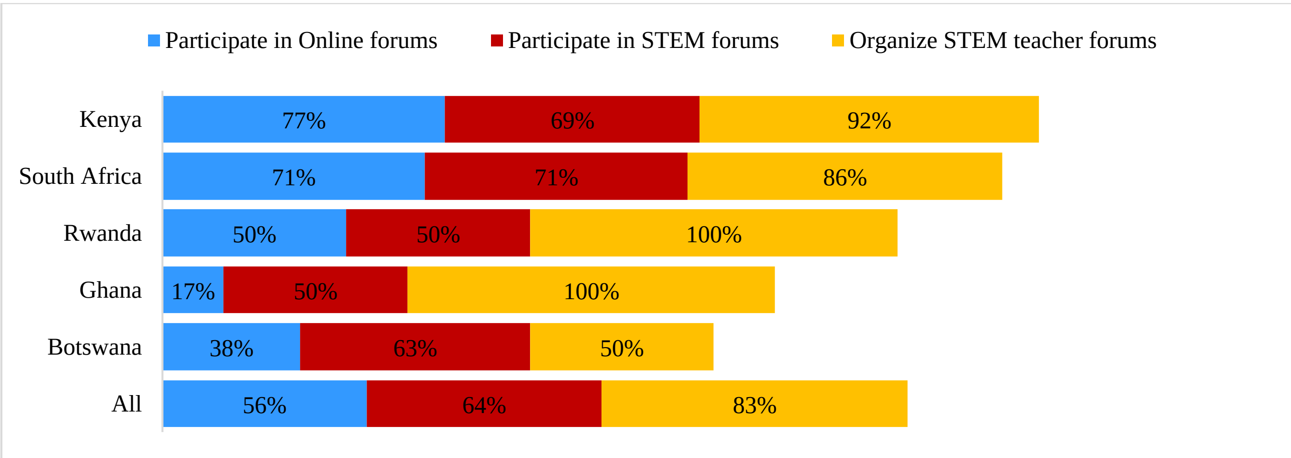
Figure 13 shows that Principals in Uganda, South Africa, and Namibia were more likely to participate in school-based, outside school, and online STEM forums, while those from Ghana and Rwanda were the least likely to participate in these forums. Across the countries, school-based forums appear to be more prevalent for the principals.

Figure 13: Principal participation in STEM forums



Overall, local education officials from Kenya and South Africa were the most likely to participate in or organize STEM for teachers (**Figure 14**). Additionally, local education officials in Kenya and South Africa were also more likely to participate in online forums while those in Ghana and Botswana were the least likely to participate in online forums.

Figure 14: Education official participation in STEM forums



4.5.2 Frequency, content, and usefulness of STEM forums

Figure 15 and **Figure 16** show that in the year (2019), teachers and principals were more likely to participate in termly within school STEM forums followed by monthly, and weekly in that order. Some teachers indicated that these forums are *ad hoc*, meaning they were not planned, or they do not happen at all. Furthermore, more than half of the teachers and over four-fifths of the principals had participated in at least one outside school STEM forum in the last one year. For both within school and outside school STEM forums, a range of issues were discussed and the most frequently mentioned by teachers were teaching and learning approaches, teaching and learning materials, and student assessment, while the principals frequently mentioned STEM improvement plans, student performance, learning environment, and resource mobilisation. While teachers found the within school STEM forums more useful than the out of school forums in terms of improving the quality of STEM education, the principal found forums in both settings useful.

Figure 15: Frequency, content, and usefulness of STEM forums – Teachers

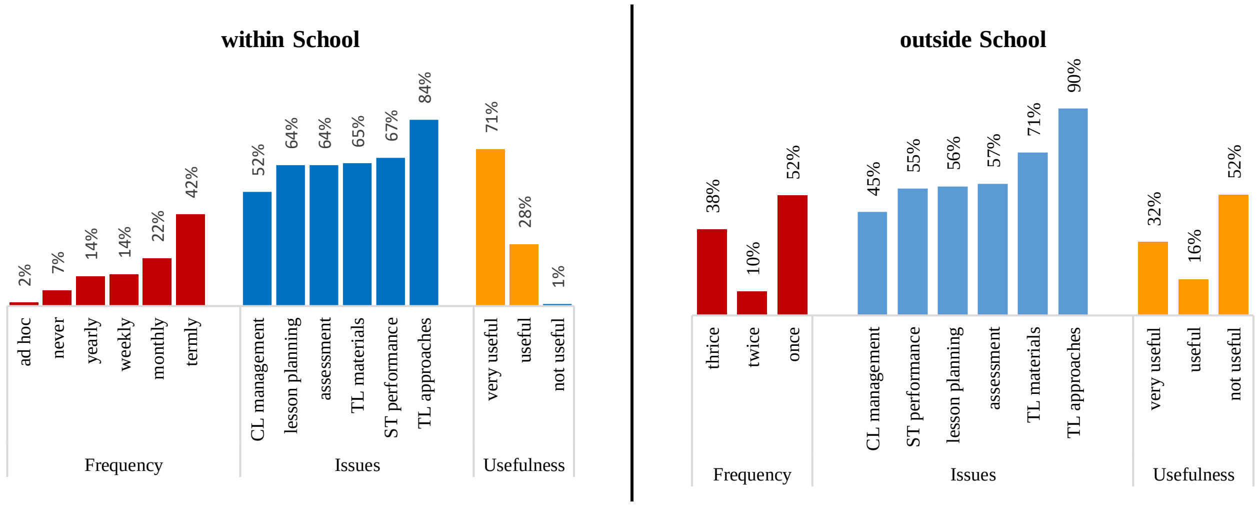
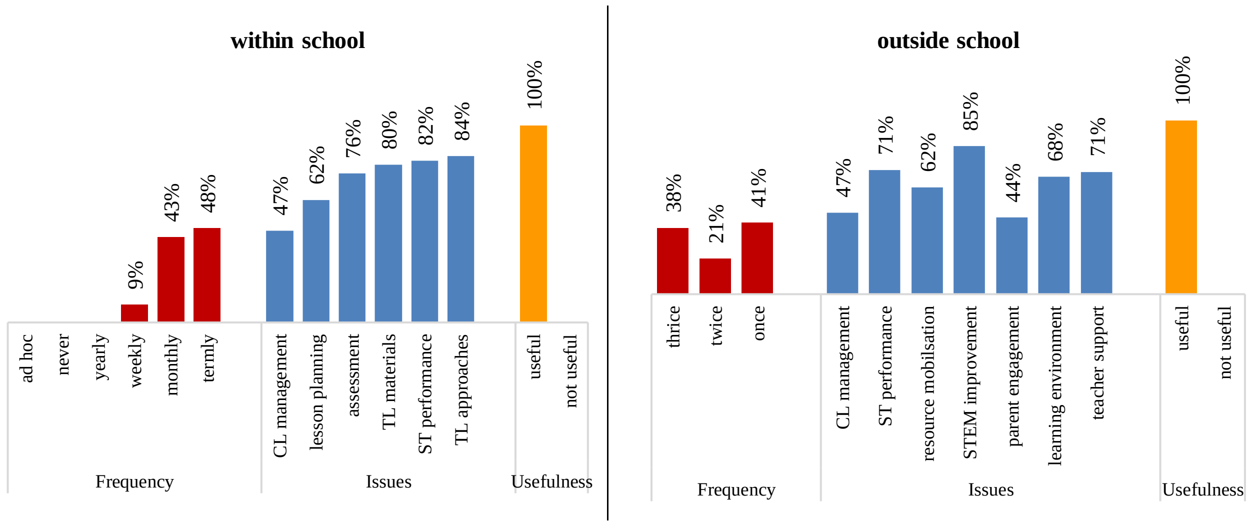


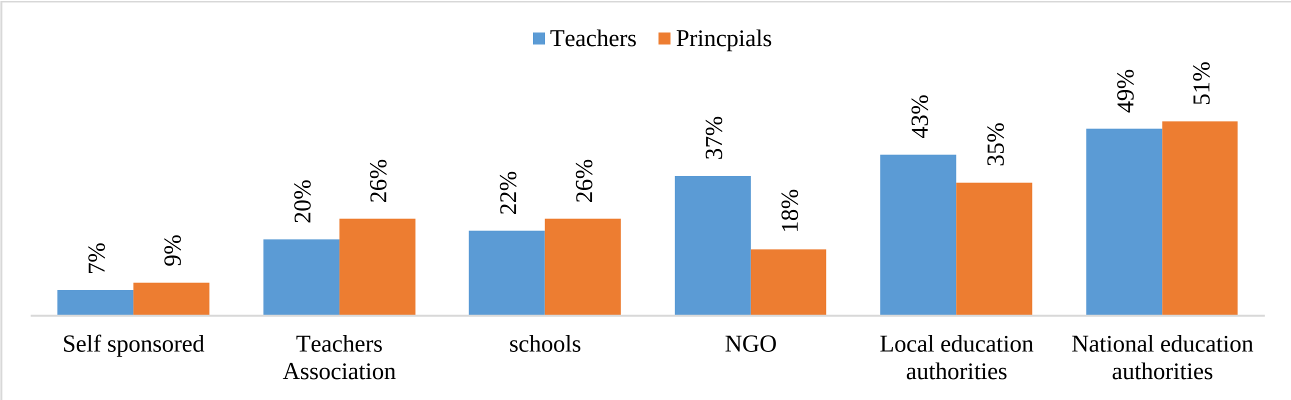
Figure 16: Frequency, content, and usefulness of STEM forums – Principals



4.5.3 Support for teacher participation in external STEM forums

A higher proportion of teachers and principals indicated that their participation in outside of school STEM forums was supported by the national and local education authorities respectively, which demonstrates commitment by the government towards improvement of this critical sector of education (**Figure 17**). Meanwhile, a third of the teachers and principals indicated that the support was provided by NGO and teacher associations, respectively. Meanwhile, almost a third of support for participation of teachers and principals in external STEM forums was provided by the schools, a pointer to the commitment of schools in improving the quality of STEM education. Furthermore, some teachers and principals made personal contributions to participate in the forums, a testimony to the importance they associated with these forums. Overall, these findings seem to imply that teachers' and principals' participation in STEM forums will require the input of different stakeholders.

Figure 17: Support for teacher and principal participation in external STEM forums



Similar to findings from teachers and principals, the local education officials indicated that the forums for teachers of STEM are organized termly (quarterly) and teaching and learning approaches and student assessment were the most frequently discussed issues (**Figure 18**). They also considered these forums useful in improving the quality of STEM education. Majority of the education officials had participated in a least one forum for teachers of STEM in the last one year with support from the local educational authorities (

Figure 19). They indicated the issues that were frequently addressed in these forums as STEM strategies, teacher support, and student performance. In addition, they also found these forums useful but about a third did not find them useful in improving the quality of STEM education which may call for a review of the quality of these forums.

Figure 18: Frequency, content, and usefulness of Teacher STEM forums – Education Officials

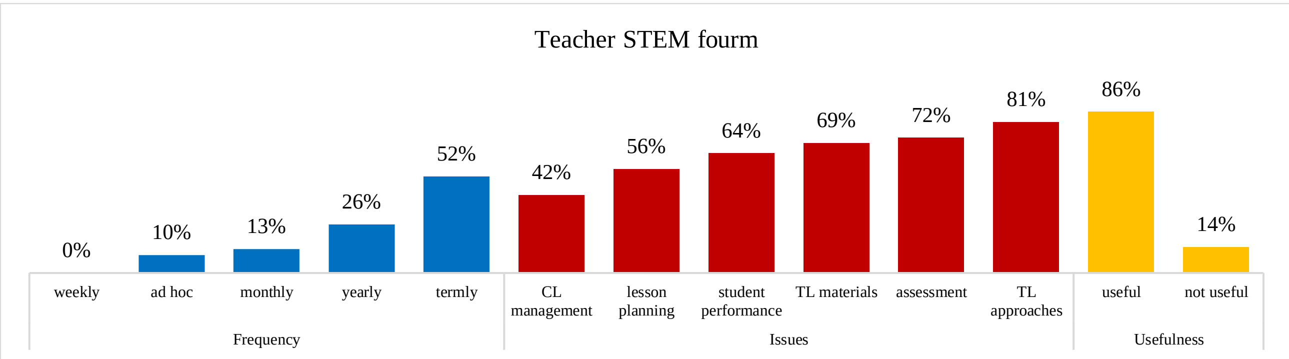
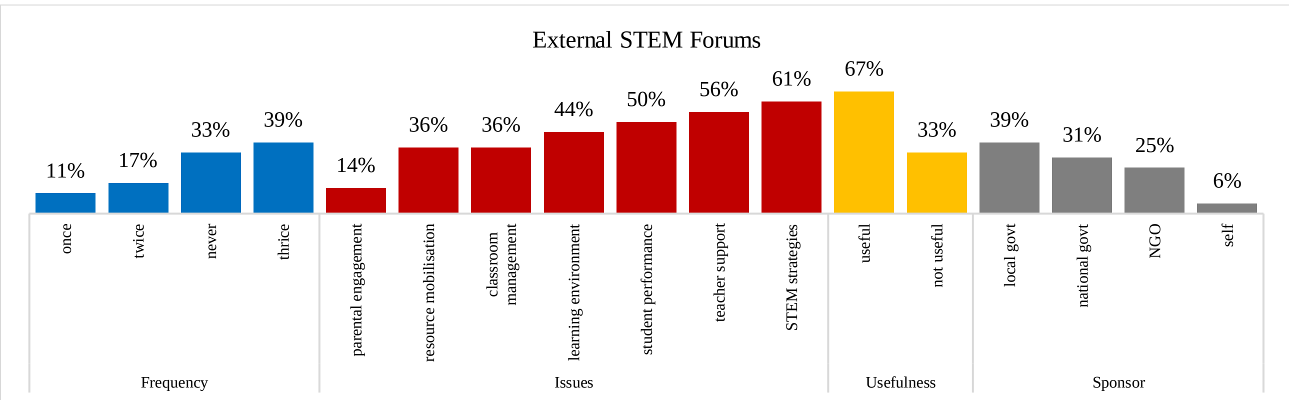
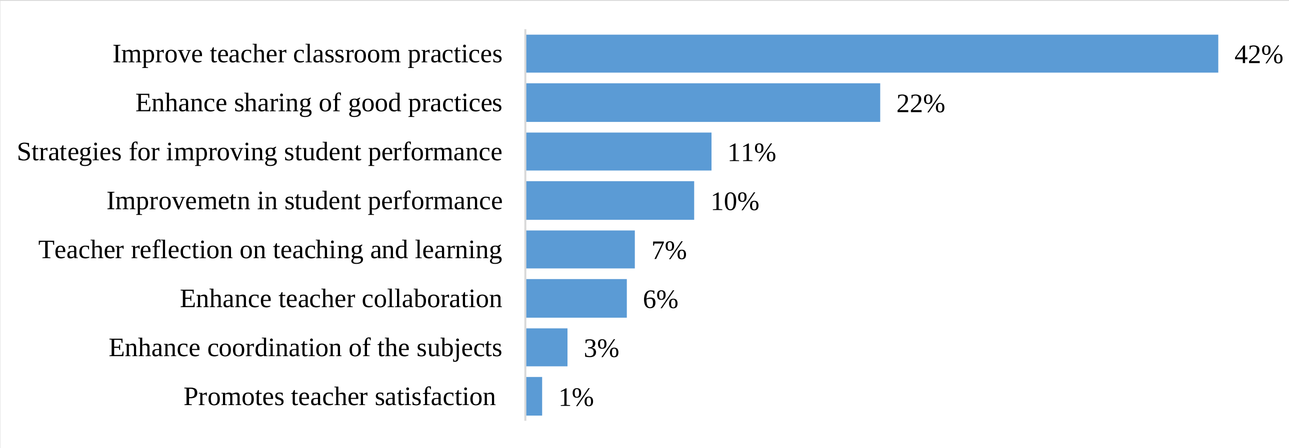


Figure 19: Frequency, content, and usefulness of STEM forums – Education Officials



Why were the STEM forums considered useful in improving quality of STEM education?
Both the school based and external forums on STEM education were considered beneficial by both teachers and principals of schools (**Figure 20**). In particular, the forum contributed to improvement of teacher classroom practices, enhanced sharing of best practices among teachers, and developing strategies for improving student performance in STEM subjects.

Figure 20: Importance of STEM forums for teachers



Teacher participation in STEM forums has contributed to improvement in teaching approaches, school management, strengthening of STEM related co-curricular activities, and teacher motivation. These key themes are further elaborated in the following.

- **improvement in teaching approaches:** STEM teachers indicated that participation in STEM forums was useful in improving teaching and learning approaches as they are supported in identifying strategies for improvement in teaching. Consequently, some teachers indicated that they have improved on their areas of weaknesses in pedagogical practices. The following are some comments from the teachers regarding how they have been supported in improving their teaching and learning approaches:

> *"The discussion covered improved ways of delivering a lesson and some new ways of teaching different topics and how to ask questions that need critical thinking. The sessions enabled us to improve our teaching and learning approaches".*
> ***Teacher, Ohangwena Region, Namibia.***

> *"The reports from the evaluation exercise, suggested a number of ways to improve on the STEM activities in the school and was quite helpful in forging the way forward".*
> ***Teacher, Aberdare Region, Kenya.***

- **improvement in school management:** Some of the STEM forums contributed to school development planning as attested by the following comments from a teacher:

> *"Furthermore, the forums guided the school management in planning for gender sensitive way of resources allocation. Additionally, it supported the school improvement of the day-to-day management in order to achieve their goals including motivation to the school staff to continue working harder".*
> ***Teacher, Eastern Region, Uganda.***

- **establish co-curricular programme:** Some teachers were able to establish STEM co-curricular activities from the advice and feedback acquired after participation on STEM forums as indicated by the following comment by a teacher:

“We managed to establish a science club and robotics club at the school and had more learners participating in STEM competitions (Science Olympiads, Eskom Expo for Young Scientist, etc)”.
Teacher, Limpopo Province, South Africa.

- **motivation to teachers:** the STEM forums are a source of motivation for the teachers particularly when they are encouraged on areas where they are performing well or when teachers are given a chance to share their plans for improvement. The following are some are illustrative comment by teachers:

“When they visited, they confirmed that the level of assessments at our school was at par with that of the common assessments set by the Department of Education”.
Teacher, Durban, South Africa

“We managed to share with them our experiences and strategies to be put in place to enhance performance. We were able to evaluate our internal processes and come up with effective teaching and learning standards”.
Teacher, North West Region, Botswana

“The feedback shows us where there is weakness to correct and improve and where we have done well and need to continue”.
Teacher, Rwanda.

“The Ministry of Education is collaboratively working with teacher training institutions like the University of Botswana in keeping teachers up to date with the changes. For example, at times some teachers are sent outside to other countries to attend to some workshops on STEM subjects and the Ministry of Education facilitates in collaboration with teacher training institution lecturers. Or at times the Ministry of Education and training institutions hold workshops for teachers on STEM Subjects. This is very motivating for the teachers.
Teacher, Kweneng, Botswana”.

4.5.4 Effectiveness and challenges of using online technologies for participation in STEM forums

A high proportion of teachers, principals, and education officials indicated that online technologies were effective for participation in online STEM forums (**Figure** 21 and
Figure 23). However, they noted several challenges in using online technologies to access forums, key among them being internet connectivity, and cost of internet. Meanwhile, inadequate devices, sources of power, and lack of time were of more concern to the teachers than the principals. Overall, the teachers were more likely than the principals to experience each of the challenges.

Figure 22: Effectiveness and challenges of participation in online STEM forums

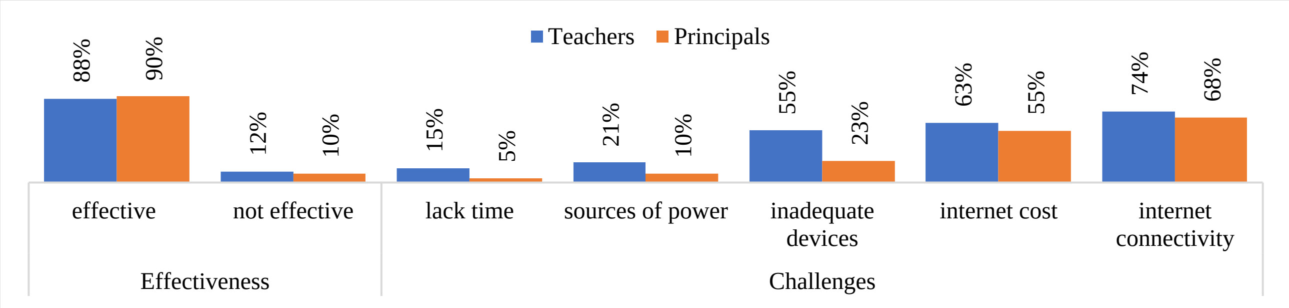
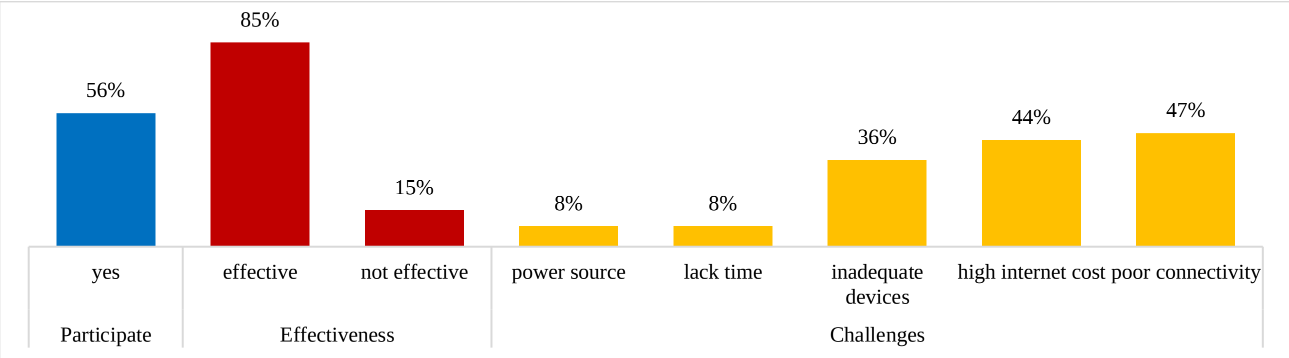
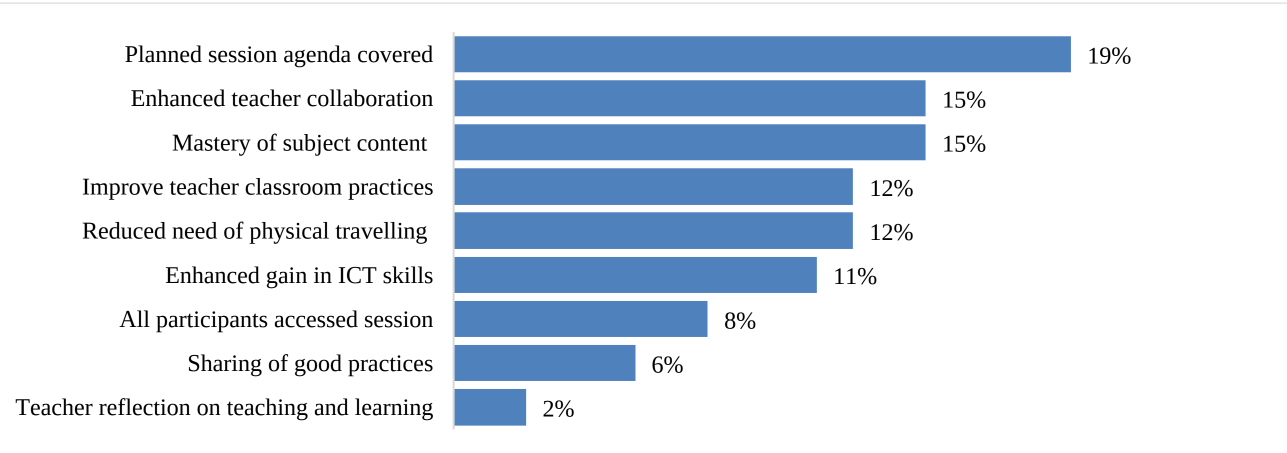


Figure 23: Effectiveness and challenges of participation in online STEM forums -Education Officials



The main reasons given by teachers, principals, and education officials for the effectiveness of the online forums on STEM were that the planned sessions agenda were covered; it enhanced collaboration among participants; and improved teacher content mastery, improved teacher classroom practices; and reduced the need for physical travel that is associated with face-to-face forums (**Figure 24**)Figure 24.

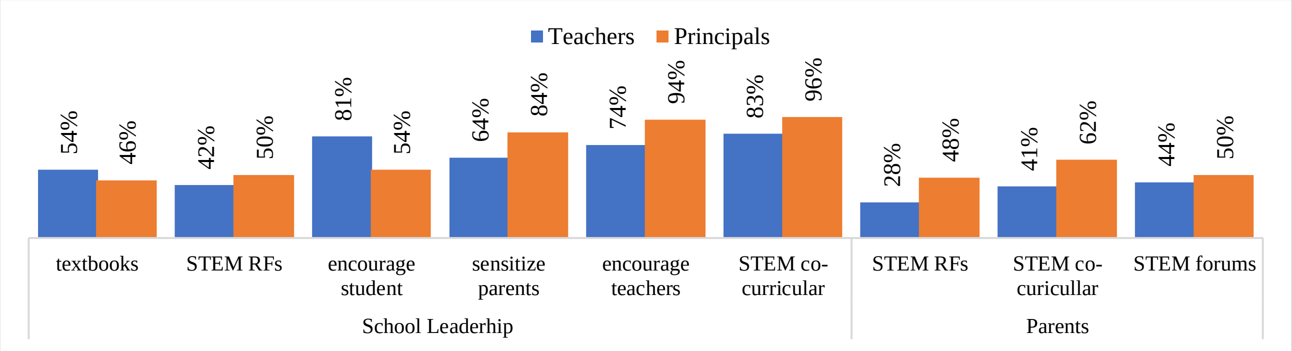
Figure 24: Reasons for effectiveness of online STEM forums



4.5.5 School leadership and parents' support for STEM

The key supports provided by the school for STEM education were encouragement of teachers and students, co-curricular activities in STEM, sensitization of parents (**Figure 25**). As noted elsewhere, resources and facilities are the least supported and this could be attributed to inadequate funding of schools. Meanwhile, both teachers and principals indicated that parents' support for STEM education was in the form of provision of resources and facilities, support of STEM co-curricular activities, and engagement in STEM forums. However, a lower proportion of teachers and principals indicated parent support which aligns with the earlier observations about inadequate parental support.

Figure 25: School leadership and parents' support for STEM



4.5.6 School Development Plan

Slightly over a third of the school principals indicated that they had a School Development Plan (SDP) (**Figure 26**), and out of this number, about a quarter indicated their SDP had an objective on improvement of STEM education in their schools. Among those who had a STEM improvement objective, only a quarter were implementing them. The key strategies in the SDP regarding STEM education were; provision of equipment and materials, professional development of teachers of STEM, building of science laboratories, and student mentorship on STEM subjects.

Figure 27: STEM strategies in the School Development Plan

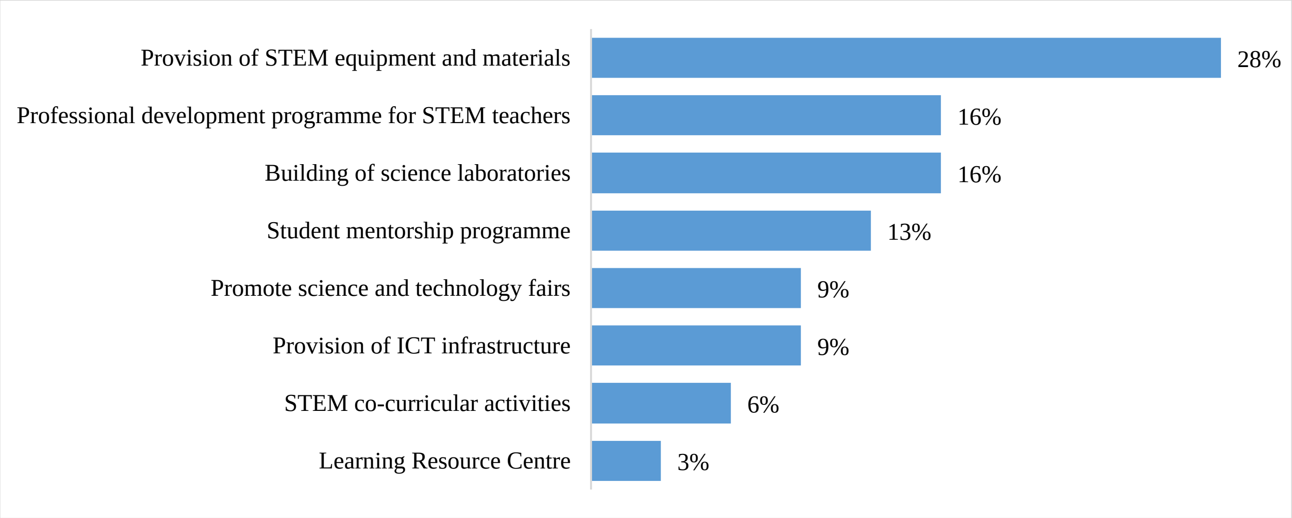


Figure 26: School Development Plan

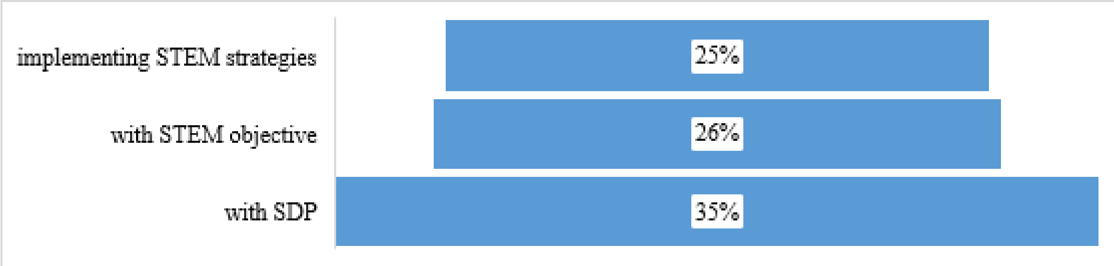
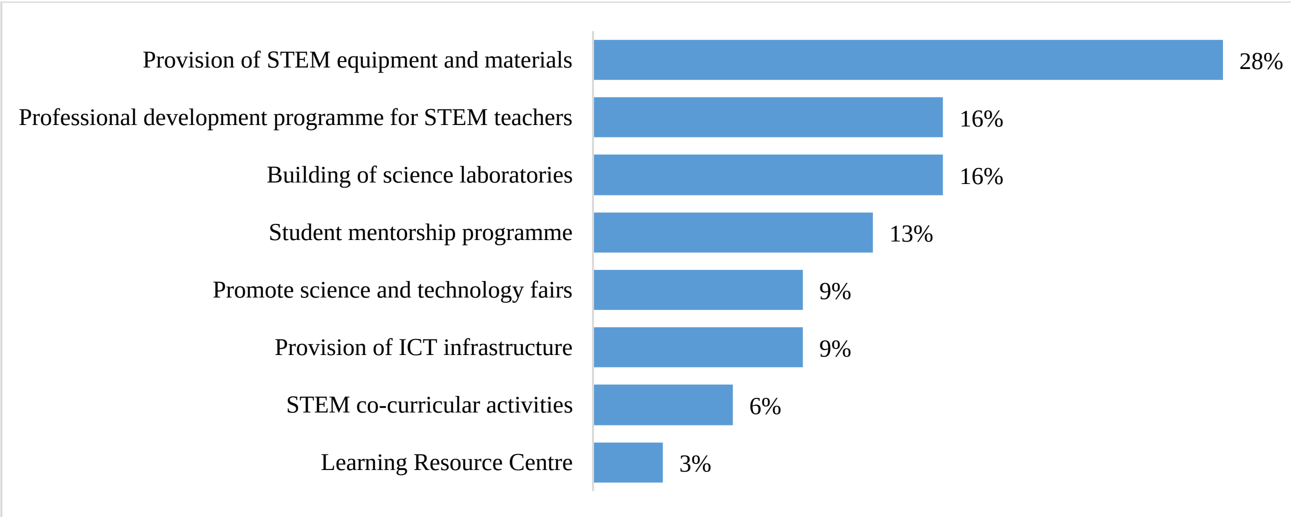


Figure 27: STEM strategies in the School Development Plan



4.5.7 Priorities and strategies for improving quality of STEM education

Has the Ministry of Education developed a policy or national plan that addresses STEM education at the basic learning level? If there is a policy or national plan on STEM education or these are included in a policy or national plan of the education sector plan, what are the key priorities that are addressed in the policy or national education plan regarding STEM education at the basic learning level? Other than an education policy or national plan on STEM subjects at the basic learning level, are there other interventions in the country that are aimed at improving the quality of these subjects?

Interviews with the senior education officials indicated that all the target countries have an education sector plan within which the issues of STEM education at the basic learning level are embedded. Therefore, there are no stand-alone policies or sector plans on STEM education at the moment. However, some countries have an ICT in education policy, for instance, Rwanda and Kenya, that addresses some issues of STEM education including integration of ICT in teaching and learning of STEM subjects. The following are the key priorities in the national education sector plans, policies, strategies, focusing of STEM education at the basic learning levels: teacher professional development in teaching and learning of STEM subjects, improving student performance in STEM subjects, improving student enrolment in STEM courses in tertiary institutions, strengthening of STEM courses, integration of ICT at all levels of education, improving teaching and learning through e-learning, and equipping schools with adequate ICT infrastructure. These are the priority areas in the education sector plans, and initiatives being implemented for improvement of quality of STEM education at the basic learning levels:

i. Teaching and Learning Resources and Facilities for STEM Education

In **South Africa**, the SASOL Foundation of South Africa has been supporting some schools with workbooks and textbooks for mathematics, science, and technical subjects. Meanwhile, Vodacom has supported 147 District Teacher Development Centres (DTDC), through the Department of Basic Education (DBE), with internet connectivity. In these resources centres, teachers from schools in the district can access resources, continuous professional development courses, and teacher professional learning communities (PLCs) have a venue for meetings. Furthermore, in **South Africa**, the Mathematics, Science and Technology Academy (MSTA) broadcasts mathematics, science, technology lessons through their online platform. The lessons are accessible to anyone with connectivity. In **Kenya**, the government has been supporting some schools with laboratory equipment, and construction of laboratories. In **Rwanda**, the government has been providing teaching and learning materials, including science kits, laboratory equipment, and textbooks. In **Uganda,** the government has been supporting some schools with science kits, laboratory equipment and chemical, and construction of science laboratories. Additionally, the government in partnership with the World Bank has invested in infrastructural development of vocational schools. Furthermore, the Uganda Communications Commission (UCC) has provided computers to some schools.

ii. Teacher professional development in STEM

In **Ghana**, the Ministry of Education is constructing 20 STEM centres across the country which will serve as teacher professional development resource centres as well as models of excellence in STEM education. The Ministry of Education has also rolled out a capacity building programme on pedagogical practices for teachers of core subjects, which include mathematics and science and so far, has reached 14,000 teachers across the country. In **South Africa**, the mathematics teaching and learning framework aims at transforming the teachers' mathematics pedagogical-content knowledge (classroom learning practices, content, teaching, and assessments). The emphasis will be on teaching of mathematics for understanding through learning-centred classroom methodologies with the overall objective of improving learning outcomes in mathematics. In **Botswana,** a partnership between the Ministry of Education and the University of Botswana has focused on teacher education through workshops to improve on their pedagogical practices. In **Rwanda**, the Ministry of Education in partnership with development partners are promoting school-based continuous professional development initiatives with emphasis on collaboration among teachers of STEM to ensure they work and learn together. The schools are being provided with computers and internet connectivity in support of this initiative.

iii. Improve student enrolment in STEM at tertiary institutions

In Ghana, the Education Strategic Plan for the year 2018 to 2030 has a priority on STEM education focusing on improving the tertiary enrolment in the Science, Engineering and Mathematics fields.

iv. Improve student performance in STEM subjects

In **South Africa**, the Action Plan to 2019; Towards Realisation of Schooling 2030 has 27 goals and nine of these are specific to STEM education and includes:

- Goal 3: Increase the number of learners in Grade 9 who, by the end of the year, have mastered the minimum language and mathematics competencies for Grade 9
- Goal 5: Increase the number of Grade 12 learners who pass mathematics.
- Goal 6: Increase the number of Grade 12 learners who pass physical science.
- Goal 8: Improve the average performance of Grade 6 learners in mathematics.
- Goal 9: Improve the average performance of Grade 9 learners in mathematics.

In **Namibia**, there are national performance targets for each subject set by the National Planning Commission in the central government. These targets are reviewed every year based on the outcomes in the previous year.

v. Science and Technology Fairs

In **Ghana**, the Ministry of Education have been supporting the Ghana Science Olympiad every year in November and is now in the third year. Through this initiative, two students selected from underprivileged schools based on their performance in mathematics and science are brought to the Olympiad. In this event, the students compete in different practical scientific activities and winners get awards. Through this strategy, the students are exposed to science activities, equipment and processes and get inspired to learn more and they become champions and ambassadors of STEM in their schools and communities. These events also contribute to motivating the teachers of mathematics and science. In **Kenya**, the Ministry of Education in partnership with development partners, including the private sector players, coordinates and funds the annual 'Kenya Science and Engineering Fair' that starts from the local to national levels, where students present ideas and innovations in science and technology. Meanwhile, in **Botswana**, the Ministry of Education in partnership with two universities; the Botswana International University of Science and Technology (BIUST) and University of Botswana, has been working on improving students' interest in STEM through science fairs, exhibitions, and road shows. In **Uganda**, the government supports the science and technology fairs which are held from the local to the national levels.

vi. STEM Clubs in Schools

In **Rwanda**, STEM Clubs are being encouraged in schools as a strategy of creating interest in this area in both primary and secondary schools.

vii. Integration of ICT at all levels of Education

In **Rwanda**, the education sector plan has prioritized integration of ICT in all levels of education. This will focus on approaches for integration of ICT in teaching and learning and equipping of schools with adequate ICT infrastructure. In **South Africa**, the Professional Development Framework for Digital Learning has been developed as a guiding document on integration of ICT in education.

viii. Strengthening of STEM courses

The **Rwanda** National Transformation Strategy has prioritized strengthening of STEM for boys and girls across all levels of education to position Rwanda among the leading African countries in technology and innovation by 2035. Meanwhile, continued development of a market-driven technical and vocational education and training (TVET) system is prioritized as being crucial in training and upskilling workers to meet the needs of the changing labour force demand while prioritizing study based competitive areas for all Rwandans, with special focus on ensuring equal access for women and girls. Accordingly, the curriculum for different levels of education will ensure adaptability to present and future types of new skills need.

4.6 Impact of interventions in STEM education.

This study also explored the impact of the interventions on quality of STEM education in the target countries. This information came from teachers, principals, local education officials and senior education officials. The issues that were explored included both the process of gathering impact information and the actual impact observed. The specific issues explored included the mechanism for quality assurance of STEM education, staffing of the quality assurance function, budgetary allocation, availability of key performance indicators, and whether education officials conduct quality assurance and how this conducted. Additionally, specific impact that has been observed was also explored. The findings are presented in the following sub-sections.

4.6.1 Institution or Department for Quality Assurance of STEM Education

Is there a dedicated / specialized institution of the Ministry of Education for quality assurance of STEM education at the basic learning level? [If 'Yes', indicate the name of the institution].

Out of the 17 senior education officials interviewed, 15 (80%) indicated there was an institution within the Ministry of Education that focused on the quality of STEM of education. However, where this institution existed, quality assurance was not the key mandate and what emerges is that there is not a stand-alone and specific institution at the moment in any of the countries that is charged with this function, but the function is embedded within existing institutions or departments that are responsible for the quality of education in general. The following are examples of departments or institutions that are responsible for education quality; a) the Inspectorate Unit in the department of basic education of the Ministry of Education in Botswana; b) Ghana Education Service , National Teaching Council, and the National School Inspection Authority (NSIA) in the Ministry of Education of Ghana; c) the Directorate of Quality Assurance and Standards (DQAS) in the Ministry of Education and Centre for Mathematics, Science, and Technology Education in Africa (CEMASTEA) in Kenya; d) the directorate of programmes and quality assurance in the Ministry of Basic Education in Namibia; e) the department of basic education and quality assurance in the ministry of education in Rwanda; f) the directorate of education standards in the Ministry of Education and Sports in Uganda, and; g) the national institute of for education development, research, and pedagogical inspection in Angola. However, there are attempts in some countries to develop specific institutions with a specific mandate on quality of education including STEM education. For instance, South Africa is in the process of establishing the Mathematics, Science and Technology Institute, while in Rwanda, the National Examinations and Standards Authority (NESA) will take this function. At the moment, CEMASTEA in Kenya is contributing to this function, although this is not clearly established in its mandate.

The closest example of staff establishment dedicated to STEM within the Ministry of Education was in South Africa where there is a Directorate of Mathematics, Science, and Technology (MST) including ICT with staff dedicated to each of these STEM areas. Under this directorate, the mathematics, science, and technology strategy are being reviewed towards the development of the Institute of Mathematics, Science, and Technology with a proposed staffing structure. Currently, the Directorate does not have staff dedicated to this directorate but engages staff drawn from the mathematics, science, and technology curriculum departments. However, the directorate will now have technical staff, specialised in teaching and learning. These staff will be in charge of monitoring and evaluation of the teaching and learning process, student participation in this process, and how this affects performance. This decision is informed by the observation that the teaching and learning process is currently affecting performance or the participation of learners because in many schools, a lot of learners are dropping in mathematics and enrolling Mathematical literacy, a subject that was introduced in South Africa for a different reason. The Directorate of MST deals with the curriculum, teaching and learning resources, and policies. It is a fully-fledged directorate with a Director, and a Chief Educational policy specialist at Deputy Director level, for different subjects and for different entities. The proposed institute of MST will be semi-independent with a focus on quality assurance for MST.

4.6.2 Staffing for Quality Assurance of STEM Education

Does the Ministry of Education at the HQ have specialized staff dedicated to quality assurance of STEM education at the basic learning level? [If 'Yes', indicate the number of staff].

Out of the 17 senior education officials, 12 reported they have specialized officers in the Ministry of Education who are in-charge of quality assurance of the STEM subjects. However, only three countries could indicate the number of staff, for instance two each in Namibia and Angola, and 10 in Rwanda. The 10 staff in Rwanda are subject inspectors in charge of mathematics, biology, chemistry, and physics. However, the specific mandate of these officers appeared to be broad as they also doubled up in other functions including teaching and training. Furthermore, some of these officers are either located within the Ministry of Education or in on-going national STEM improvement projects as was the case of SESEMAT project in Uganda.

4.6.3 Budgetary Allocation for Quality Assurance of STEM Education

Does the Ministry of Education at HQs have an annual budget allocation dedicated for quality assurance of STEM education at the basic learning level?

Fifteen of the 17 senior officials (88%) indicated there was a budget dedicated to the quality assurance in the Ministry of Education, but this was not specific to STEM education, and none could either specify an amount for the overall quality assurance directorate or specific allocation for quality assurance of STEM education. However, all the officers indicated that the budget for quality assurance was not adequate. The current practice is that the budget is allocated as a lumpsum to the department in-charge of quality assurance who then apportion the amounts for each functional area on a needs and on-going basis. Almost all the officers indicated that budget was not adequate to deliver on the mandate of quality assurance in general, and not specifically for the STEM education sub-sector. However, there were instances where the allocation for STEM education within the Ministry of Education, though not specifically for quality assurance *per se,* was more specific as was the case of budgetary allocation for CEMASTEA in Kenya, where a specific amount is devoted for monitoring and evaluation of the STEM programme in Kenya.

The following are illustrative examples of attempts in budgetary allocation for STEM education in select countries:

i. **Kenya:** The Centre for Mathematics, Science, and Technology Education in Africa (CEMASTEA) in Kenya receives a capitation grant amount from the Ministry of Education that is allocated based on student enrolment in secondary and primary schools in Kenya. These funds are shared by the MOE to CEMASTEA for disbursement to the County Education Boards (CEB) in the 47 Counties to support capacity building interventions for teachers of Mathematics and Science within those counties, and other related supportive activities. The County Education Board in collaboration with CEMASTEA uses these funds in implementing activities that are either planned at the national or at the county level with approval from CEMASTEA. Within this system, CEMASTEA regularly conducts monitoring and evaluation of quality of STEM education and reports on the same to the Ministry of Education and other key stakeholders.

ii. **Rwanda:** Meanwhile, in Rwanda, the REB has a budget that is devoted to STEM, for instance, science competition. Even if it is the money for only inspection, that money is not too big. Still in Rwanda, the funds devoted specific to school inspection in general, may not be adequate. However, a lot more funding is devoted to improving the quality of STEM education through input like construction of science laboratories and procurement of science laboratory equipment, and science kits. The specific amount that has gone into this was not stated or whether this is an activity receiving annual budgetary allocation.

iii. **South Africa:** After a three-month Mathematics, Science, and Technology strategy development, the next step is mobilisation of funds for implementation. The government has indicated that implementation will use the existing budgetary allocations. Therefore, the team is looking at the different departments within the Ministry of Education where funds could be used for implementation. For instance, the Department of Higher Education and Training has a budget allocation for training, specific to professional development of teachers, while the departments of Basic Education, and Science and Innovation, also have budget allocations that could be leveraged in implementing the strategy. Furthermore, beyond the public sector, the government is looking at development partners and public-private partnerships for resource mobilisation towards implementation of the policy. Currently, parliament allocates the Mathematics, Science, and Technology (MST) grant of 400 Million Rand (USD 27M) which is equitably shared across the nine provinces to support MST curriculum implementation within the provinces. However, this amount is not enough as the need is high and has now been exacerbated by the COVID-19 pandemic which now calls for ICT infrastructure and devices, improved internet connectivity, and training of teacher on how to deliver instruction through online technologies. At the moment funding is low due to the lockdowns occasioned by COVID-19 pandemic meaning there are no tax revenues. A small component (10%) of the MST grant is allocated to the headquarters for coordination, support, oversight. Meanwhile, the MST directorate monitors whether the provinces are spending according to a framework that requires 50% to go to resources and facilities (science laboratories, ICT infrastructure, etc), while 30% goes to professional development.

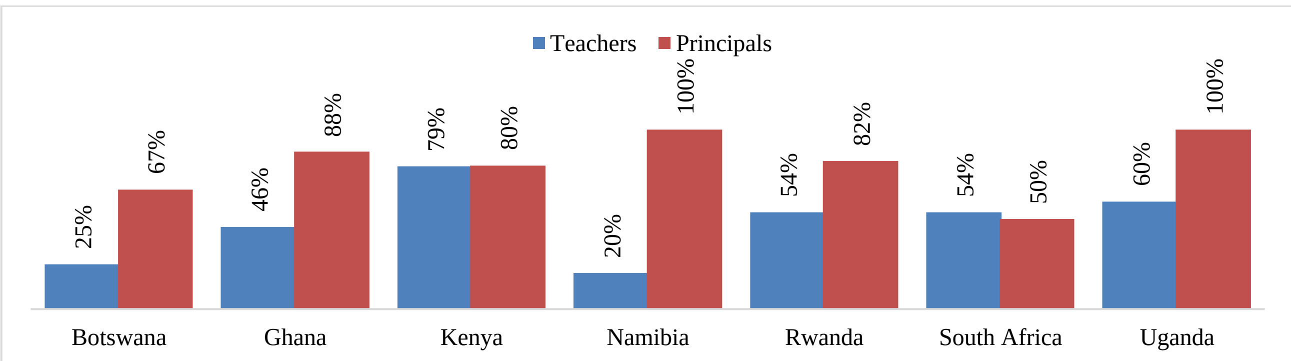
iv. **Uganda:** Funding for SESEMAT is done at the national level by the Ministry of Education but the activities at school level are funded by the student with each UGX 1,000 (USD 0.82) per year. The budgetary allocation at the national level is disbursed quarterly but it is not specific to STEM for quality assurance in secondary schools in general. However, the money is not adequate, and it is not possible to cover all regions in the country, so only a few of them are covered.

4.6.4 Key Performance Indicators (KPIs) used for tracking quality of STEM education

In tracking progress in improvement in the quality of STEM education, Key Performance Indicators and targets are critical as they serve as signals on progress towards quality improvement. Therefore, there is need for a set of clearly articulated indicators and respective targets at the national level, regional level, and school level. Some indicators may be relevant only at certain levels in the system, for instance at the national or school level, while others may cut across the different levels on the education system. As part of the system for monitoring the quality of STEM education, the teachers, principals, and education officials were required to indicate the Key Performance Indicators (KPIs) that they were using for tracking quality of STEM education, in their subjects in schools, regions, and in the country, respectively. The information gathered was analysed and presented in graphs and tables.

Overall, teachers and principals had KPIs that they were using in monitoring the quality of STEM education in their subjects (**Figure 28**). However, there were differences across countries with proportionately more teachers in Kenya, Uganda, South Africa, and Rwanda in that order having a higher proportion of teachers indicating the availability of the KPIs. Meanwhile, Namibia, Uganda, Ghana, and Kenya had a higher proportion of principals indicating availability of the KPIs. Furthermore, a higher proportion of principals than teachers indicated availability of KPIs in their schools for tracking quality of STEM education. This trend appears to be associated with the trend observed in the proportion of teachers and principals who indicated they were participating in STEM forums within and outside their schools (Figure 27).

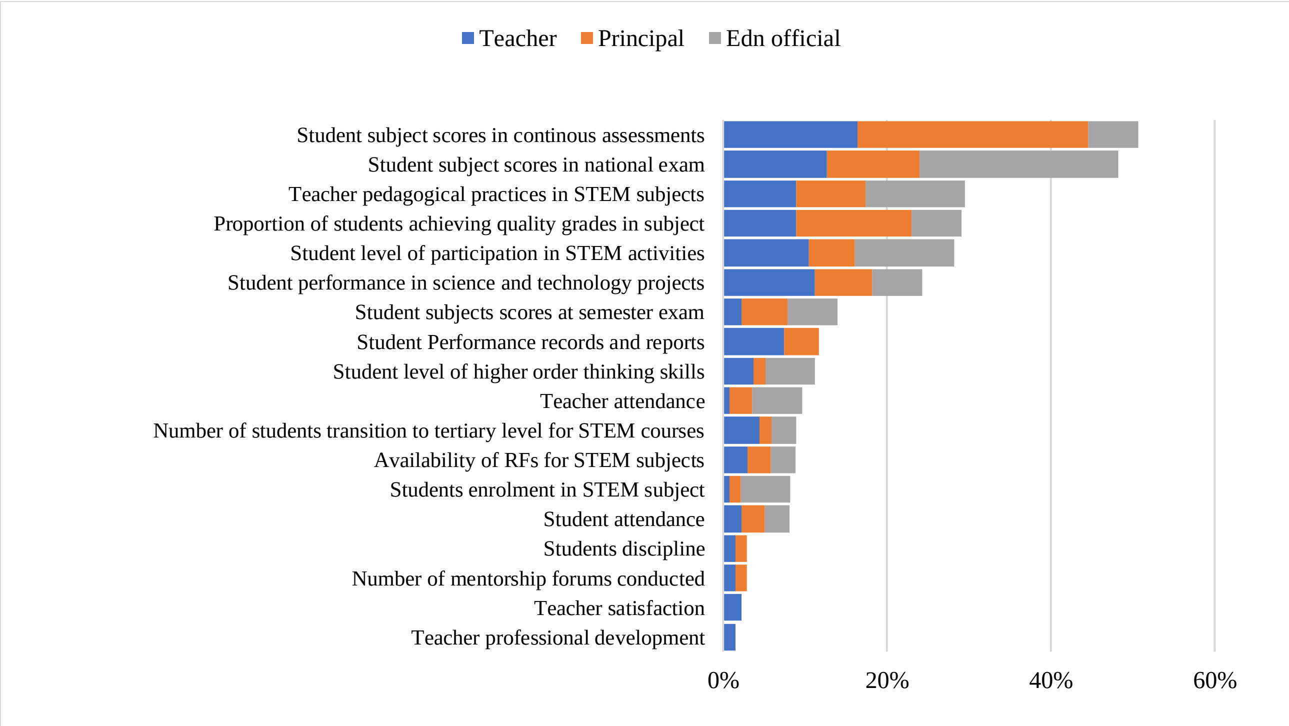
Figure 28: Teachers and Principals with KPIs for monitoring STEM Subject



Teachers, principals, and education officials identified 18 indicators that were used in monitoring quality of STEM education (

Figure 29). The top three most frequently mentioned indicators were student subject scores in continuous assessments, proportion of students achieving quality grades in the subject, and student scores in national examinations. Other equally important indicators that were mentioned included teacher pedagogical practices in STEM subjects, student performance in science and technology projects, and students' level of participation in STEM activities. However, there were some differences between teachers and principals in terms of prioritising the indicators, for instances, the principals placed a higher priority on the subject scores in continuous assessments, while teachers placed more priority on the proportion of students achieving quality grades in subjects. While there were similarities in type of indicators between teachers and principals, these differences could imply lack of consensus at school on how to track quality of STEM education, or this area was not prioritized at school level.

Figure 29: KPIs for monitoring quality of STEM education



Cumulatively a total of 205 indicators were mentioned by the teachers and principals and based on an analysis of the content of these indicators, they are grouped into different levels of the results they were tracking including: inputs, activities, outputs, lower outcomes, and higher outcomes (

Figure 30). While the focus of STEM education should be to enable students achieve higher outcomes, these findings indicates that almost a third of the areas that were being tracked by teachers and principals were outputs, activities, and inputs. Meanwhile, more than half of the areas being tracked were lower outcomes, which were largely subject scores of either internal school continuous assessments or national examinations. The higher outcomes, which should be the areas of greater focus in STEM education were less prioritized.

Figure 30: Level of results of quality STEM education tracked at school

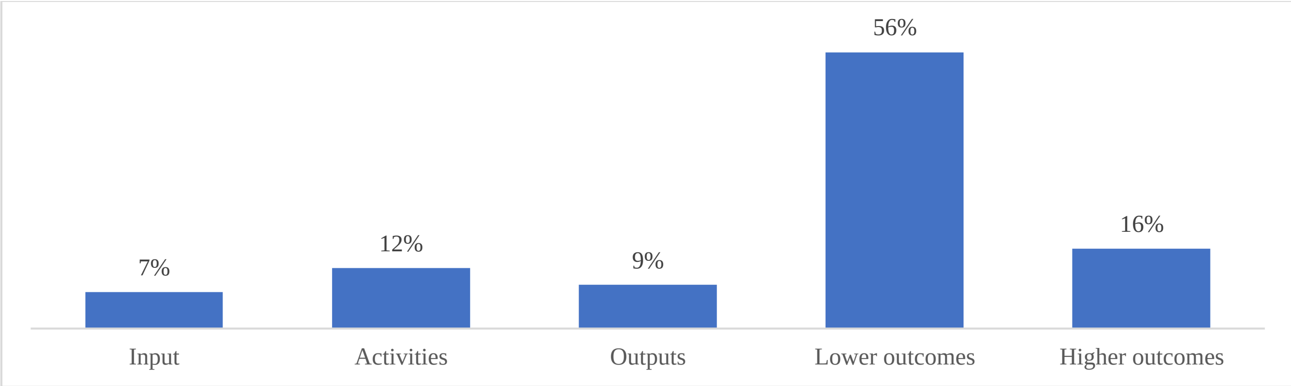


Table 6 shows the specific indicators that teachers were using in tracking the quality of STEM subjects which shows a wide range of indicators, mostly general in nature, and inconsistent. This could imply that the teachers may not be fully equipped with improved methods of tracking the quality of STEM subjects and mainly rely on the traditional approaches in the form of subject scores based on internal school tests and national examinations.

Table 6: KPIs for tracking Quality of STEM by Teachers

What are the Key Performance Indicators that you use to track the quality of STEM education in your school?
Inputs
Grading system, involvement of stakeholders in the education of learners, marks book, tools to measure or monitor, ICT teaching and learning materials, class test, national exams, end of year exam, teacher satisfaction, Improvement index in stem subjects, availability of teacher instructions instruments, change in school environment,
Activities
Use grade system to evaluate the performance of students in different subjects, class test, competition records, conducting of exams every month, continuous assessment tests, course projects in the school, group activities, laboratory experiences, lesson planning, make learners to be aware of things not understood and areas of difficulty, making science clubs, monthly tests, open discussion of analysis reports from different departments, professional development, use of realia for more practices, school reports, science competition at school, setting of objective test to evaluate learners' application of concepts in the subject, setting up of physical projects in the school for learners to have hands on experience, summative evaluation, teachers supervise student during night self-learning, teaching methods, assessment, formative evaluation, activities learners have been engaged in teaching and learning, remedial lessons planning and implementation, engage with all school stake holders to achieve our objectives.

Outputs
Class exercises, attendance, handling of apparatus or equipment and the ability to use them appropriately, learner response to project work and assignment, increase learner enrolment in STEM subjects, increase learner participation in STEM projects, keeping learner profile, learners participation in science fair and symposia, list of STEM participants, marks record, number of learners achieving pass for the subject at different grades (disaggregated by gender), participation in science competitions, participation in national science and engineering fair, participation of students in clubs, report form of students at the end term, results of learners syllabus content feedback, robotics performance in STEM subjects, school report, student participation in science fair, students assessments completion of topics, students participation during lessons, students participation during lessons, students participation in STEM activities, students results report, timely syllabus coverage.
Lower outcomes
Coming up with STEM schools exchange programmes, attitude change towards the subjects, student change in behaviour, student innovation, choice of STEM related courses for tertiary education, comparison with of performance of other schools, comparison with previous results and the performance of other schools, completion rate, discipline referrals, district tests, grades that are earned in STEM subjects, improved learner performance level, improvement among learners performance, improvement in performance achievement levels, improvement in success in national examinations, learners perform well in national examination, learners perform well in STEM competitions, more experiences and practices, national terminal high school examination performance, outcome of final results, outcome of semester results, pass rate, percentage of the students with the highest grade, percentage pass rate in the various subjects in WASSCE, performance in stem subjects in national examination, performance in tests, performance in the subject, performance in WASSCE results in STEM subjects, performance of STEM subjects, results of national examination done at the end of every year, results of national examinations in science and mathematics in our school, student achievement, student performance, student achievement, student performance in weekly tests, student's results, students results in the stem subjects, subject score, termly tests, test score, value addition index per student in key subjects, yearly percentage of scores, critical analysis.
Higher outcomes
Ability of students to design and come up with projects in Maths and Science fair, quality of students' ESD projects, student performance in agricultural projects like rabbit keeping and crop yields, student performance in real projects like making sanitizers, collaboration, communication, enrolment in STEM related courses in the university, increase collaboration between schools, innovation, creativity, inquiry skills, initiative, number of students pursuing science related courses at higher institution, number of students pursuing stem related courses in higher institution, problem solving, progression of my students in universities of sciences and technology (both boys and girls), comparing results of national examinations with other local school, student choice of science related careers, students ability to solve real problems, students' confidence during presentation, team work, creativity of students, digital literacy.

Interview with senior education officials provided more information on the key performance indicators that they considered important in the tracking progress in quality of STEM education. However, they did not indicate specifically at what level in the system that the indicators would be relevant. Additionally, it was apparent that, while they had ideas about what could be tracked, the focus in practice has been on very few indicators related to student performance in national examinations. Therefore, the indicators presented are indicative of what could be tracked in assessing the quality of STEM education but there was no information to indicate whether they were actually being tracked. The following are the key performance indicators that were suggested based on the thematic analysis of the interviews: a) teacher pedagogical practices in STEM subjects; b) student performance in national examinations; c) Quality of continuous teacher training programmes; d) Number of students enrolled in STEM subjects; e) Number of trained teachers of STEM subjects; e) Availability of teaching and learning resources and facilities; f) Satisfaction of teacher of STEM in their work; g) Teacher attitude towards teaching of STEM subjects, and h) Number of school based STEM activities being implemented. These indicators are further elaborated based on analysis of the information gathered through the interviews:

i. Teacher pedagogical practices in STEM

In **Ghana**, there is a deliberate focus on transforming teaching and learning of science from theoretical to practical, activity-based approach, with the aim of demystifying the science subjects. Therefore, teachers of STEM are trained on the pedagogical practices that promote practical, and activity-based teaching and learning approaches. Using these approaches, learners are expected to enjoy science lessons and understand the underlying concepts, ultimately improving their performance in these subjects. Therefore, in **Ghana**, the specific areas of focus in teacher pedagogical practices are type of activities and exercises that students are engaged in through lesson observation, review of student workbooks, conversation / interview with students on their participation on STEM activities, and teacher preparedness for the lesson. In **Uganda,** the specific areas of focus in teacher pedagogical practices are lesson preparation, availability of a lesson plan, and use of hands-on learner based practical activities in the lesson.

"our program emphasizes learner based or activity-based teaching and learning. So, we want the teachers to teach by doing and the learners also to learn by doing. So, if we went to a school and found a teacher teaching without any practical activity in the lesson, we consider that as a reference lesson that can be used to demonstrate the starting point towards improvement in practical activity-based teaching and learning approach".

Senior Education Officer, Uganda.

ii. Student performance in national examinations

In **Kenya**, there is a focus on student performance in the national examinations, specifically, the Kenya Secondary Certificate of Education (KCSE). Therefore, the performance trends are tracked over time for instance in mathematics or physics to establish whether there are discernible improvements over time. Additionally, a comparative analysis of performance in the different subjects is done particularly between STEM subjects and humanities. In **South Africa**, the Action Plan to 2019; Towards Realisation of Schooling 2030 has articulated education goals and their respective indicators including:

- Indicator 2.2: Percentage of Grade 6 learners performing at the required mathematics level according to the country's Annual National Assessments.
- Indicator 5: Number of Grade 12 learners passing mathematics.
- Indicator 6: Number of Grade 12 learners passing physical science
- Indicator 8: Average score obtained in Grade 6 in mathematics in the SACMEQ assessment.
- Indicator 9: Average Grade 9 mathematics score obtained in TIMSS.

iii. Quality of continuous teacher training programmes

In **Kenya**, it is anticipated that quality and continuous teacher training programmes in STEM subjects through CEMASTEA will improve teacher pedagogical practices and ultimately improve student performance in these subjects. Therefore, one of the key indicators is the quality of continuous teacher training programmes and this is led by the Research and Development (R&D) department at CEMASTEA. The information on this indicator is gathered through multiple sources including survey of teachers at the start and end of training workshops.

iv. Number of students enrolled in STEM subjects

In **Namibia**, the number of students enrolled in STEM, particularly the optional STEM subjects is a key indicator. Furthermore, the number of students who transition into tertiary institutions and take STEM courses in another key indicator that is tracked. Additionally, some of these indicators are derived from the national education sector plan. In **Uganda**, the number of students taking up STEM courses in tertiary institutions is also tracked. Furthermore, there is greater focus on the number of girls taking STEM related courses at tertiary institutions, with associated scholarship schemes for students taking up STEM based courses in both private and government institutions. A key indicator in the **Rwanda** National Transformation Strategy 1 is the percentage of graduates in STEM related programmes with a target of 44% in 2035 and 50% in 2050.

v. Number of trained teachers of STEM subjects

In **Rwanda**, the number of trained, qualified teachers of STEM deployed in schools is an indicator that is tracked over time as part of effort to ensure that schools are well staffed with high quality STEM teachers.

vi. Availability and adequacy of teaching and learning resources and facilities

As part of tracking the availability and adequacy of teaching and learning resources and facilities in schools in **Rwanda**, the statistical yearbook for education documents presents the student / textbook ratio and number of smart classrooms, increase in number of computers in schools, number of science laboratories, internet connectivity, number of schools with adequate science laboratory and science kits, among other key education indicators. Therefore, there is regular tracking of the number of science kits in schools, the number of schools with laboratories, number of computers in schools, and number of schools with internet connectivity.

vii. Teacher level of satisfaction with their work

In **Uganda**, one of the goals of the SESEMAT programme is to positively change the attitude of teachers towards teaching of STEM subjects. It is anticipated that this change will lead to change in teacher pedagogical practices, and ultimately, improved student performance in the STEM subjects. However, this is a long-term change, and in fact change in attitude and pedagogical practices are re-enforcing, and most often changes in pedagogical practices precede change in attitude. During the implementation of SESEMAT in **Uganda**, the issue of motivation of science teachers was a persistent issue as teachers felt the new teaching approach required more time to prepare for lessons, in addition to participation in trainings. Therefore, an indicator on teacher satisfaction with their work is important as this is an important predictor of teacher ability to deliver quality lessons. Regardless, mathematics and science teachers in Uganda are paid a slightly higher salary than other teachers. In **Rwanda**, there are efforts to improve the supervisory practices of the school administrators, with the anticipation that it will translate into improved rapport with teachers, nurture positive attitude among teachers in their work, and ultimately improve student performance in STEM subjects.

viii. Student participation in STEM subjects

A key indicator is learner participation in STEM lessons that is tracked in some of the countries through lesson observations.

ix. Student attitudes towards STEM subjects

Student attitude towards STEM subjects was mentioned as a key indicator with the focus of assessing positive change in attitude. However, it was not certain whether and how this indicator was being tracked currently.

x. Number of school-based STEM activities /interventions

Under SESEMAT programme in **Uganda**, a key indicator is the number of school-based STEM activities that are being implemented. Under this indicator the aspects that are tracked are: whether teachers are developing lessons plans, number of remedial lessons delivered in the school, and number of lesson observations conducted by the school administrators to support their teachers. Other aspects include the number of lesson studies that the teachers have conducted. In Ghana, an aspect that is also tracked is time allocation for STEM subjects in the school timetable.

4.6.5 Strategies and Mechanisms for Quality Assurance of STEM Education

How does the Ministry of Education conduct quality assurance of STEM education at the basic learning level?

Regarding how the Ministry of Education conducts quality assurance of STEM education at the basic learning levels in terms of mechanisms and strategies, six key themes emerged from the interviews: a) teaching and learning; b) teaching and learning resources and facilities; c) continuous teacher professional development; d) benchmarks and standards of performance; e) students' enrolment and attendance, and f) performance assessment of the Ministry of Education. In the foregoing, the findings are presented under these thematic areas.

i. Teaching and learning

Teaching and learning refer to the processes that occur between and among teachers and learners around a subject area in and outside the classroom. It is a complex process that involves teaching approaches adopted by the teacher, engagement in a subject content area, learning objectives, instructional activities, and classroom interactions. The quality of the teaching and learning process is important as it determines how well the learners are likely to learn and gain important knowledge, skills, competencies, and attitudes. Therefore, monitoring the quality of teaching and learning of STEM subjects in schools is important as it provides relevant feedback on gaps in curriculum delivery for adjustments, and what is working or not and why. This information is critical also for decision making at policy level for system wide changes.

In **Botswana**, there is a focus on the quality of teaching and learning with emphasis on shifting teacher practices from teacher to learner centred teaching and learning approaches. Therefore, teachers are observed as they teach, and after the lesson, a discussion is conducted between the teacher and the observer to identify the gaps. For instance, the teacher could be advised on how to involve the learners more in the lesson and engage them in practical activities. The MOE teams who visit the schools are not necessarily subject specialists in STEM but a mix of different subject areas. In case among them is a STEM subject specialist, for instance, a mathematics subject specialist, s/he could focus on a mathematics lesson observation at that time, and not necessarily as deliberately planned mathematics lesson observation activity in the school. This implies that the school visits and lesson observations are not meant for specific STEM subjects, but rather are general observation of the school and classroom. Therefore, there is no deliberate monitoring of the quality of teaching and learning of STEM subjects.

In **Kenya,** the Ministry of Education where Quality Assurance and Standards Officers are deployed to schools for whole school assessment organizes quality assurance exercises. Among the officers are STEM subject specialists, who check on how Biology, Chemistry, Physics, and Mathematics are being taught. However, these quality assessment exercises are not specific to STEM only. In case they observe a gap or issue on STEM subjects, they share this information with CEMASTEA who will then organize training programmes and workshops to address the identified needs in the schools. From the foregoing, it implies that monitoring of the quality of teaching and learning of STEM subjects is incidental and *ad hoc* rather than deliberately planned programmes for tracking key performance indicators regarding STEM education in the schools.

In **Uganda,** they have a conceptual framework that advocates for a paradigm shift from teacher centred or talk and chalk-based activities or pedagogies to learner centred or activity-based pedagogies. Therefore, the focus on school monitoring visits is to establish how teachers are engaging with learners in activity-based learning, or learner centred approaches in teaching of STEM subjects.

"So normally, we focus on that, if there is a shift, because normal our teachers have been characterized with the idea of talk and chalk. And which we have always discouraged as an effective pedagogy, pedagogical approach, especially at a secondary level. So, we monitor if the teacher has

activity-based teaching, and students are practicing. We have other method of co-inquiry at the students, is a teacher engaging the children into co-inquire approaches".

Senior Education Official, Uganda

They have a customized lesson observation tool that they use to observe teachers of STEM in their classrooms. The tool enables observation of lesson plan, learner participation in the lesson, lesson objectives, learner engagement, questioning techniques, and learner responses to teacher questions. These aspects of the lesson are rated on a scale with four levels accompanied with remarks based on the observations. After the lesson, the teacher and observer hold a post-lesson observation conference to discuss the observations, both strengths and areas for improvement. The observer also gives feedback on how the lesson delivery could be improved in future. This example from Uganda articulates a deliberate and comprehensive process that could enable gathering information on the quality of teaching and learning of STEM subjects.

In terms of the process of conducting monitoring of quality of teaching and learning in schools, **Ghana** has a system starting with a national inspectorate board, national team, and regional coordinators for the 260 districts. The monitoring of teaching and learning in schools is focused on teacher qualifications, their pedagogical skills, and whether students are learning. In the 260 districts in Ghana, there are 17,017 Circuits with Circuit Supervisors or School Improvement and Support Officers. Therefore, the Circuit Supervisor coordinates with the science coordinator at the district level. The monitoring of lesson delivery by the teachers is done every month, and feedback is provided to schools after the observation. The implication is that monitoring of quality of teaching and learning of STEM subjects in schools is being conducted regularly but the specific aspects of quality were neither clear nor specific in terms of the key performance indicators that were being tracked.

ii. Teaching and learning resources and facilities

Teaching and learning resources and facilities include a range of requirements in the teaching and learning process, ranging from physical infrastructure, science laboratories and their associated fittings, science equipment, reagents and chemicals, computer laboratories, computer devices, internet connectivity, power sources, and course books. These learning resources and facilities are critical in supporting learning as they are the sources of information that teachers and student engage in, for instance, the course books and internet sources. They enable teachers to design learning activities and experiences that support learning of critical concepts, and they support student experimentation and innovation that enhance their creativity and critical thinking skills. Therefore, availability of adequate, relevant, and appropriate teaching and learning resources and facilities is critical in the teaching and learning of STEM subjects.

In **Botswana,** the Ministry of Education checks on all facilities in terms of whether they are well equipped, and there is a specific unit in the Ministry that assesses school infrastructure and reports on the availability, adequacy, condition, and appropriateness of the infrastructure for teaching and learning. Among the infrastructure that are assessed are the laboratory equipment and how they are being utilized. They also sample the course books to establish their availability, adequacy, and relevance in teaching and learning. The team makes recommendations and shares the report with the schools and the Ministry of Education. This inspection is part of the school monitoring visit that also assesses the quality of teaching and learning as they visit the school as team. While this process appears good in assessing the STEM resources and facilities in schools, it is not clear how this is consolidated into a whole piece that could demonstrate the quality of STEM education, and this could illustrate the fragmentation of efforts in addressing quality of STEM education.

In **Rwanda**, the government provides teaching and learning resources and facilities including laboratories and STEM textbooks. The following is an excerpt from an education official on monitoring of STEM infrastructure in schools.

"In Rwanda, the first thing to do during the school inspection visit is to see how the laboratory is being equipped, how frequently students are visiting the laboratory, how teachers are able to conduct practical lessons, and how teachers are able to make assessment and course, to see uh how uh teachers themselves are trying to, to organize themselves to find solution to, to some of the challenges, if like in that school, they lack some materials, how teacher are being able to improvise and make thing like some demonstration using locally available materials to help students to understand the STEM concept. So basically, they will be looking at infrastructure".

Senior Education Official, Rwanda

"In terms of the books that have been delivered, what about the resources in the science laboratories, what about the resources in technical schools because technical schools have workshops, like it would be electrical workshop, it will be mechanics, mechanical workshops, where people are doing mechanical".

Senior Education Official, South Africa

iii. Continuous teacher professional development

The teacher in-service training programmes are those programmes that teachers undergo after the initial pre-service training. They are continuous in nature and are meant to continuously improve teacher pedagogical practices in response to emerging needs and gaps due to the constant change in education, including curriculum reforms. Currently, there are a range of teacher training programmes in STEM in the sample countries of different scale and scope. Monitoring the quality of these programmes is critical to gather information on their relevance, effectiveness, efficiency, impact, and sustainability in improving the quality of teaching and learning and ultimately the quality of STEM education. In this study, some countries reported monitoring of quality of continuous teacher professional development programmes undertaken.

In **South Africa**, there are subject advisers including mathematics, science, and technical subjects at the district level. They support the schools through regular visit to assess the quality of teaching and learning, for instance, they review the School Based Assessments (SBA). At the school level, the quality of the SBAs is overseen by the subject advisors who are part of the teaching staff with the additional responsibility, and Heads of Department (HoD). When teachers undertake professional development programmes, including diplomas and degrees, they earn professional development points (PD) and the number of these points are determined by the South African Council of Educators (SACE) based on the nature of the programme. Therefore, the Subject Advisors from the Ministry of Education at the District level make follow-ups to confirm and endorse courses and the PD points earned by the teachers for accreditation through the Universities based on their teacher qualification frameworks. ***The implication of this process is that it helps to address the issue of terms and conditions of service of teachers by supporting improvement of teacher qualifications, with the added potential for teacher promotions and higher incomes.***

In **Uganda**, a cascade training model is adopted where a team of National Trainers within the SESEMAT programme train Regional Trainers at the national level, who in turn train teachers of STEM subjects at the regional levels. During training at the regional level, the national trainers make a follow up to assess the quality of training delivered by the Regional Trainers to teachers of mathematics and science. In **Rwanda**, the Ministry of Education assesses the quality of on-going teacher training at the point of delivery in the STEM centres, which are selected schools where the teacher training is provided periodically. Meanwhile in **Ghana**, quality assurance also focuses on licensing of teachers and continuous professional development of teachers to ensure high quality of teachers in the classrooms.

iv. Benchmarks and standards of performance in STEM

In assessing the quality of STEM education, an important factor is a framework which sets the quality aspects to be assessed, the benchmarks and standards for assessment, and the process of assessment of the aspects. Without set benchmark and standards of performance, it is difficult to assess and determine quality, and even more difficult to report on quality or use the feedback on assessment in any meaningful way. Therefore, the senior education officials identified a gap in the process of quality assurance of STEM education, depending on the perspective one has on quality, for instance, when one observes a lesson, what will be quality will be based on the background, traditions, and perception of quality assurance. Since quality assurance is very diverse there is need to set standards, benchmark for performance, and expectations (targets) on the quality of STEM education so that teachers training, teaching, and other activities for improvement of quality of STEM education are based on an established framework of standards and benchmarks of performance, with set acceptable limits within which to operate. The implication is that there is need for a framework with set standards and benchmarks for performance in improving the quality of STEM education.

In **Namibia,** the directorate of programmes and quality assurance has professional development divisions or sections in the regional Ministry of Education offices in each of the 14 administrative regions. This division has staff responsible for coordination of implementation of the curriculum in schools in the regions, and they have a programme for school visits, with scheduled visits of teachers in the classroom. Furthermore, staff at the national level, conduct analysis of the results of national examinations by subject and identify those subjects that are poorly performed. A target performance is set for the poorly performed subjects for the year. Meanwhile, continuous teacher professional development programmes are planned and delivered through a cascade model, where staff at the regional professional development division are trained at the national level, and they in turn deliver the training to the teachers at the regional level. Therefore, every year, teacher training workshops are conducted based on the assessment and delivered at the end of the examination cycle. Teachers are trained on skills that they are lacking based on the classroom observations and the results of the national examinations. Note that this process is done for all teachers of all subjects and it is not exclusive for the teachers of STEM. Meanwhile, it is not clear whether a framework of standards of performance benchmarks exists that is used to guide in identification of the issues that need to be addressed during the continuous teacher professional development programmes.

v. Student innovations and projects

In **Ghana**, the Ministry of Education tracks on the kinds of scientific projects or innovations at school level, that teachers and learners have developed. In **Rwanda**, science and innovation fairs are organized at the national level, where students compete by presenting oral / written ideas or tangible scientific innovations. Students with winning innovations are recognized and awarded certificates and other gifts. There was no clarity on what happens after the presentations of winning scientific innovations by the students.

vi. Assessment of school enrolment and attendance

Meanwhile, the Ministry of Education in **Ghana** monitors student enrolment and attendance to ensure that all have access to education regardless of their demographic status for equitable access to both primary and secondary education.

vii. Performance assessment of the Ministry of Education

In **South Africa**, the Quality Assurance for the overall Ministry of Education is done through Private - Public partnerships. The Minister for Education appoints people / team or the Department of Planning, Monitoring, and Evaluation (DPME), to conduct the performance assessment. This is a system wide assessment, and it was not very certain on the scale and scope of the assessment.

4.6.6 Reporting on Quality Assurance of STEM Education

Does the Ministry of Education at HQ compile quality assurance reports for STEM education at the basic learning level?

Once quality assurance exercises have been conducted and information gathered on different aspects of quality, the next important phase is compilation of reports and dissemination to relevant stakeholders for feedback, and action. Quality reporting is an essential ingredient of a quality improvement system as it is the feedback and interpretation that influence the type and quality of decisions that are made. From the interviews with senior education officials, four key themes emerged on reporting including: a) purpose of the report; b) frequency of reporting; c) key report stakeholders, and d) use of the report feedback.

i. Purpose of the reports

The purpose of the reports refers to how the report once compiled will be used. It is important to note that every report should have a purpose in terms confirming development hypothesis, identifying issues that affect target groups, and determining whether the strategies and service delivery mechanisms are working or not. Given the time, efforts, and resources that are devoted in gathering information and compilation of reports, it is critical that the reports are of high quality and are put to good use.

In **Uganda**, reports of the SESEMAT projects are compiled for each school that is visited and consolidated for each district on a quarterly basis. These reports are reviewed internally, and the key emerging challenges are isolated and submitted to the district education office where the reports were gathered. The district education office reviews the reports and determines the necessary actions for addressing the challenges, which may include calling for a meeting of key stakeholders to deliberate on the challenges and identify solutions. Additionally, the report informs on the needs of and plans for future trainings. Furthermore, the reports are used to inform other stakeholders about teacher experiences and type of support required in schools to improve quality of STEM education. Specifically, the reports shared are also shared with head teachers at schools for follow-up. They are shared with the commissioner of education at the Ministry of Education. Finally, the reporting is seen as part of accountability of the funds and other resources that are committed to the SESEMAT programme. It is instructive to note that SESEMAT is a key programme for improvement of STEM education in Uganda that started as project but now institutionalized within the Ministry of Education and Sports (MoES) Uganda. In **South Africa,** the provinces also present the reports during a meeting on Teacher Development and Curriculum Management (TDCM) that is held at the national Ministry of Education. Emanating from this meeting, the Directorate of Mathematics, Science and Technology is able to pick issues that form the agenda for oversight visits in provinces for instance to review the adequacy of course books and other curriculum support materials. In **Rwanda**, the school inspection reports are prepared quarterly and submitted to the Minister for Education. These reports include, challenges, and recommendations for improvement of delivery of education services, among them, STEM education.

ii. Frequency of reporting and stakeholders

In dissemination of reports, timeliness is key to ensure that decisions on necessary actions are made in a timely manner to avoid costly delays in addressing any issues. Therefore, the frequency of reporting on different aspects contributes to the quality of STEM education if this is done at the right time to facilitate decision making and action.

In this study, the frequency of reporting on the quality of education within the Ministries of Education ranged from quarterly, semi-annually, and annually. However, this reporting is not necessarily for quality of STEM education as no unique reporting mechanism for STEM education was identified, except for Uganda under the SESEMAT programme. In **Ghana**, detailed quarterly reports are compiled every year and shared with the Director General of Education at the Ministry of Education Headquarters. A similar mechanism exists in **Botswana**, where the reports are compiled quarterly, semi-annually, and annually for each year. In **Namibia**, the reports are compiled semi-annually based on inspections conducted during school visits in the regions and shared within the respective region but are not necessarily shared with the national Ministry of Education. In **South Africa**, the provinces compile quarterly reports which are shared with the Department of Basic Education (DBE) of South Africa at the National Ministry of Education.

iii. Special Reports

In certain circumstances when unique persistent and systematic issues become recurrent, authorities in the Ministries of Education organize for a special task team to analyse the issue and advise the Ministry on possible courses of action to address the issue. Most curriculum reforms at the basic learning levels in Africa have been as a result of such special task teams.
In 2010, the Minister for Education in **Kenya** established a special committee to investigate the causes of poor performance in Mathematics and Science Education in Kenya based on the national Kenya Certificate of Secondary Education (KCSE) 2009. This report has continued to inform strategies and mechanisms for quality STEM education in Kenya at the basic education level. In 2013, the Minister for Education in **South Africa**, established a task team involving the Department of Planning, Monitoring and Evaluation (DPME) in the Presidency to investigate on how the education strategy was being implemented in the nine provinces. The report is being used in improving strategies for service delivery in the education sector. It is instructive to note that this report was not specific to STEM education.

iv. Diagnostic Report

In South Africa, after release of the results of examination for the National Senior Certificate (NSC) or the matriculation (matric) certificate at grade 12, an analysis is conducted on performance in each subject to identify the weaknesses that could be associated with poor results. Based on this analysis, remedial measures are instituted. In **Uganda**, the final evaluation of the secondary Science and Mathematics (SESEMAT) programme was conducted in 2017 to determine the project achievements in terms of relevance, effectiveness, efficiency, impact, and sustainability.

4.6.7 Impact evaluation of interventions on improvement of STEM education

Have you conducted an evaluation on the impact of the interventions implemented for improvement of STEM subjects at the basic learning level in your country? What are the key findings from the evaluation?

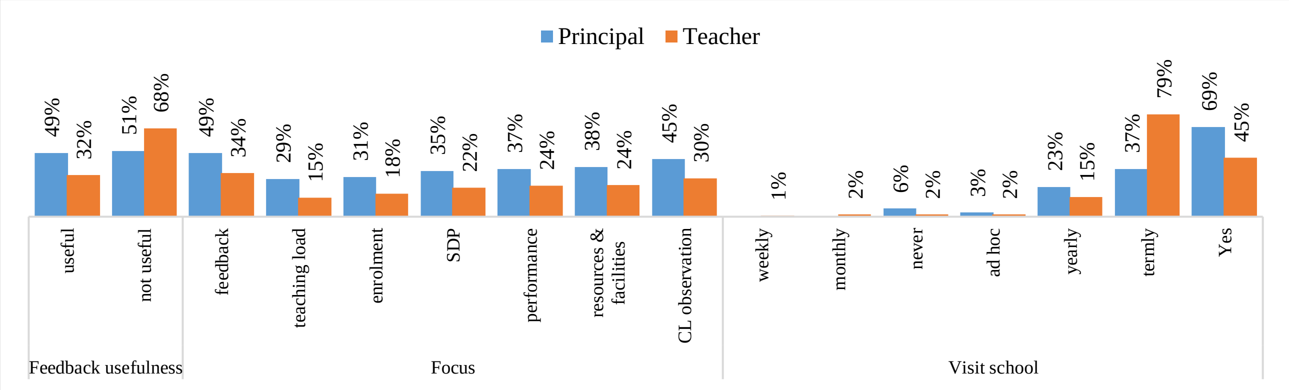
Aside from the donor funded projects that normally conduct *ex ante*, Final, and *ex post* evaluations, none of the sample countries have conducted a comprehensive impact evaluation of the interventions on STEM education at the basic learning levels. However, they have been making observations on changes that could be attributed to the interventions, for instance, improved student performance in STEM in national examinations, increased enrolment in STEM courses at tertiary institutions, and increased student interest in STEM careers.

As part of the national school assessments that are conducted by the Ministries of Education in some countries, information on progress in school improvement is gathered, though without a specific focus on STEM education. However, there are some exceptions, for instance, in **South Africa**, attempts have been made on systematic impact evaluation through the Annual National Assessment (ANA). This initiative was however found demanding by teachers and schools and it is being reconceptualized. Additionally, some countries including Botswana, Ghana, Morocco, and South Africa have been participating in the Trends in International Mathematics and Science Study (TIMSS).

4.6.8 Monitoring of STEM education at school level by local education officials

More than half of the school principals and slightly less than half of the teachers indicated that education officials had made a school monitoring visit to their school in the last one year (**Figure 31**). The monitoring visit was most often, once in a term / semester though some indicated it had happened only once, while a few cases indicated that the schools had not been visited. During these visits, the main focus was classroom observation, review of school resources and facilities, and student performance. Less than half of the teachers and principals indicated that they received feedback after the school visits by the MOE officials. Additionally, only a third of the teachers and principals found the feedback provided useful in improving the quality of STEM education. Furthermore, proportionately more teachers than principals found the feedback useful.

Figure 31: School monitoring visits by education officials



Over a third of the local education officials indicated that they have a strategic plan for education in their regions, that includes an objective on STEM education, and have KPIs for monitoring quality of STEM education in the region **(Figure 32**). Among those who indicated availability of a strategic plan for the region, almost three-quarters indicated that strategies for improvement of STEM education in the plan were being implemented (

Figure 33) and these included: teacher professional development, provision of STEM infrastructure, and increased student access to STEM subjects.

Figure 32: Monitoring of Status of STEM Education in the Region by Education Officials

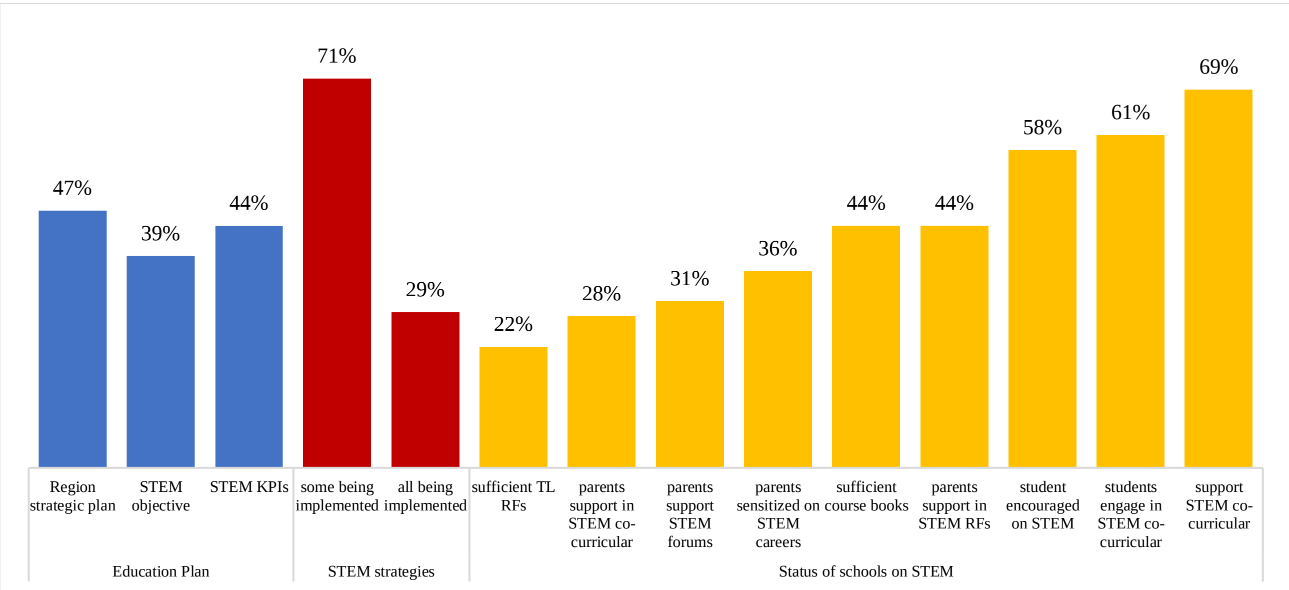
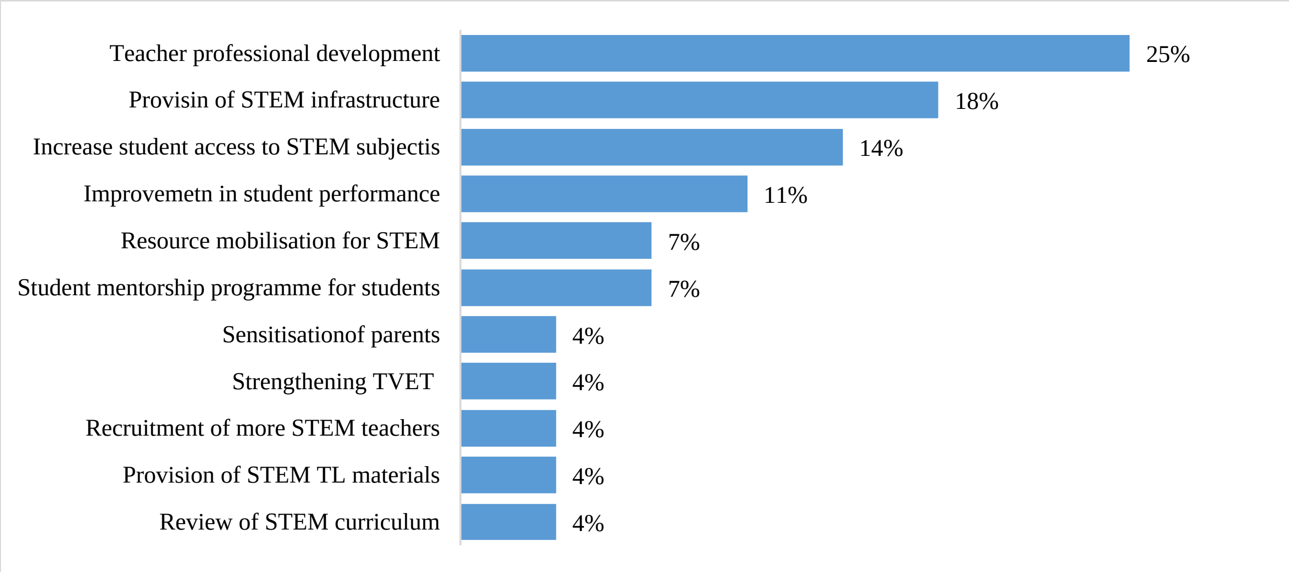
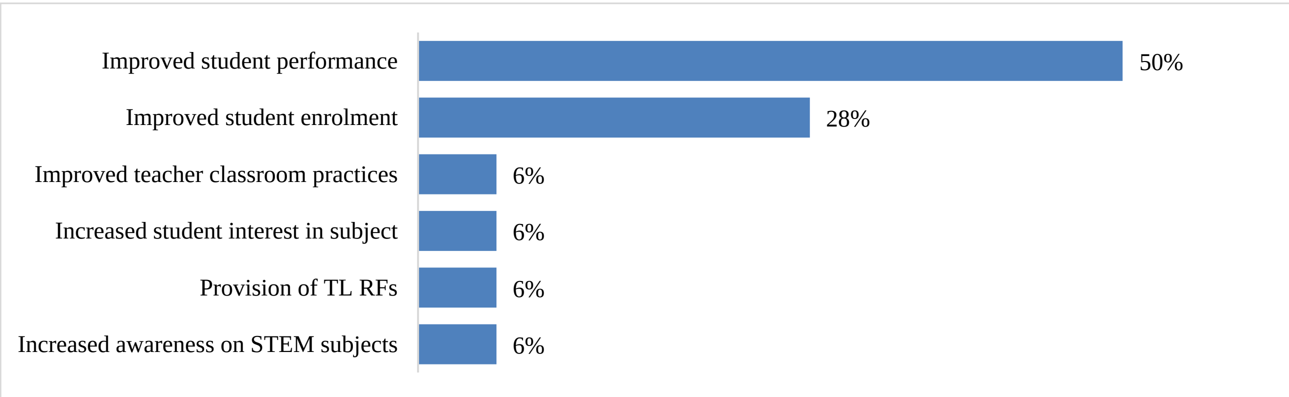


Figure 33: Status of implementation of STEM strategies in Region Education Plans



The local education officials further indicated that they have observed impact of implementation of the STEM improvement strategies in terms of improved student performance, enrolment, and teacher classroom practices (**Figure 34**).

Figure 34: Impact of implementation of STEM strategies in Region Education Plans



5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary

This study sought to establish status of STEM education at the basic learning levels in Africa in terms of student enrolment and performance, challenges derailing achievement of quality STEM education, interventions for addressing these challenges, and their impact on quality of STEM education. Focusing on nine sample countries, teachers of STEM subjects in public schools, school principals, and education officials were surveyed as they were considered knowledgeable about issues of STEM education from their professional training, experience, and practice.

The term STEM, which stands for science, technology, engineering, and mathematics includes the curriculum, courses, and careers that integrates knowledge and skills from these disciplines. Currently, there is inadequate understanding on the status of STEM education at the basic learning levels in Africa. The sample countries offer relatively the same STEM curriculum, at the basic learning levels, with some differences in range, and scope of content, as adaptations to local context.

STEM skills are the foundation for sustainable economic and human development as they support technological innovations, creating jobs, employment opportunities in STEM careers that are expanding faster than those in non-STEM occupations, and with higher earnings. While the global north has made great advances in STEM education, the global south, particularly African countries are in the nascent stages of investing in this critical sector. Therefore, African countries must take decisive actions to improve quality of STEM education at the basic learning levels and equip the youth with relevant STEM skills as a strategy for youth employment and accelerated economic growth.

5.2 Conclusions

The following are the conclusions arising from this study and aligned with the thematic areas that were the focus of the study.

5.2.1 Enrolment and Performance in STEM education

Comparative indicators show Africa lagging behind in access to STEM education. Enrolment in STEM subjects had increased over the previous three years, and the main reasons were natural demographic changes and favourable policies that are supportive of access to basic education. Meanwhile, despite lack of adequate data on trends in enrolment and performance, both Gross Enrolment Rate (GER) and Net Enrolment Rate (NER) at secondary school level in the sample countries were indicative of low achievement in access to secondary education. This has a negative spill over effect on number of students accessing STEM education, secondary schools and institutions of higher education, and STEM careers, which affects girls more a than boys. Consistent longitudinal data on performance in STEM subjects at the secondary school level in Africa is lacking, but available information points to persistent poor performance in these subjects, which disproportionately affects girls than boys. Four of the nine countries in the sample (Botswana, Ghana, Morocco, and South Africa) participate in the four yearly Trends in International Mathematics and Science Study (TIMSS), but have consistently scored below the benchmark of 500, and are all consistently ranked in the bottom quartile of the league. The key factors that are associated with the poor performance are inadequate teaching and learning resources and facilities, poor teacher pedagogical practices, students' lack of interest in the STEM subject, negative stereotypes regarding girls' ability in these subjects, insufficient number of qualified teachers of mathematics and science, and poor conditions of service for teachers. There were gender disparities in enrolment and performance in STEM education, and the key factor was identified as negative gender stereotypes. Other reasons were student lack of interest in the subject, and poor learning environment. While these reasons are well known in gender literature, they have been persistent. This calls for deliberate strategies for sustained mainstreaming of gender in the STEM education agenda. Notably, there are no cross-country assessment programmes at the secondary school level in Africa as both SEACMEQ and PASEC assess learning outcomes in literacy and numeracy at the primary school grades.

5.2.2 *Challenges of achieving quality in STEM education*

A range of challenges confronts achievement of quality in STEM education at the basic learning levels in Africa from school level to the national level and include: a) inadequate teaching and learning resources and facilities; b) poor teacher pedagogical practices; c) student lack of interest in the subject; and d) insufficient number of teachers of STEM subjects. Teaching and learning resources and facilities are either insufficient or lacking altogether at secondary school level in most Sub-Saharan African countries while poor teacher pedagogical practices are due to several underlying issues including under-qualified teachers, gender stereotypes, as well as teachers' negative perception of the students' ability to learn STEM subjects. Some students lack interest in STEM, particularly girls and this emanated mainly from peer influence, negative gender stereotypes, and low aspirations for good performance in STEM subjects. Other factors included relevance of STEM curriculum, and inadequate number of teachers of STEM.

5.2.3 *Interventions on quality of STEM education*

The countries generally lacked a specific plan or policy on STEM education except for South Africa that has finalized one. However, some strategies addressing the quality of STEM education are identified in the education sector plans, which is indicative of commitment by education authorities to address this sector. Additionally, some schools and regions had a School Development Plan (SDP) and regional education strategic plan respectively, that had an objective on improvement of STEM education and key strategies that were being implemented. These key strategies included review of STEM curriculum, recruitment of qualified staff, provision of STEM resources and facilities, continuous teacher professional development, establishment of model schools of excellence in STEM, student mentorship programmes on STEM, strengthening capacity of the Ministries of Education in quality assurance of STEM education, improving student enrolment and performance in STEM subjects and courses in tertiary institutions, and integration of ICT in education.

Meanwhile, a sample of 27 on-going interventions were reviewed and they had the following key characteristics: a) some are national in scope, while others are localized in specific sub-geographies within a country, while still others are cross-country interventions; b) governments and development partners were joint sponsors for most of the interventions, however, some interventions were sponsored by private entities and individual philanthropists; and c) most of the interventions focus on multiple strategies in addressing quality of STEM education. Teachers, principals, and education officials were participating in forums focusing on STEM subjects, within school, outside school, and online, and a high proportion of teachers were participating particularly in school-based forums. There were differences across countries in participation which could be associated with availability of STEM programmes, and ability to participate or access these forums. The forums were mainly supported by the government, which further demonstrates commitment, and were considered useful in improving the quality of STEM education. While online forums were found equally useful, they faced challenges of internet connectivity, cost of internet, and devices.

5.2.4 *Impact of interventions on quality of STEM education*

Apart from donor funded interventions in STEM education, educational authorities in the sample countries rarely conduct impact evaluations. However, they conduct regular general review of the education sector, although this is not specific to STEM education, but issues of STEM education are included in the review agenda. **South Africa** has a systematic impact evaluation system through the Annual National Assessment (ANA). Additionally, some countries including Botswana, Ghana, Morocco, and South Africa have been participating in the Trends in International Mathematics and Science Study (TIMSS). Meanwhile, Key Performance Indicators for tracking quality STEM education were mentioned, but these were neither consistent nor adequately applied at national, regional, and school levels. Overall, most of the indicators mentioned were measuring lower-level results areas, for instance outputs, inputs, and activities. Higher outcomes, which should be the areas of greater emphasise in STEM education were less prioritized. Furthermore, the range, wording, and phrasing of the indicators was indicative of lack of adequate understanding of the measures of progress in the quality of STEM education, and this implies a critical gap in strategies for improving STEM education, expected results, and measurement for the same. Additionally, the main indicators were test scores and performance results of national examinations. An exception was South Africa, where there were well articulated goals and corresponding indicators that were found relevant at multiple levels in the system, and the following are illustrative examples:

- Indicator 5: number of grade 12 learners passing mathematics,
- Indicator 6: number of grade 12 learners passing physical science,
- Indicator 9: average grade 9 mathematics score obtained in TIMSS

Meanwhile, Rwanda has also identified two high level key performance indicators in the Rwanda Vision 2050 policy document, including: a) percentage of graduates in STEM related programmes with a target of 44% in 2035 and 50% in 2050, and b) percentage of student's enrolment in TVET as proportion of total students in basic education with a target of 60% by 2050.

There was no specific stand-alone institution in any of the countries charged with quality assurance of STEM education, and this function was being discharged by departments within the Ministry of Education. However, some institutions play a role in quality assurance of STEM education, for instance, CEMASTEA in Kenya. An exception was South Africa where they are in the process of establishing a fully-fledged institution for quality assurance, the UMULASI, and a strategy towards this process has been finalized. In some countries, there are staff in the quality assurance departments, charged with role of quality assurance of STEM education, but these were not sufficient in number. Furthermore, there lacks a specific budget line for quality assurance of STEM education as the budget allocation is lumpsum for the department.

The areas of focus by Ministries of Education in quality assurance are: monitoring of teaching and learning in schools, teaching and learning resources and facilities; continuous teacher professional development; student innovations and projects; and assessment of school enrolment and attendance. Meanwhile, teachers, principals, and education officials confirmed that school monitoring visits are done by the local education authorities at least once in a year, and in some cases more frequently, but some schools had not been visited in the previous year. Some schools get feedback on observations made during the visits and most find the feedback useful in improving quality of STEM, though some did not find it useful. Based on the monitoring activities, the Ministries of Education compile quality assurance reports, either quarterly, semi-annually, or annually but these were not specific for STEM education, although issues of STEM education are part of these reports. In some countries, the reports are aggregated up to the nation level, while in others, reports of quality assurance are compiled at the regional level and are not necessarily shared with the education authorities at the national level.

5.3 Recommendations

Based on the findings and conclusions in this study, several recommendations are made to improve the quality of STEM education at the basic learning levels in Africa in the following sections.

5.3.1 Policy on STEM education at basic learning level

The national education authorities should develop and implement a policy on STEM education at the basic learning level as a first step towards greater focus on this area. This policy will lay the ground for structured engagement in the whole spectrum of delivery of quality STEM education, by informing strategies, mechanisms, resource mobilisation and funding models, structures, partnerships, collaboration, coordination, and quality assurance in the delivery of quality of STEM education at the basic education learning levels. The policy should clearly articulate expected outcomes, and measurement, while ensuring harmonisation and coordination across multiple levels. The policy should further provide guidelines on how to support innovations generated by both teachers and students, including proprietary rights where necessary.

5.3.2 Review STEM curriculum

There were indications that the STEM curriculum in some countries was too broad against the time that it is assigned for coverage and more time was desired for instance in mathematics. Additionally, the curriculum should be made more relevant to the market demand with a focus on contextual realities. Furthermore, the course books for STEM subjects should be well aligned with the curriculum. Therefore, alongside the recommendation for a policy in STEM education, review of STEM curriculum should be considered in ensuring relevance and alignment with the job markets and the constant changes in the environment driven by technological advances.

5.3.3 Mapping of interventions in STEM education

Given the many on-going interventions on STEM education in African countries, the government should conduct a mapping exercise of all existing interventions. The mapping should document; scale of operations, focus geographies, key strategies, timelines, reach, and impact, and funders. Using this information, the education authorities should establish a comprehensive database on existing interventions to be able to constantly assess whether the areas of need are being addressed as well as consolidation of emerging innovations and best practices. Furthermore, the education authorities should nurture communities of practice among the existing players in this area, and regularly convene forums for synthesis and dissemination of lessons learnt from the interventions. Through this process, a repository of contextual knowledge will be accumulated that will ensure relevance of interventions, harmonisation, and coordination of efforts in this critical sector. Finally, the ADEA ICQN-MSE should offer technical support in the mapping exercise.

5.3.4 Resource mobilisation to fund STEM education

Education authorities in African countries should provide adequate funding to support initiatives for improvement of science and mathematics education in the primary and secondary schools to ensure that students are able to perform at the highest level possible. This will enable the teachers, principals, and students to participate in supportive activities for implementation of a STEM curriculum. Precedent to this, there should be elaborate policies and plans on STEM education to ensure clarity and coordinated efforts by various stakeholders. Meanwhile, the Government should partner more with development partners in delivery of STEM curriculum particularly in supporting teacher professional development and provision of resources and facilities. Therefore, education authorities should develop innovative strategies on resourcing initiatives in STEM education. Some of the potential sources of funds could include the private sector, for instance, the mining community in Namibia are funding STEM initiatives including establishment of science resource centres in some regions where teachers and students can conduct science experiments. The funding should also support infrastructure development in schools including laboratories, ICT infrastructure, and staffing, among other critical needs.

5.3.5 Adequate staffing with STEM teachers

Currently STEM subjects are under-staffed and the fact that they require a lot of preparation prior to the actual lesson delivery further compounds the challenge. Therefore, adequate staffing would reduce the workload for STEM teachers and enable them to prepare adequately. Furthermore, high student enrolment in some schools exacerbated the issue of staffing, as teachers cannot provide the required individual attention for the learners. Additionally, more female teachers were required in STEM as role models for girls, encouraging more of them to take up STEM subjects.

5.3.6 *Regular teacher professional development in STEM pedagogical practices*

A sustainable model for regular capacity building of teachers of STEM through different modalities should be implemented in each country. Already, this model exists in some countries including Kenya, Uganda, Zambia, and Nigeria. A variety of strategies should be devised and should include face to face training workshops, online courses, blended learning, meetings, and webinars. The programmes should be clearly articulated in the policy to ensure that they are implemented in a structured manner. Meanwhile continuous research on STEM teaching methods, student experiences, and teacher experiences will generate insights on what is working or not, and there should be adequate exposure of STEM teachers to creative and innovative teaching strategies that promote learner engagement.

5.3.7 *School leadership training programmes on management of STEM education*

For sustainability of school level STEM initiatives, the school leaders including principals / directors of schools and school boards of management or committees should be trained on management of STEM education. This training could include resource mobilisations, benchmarks and standards for STEM education, and monitoring quality of STEM education.

5.3.8 *Improve conditions of service for teachers*

A recurring theme was the poor conditions of service for teachers and therefore, strategies should be devised to attract people into the STEM teacher field, reduce teacher attrition, and improve commitment to delivery of the STEM curriculum. It was felt the teacher salary and other conditions of service should be addressed. As part of these strategies, champion STEM teachers should be recognized to boost teacher motivation and commitment to improve quality of STEM education. An incentive system as part of the school STEM strategy could raise the profile of STEM education.

5.3.9 *Provision of resources and facilities*

Provision of resources and facilities was the most frequently recommendation as a way of achieving quality STEM education. The resources and facilities that came up more frequently were classrooms, laboratories, laboratory equipment and chemicals, computers, textbooks, and internet connectivity. Therefore, the school leadership, parents, government, education authorities, and development partners should work collaboratively in provision of resources and facilities for STEM education.

5.3.10 *Equipping of schools with adequate ICT infrastructure*

There are indications that delivery of STEM curriculum could greatly benefit from integration of ICT in the pedagogy. This has become more apparent with the advent of COVID19 pandemic where education authorities and individual schools explored opportunities of utilising ICT for students to continue learning from home during the lock-down, when schools closed. Institutions of teacher professional development also ventured into online virtual platforms as alternative delivery mechanisms. Therefore, education authorities should invest in enhanced ICT infrastructure and teacher capacity development in curriculum delivery through ICT to ensure that learning is not only continuing uninterrupted but is also innovative. With on-line learning fast becoming the new normal due to the COVID-19 pandemic, the importance of ICT in education cannot be over-emphasized. Interventions on quality of STEM education must endeavour to equip teachers and students for technology enabled innovative approaches in STEM subjects.

5.3.11 Monitoring and Evaluation Framework for STEM education

Drawing from the policy on STEM education at the basic learning levels, a framework for guiding quality assurance should be developed. This is an important tool that sets the quality aspects to be assessed, the benchmarks and standards for assessments, and the process of assessment of the aspects. Without set benchmarks and standards of performance, it is difficult to assess and determine quality, and even more difficult to report on quality, use the feedback on assessment in any meaningful way, or engage in constructive discourse on quality issues of STEM education. For instance, when one observes a STEM lesson, what are the quality aspects and standards of judgement? Without benchmarks and standards, any description of quality is likely to be highly subjective and dependent on undesirable backgrounds, traditions, and perception of the assessors of quality. Since quality assurance is very diverse and context based, the aspects of quality, standards of performance, and benchmarks and target thresholds should be clearly defined in a participatory and consultative process for the understanding of all stakeholders in STEM agenda. These aspects, standards, and benchmarks should be set within acceptable limits, and all interested parties should know how they are applied and interpreted. The agencies responsible for national assessments should provide teachers of mathematics and science with concrete examples of student performance at different achievement levels. The education authorities should also put in place comprehensive feedback systems to supply schools, teachers, and other practitioners with both qualitative and quantitative information on student performance in mathematics and science. As part of the monitoring and evaluation framework, countries should develop and use ***Key Performance Indicators*** for tracking progress in quality of STEM education. The indicators should be aligned with specific strategies for improvement of quality of STEM education. Therefore, there is need for a set of clearly articulated indicators and respective targets at the national level, regional level, and school level. Some indicators may be relevant only at certain levels in the system, for instance at the national or school level, while others may cut across the different levels on the education system.

5.3.12 Comparative Analysis of Trends in Performance in STEM

As part of the quality assurance efforts to improve performance in these subjects, countries in the region should embark on comparative analysis of national examinations using rationalized benchmarks to identify undesirable trends in performance that could be addressed through targeted interventions. Secondly, the countries in the region should start initiatives on cross-country assessment of mathematics and science at the secondary school level as a strategy for accelerated progress in achieving quality in STEM education, and finally; countries in the region should address identified challenges by designing comprehensive, targeted, and sustainable interventions to address the root causes of poor performance in these subjects. Governments should establish national assessment programmes where these are lacking, and plan for participation in relevant regional, and international assessment such as TIMSS as this will enable governments to design targeted interventions based on evidence emerging from the assessment. Meanwhile, education authorities in those countries in Africa that are already participating in TIMSS should continue to support participation in TIMSS, while the others should be encouraged to participate. Most importantly, countries in Africa should develop and implement a system for cross-country comparative studies on STEM education at the basic learning levels, particularly at the secondary school education cycle. This could be modeled on the existing SEACMEQ and PASEC.

5.3.13 Regular school support visits by MOE

The education authorities should conduct regular school monitoring visits to track on the quality of STEM education while offering the necessary support where gaps are identified.

5.3.14 Student mentorship programmes on STEM

Student mentorship programmes, where they exist, contribute significantly to influencing students for higher uptake of STEM subjects and careers. Therefore, these programmes should be strengthened, and students be engaged at an early age to spark interest in STEM. Adequate sensitisation of students and career guidance on STEM education will encourage them to take up STEM courses and careers. The mentorship programmes should be made comprehensive by engaging parents and guardians, experts in STEM, school leadership, teachers, and role models particularly, female role models. A comprehensive mentorship programme has the potential to enable learners to make early decisions on their career choices. Meanwhile, parents and guardians should be sensitized on the importance of STEM careers given the potential for job opportunities in this sector unlike other career paths. Students should be encouraged to explore their talents in science and technology fairs as part of this mentorship programme. This will make STEM education more enjoyable for the students and act as a great incentive to pursue these careers.

5.3.15 Student outreach programmes on STEM

The Botswana International University of Science and Technology presents a good example of partnerships in STEM between the basic learning levels and higher education. The outreach programmes supported by BIUST could be replicated in other Universities in Africa. Such outreach programmes could greatly contribute to creating interest in student uptake of STEM courses and career.

5.3.16 Sensitisation programme for parents, guardians, and communities on STEM education

Parents and guardians have a critical role in the education of their children, and teachers felt that they are part of the solution to the delivery of quality STEM education at school. In this context, parents and guardian should support the school in providing resources and facilities for STEM, participating in school forums for STEM such as a science and technology fairs, and encouraging their children to pursue STEM subjects, and careers. Therefore, schools with support of education authorities should mount sensitisation programme on awareness of STEM education for parents. Admittedly, parents and guardians play a critical role in influencing the career choices of their children. Therefore, schools through support by the Ministry of Education should mount sensitisation programmes for parents and guardians to secure their support not only with resources but in engaging their children in conversations that will encourage them to create interest in STEM careers. Given that job forecasts suggest that careers in STEM will become increasing important, this strategy would support changing of mindsets at a stage when children start exploring career opportunities.

5.3.17 Science and Technology fairs and excursions

The STEM interventions should include student exposure initiatives through external educational opportunities to spark student interest and develop a passion for STEM subjects. Additionally, initiatives on students' attachments in enterprises should be implemented where students can physically see and feel the practical application of STEM in the real world.

Currently, several countries in Africa are running these fairs and this should be sustained and improved. Meanwhile, a system for patenting student innovations should be developed to protect their intellectual property, support them to benefit from these innovations, and ensure quality as well.

5.3.18 School STEM strategy

The school leadership should develop a school STEM strategy that details the necessary actions to be implemented within given timelines to improve the quality of STEM education. This strategy should be developed collaboratively through a participatory process involving the students, teachers, parents, school managements, among other key stakeholders. The school STEM strategy should articulate specific milestones, responsibilities, and any costs where relevant, and should form as a critical engagement tool for resource mobilisation towards STEM education. In view of the central role of school leadership in implementation and monitoring of the STEM strategy at school level, school principals should undergo appropriate capacity building and be fully inducted on the teacher professional development programme in STEM pedagogical practices

5.3.19 Communities of practice on STEM education

The education authorities should take the lead in nurturing communities of practice on different aspects of STEM education at the basic learning levels. Given the multi-faceted nature of STEM education, the government could form a technical working group on STEM education at the basic learning level to guide and advice on strategies to promote STEM education at this level as well as address the various challenges that are confronting this critical sector of education.

5.3.20 Strategies on management of COVID19 and other pandemics

COVID19 has re-awakened the world to reality that normal life can be greatly disrupted or brought to a standstill altogether by a pandemic. For sustainable management of COVID19 and other pandemics, education authorities should develop comprehensive guidelines on how to implement health protocols within the curriculum delivery mechanisms. Additionally, there is potential to review STEM curricula and integrate issues of health and other pandemics as cross-cutting issues. More importantly, practical guidelines and contingency plans on how to manage health pandemics at the individual, family, community, and societal level should be addressed through the STEM curricula. With regard to STEM education, ministries and schools should put in place a continuity strategy to minimize disruption due to such unexpected occurrences.

REFERENCES

Abotowuro, S. (2015). *Factors influencing the perceived difficulties of Senior High School Students in Electives Mathematics.* Accra: Unpublished Thesis in Master of Science, Kwame Nkrumah University.

African Development Bank. (2020, 12 11). *African Economic Outlook 2020 - African Development Bank*. Retrieved from African Development Bank Group: https://www.afdb.org/sites/default/files/documents/publications/afdb20-04_aeo_supplement_full_report_for_web_0705.pdf

African Union. (2005). *Second Decade of Education for Africa (2006-2015) Plan of Action.* Addis Ababa: African Union.

African Union. (2015). *African Union Agenda 2063 Framework Document.* Addis Ababa: African Union.

African Union. (2015). *Continental Education Strategy for Africa 2016-2025.* Addis Ababa: African Union.

Ahmed, H. O. (2016). Strategic future direction for developing STEM education in higher education in Egypt as a driver of innovation econonmy. *Journal of Education and Practice, 7(8)*, 127-145.

Anderson, I. K. (2006). *The relevance of science education: As seen by pupils in Ghanian Junior Secondary School.* Cape Town: Unpublished Doctor of Philosophy Thesis in Mathematics and Science Education, University of Western Cape, South Africa.

Appiahene, P., Opoku, M., Akweittey, E., Adoba, E., & Kwarteng, R. (2014). Assessing the challenges of learning and teaching of mathematics in second cycle institutions in Ghana. *International Journal of Innovation and Applied Studies, 6(3)*, 362-368.

Asabere, A. A., & Mereka, D. K. (2009). Comparative analysis of performance of eighth graders from six African countries. *Mathematic connection volume 8*, 17-27.

Awuor, C. R. (2013). Factors influencing Girls' Performance in Mathematics and Science Subjects in the Kenya Certificate of Secondary Education in Public Secondary Schools in Westlands District, Nairobi County, Kenya. *Unpublished*, 1-87.

Barrett, A. M., Gardner, V., Joubert, M., & Tikly, L. (2019). *Approaches to strengthening secondary STEM and ICT education in Sub-Saharan Africa.* Bristol, United Kingdom: University of Bristol.

Basham, J. D., Israel, M., & Maynard, K. (2010). An ecological model of STEM education: Operationalizing STEM for All. *Journal of Special Education Technology, 25(3)*, 9-19.

Bethell, G. (2016). *Mathematics Education in Sub-Saharan Africa: Status, Challenges, and Opportunities.* Washington DC 20433: The World Bank.

Blom, A., Raza, R., & Kiamba, C. (2016). *Expanding Tertiary Education for Well-Paid Jobs: Competitiveness and Shared Prosperity in Kenya.* Washington, DC 20433: The World Bank.

Bronfenbrenner, U. (1979). *The Ecology of Human Development: Experiments by Nature and Design.* Cambridge: Harvard University Press.

Buabeng, I., Owusu, K. A., & Ntow, F. D. (2014). TIMSS 2011 Science Achievement Results: A Review of Ghana's Performance. *Journal of Curriculum and Teaching, 3(2)*, 1-12.

Carnegie Mellon University. (2020, November 9). *ww.cmu.edu.* Retrieved from STEM Education - Carnegie Mellon University: https://www.cmu.edu/gelfand/documents/stem-survey-report-cmu-iu1.pdf

Carr, W., & Kemmis, S. (1989). Becoming critical: Education, knowledge and action research. *Journal of Educational Thought, 23 (3)*, 209-216.

CEMASTEA. (2019). *Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA) Strategic Plan 2020-2024.* Nairobi: CEMASTEA.

Di Pietro, G., Giagi, F., Costa, P., Karpinski, Z., & Mazza, J. (2020). *The likely impact of COVID-19 on education: Reflections based on the existing literature and recent international datasets.* Luxembourg: European Commission.

Donkor, A. K., & Justice, D. K. (2016). Girls Education in Science: The Challenges in Northern Ghana. *Journal of Education and Social Policy, 3(1)*, 82-96.

Duarte, C. I., Tillostson, C., & Jankowski, M. R. (2018). *Assessing STEM education in Namibia: Focusing on the primary level.* Windoek: SEMANTIC SCHOLAR.

EdTech Hub. (2021, February 15). *The effects of COVID-19 on education in Africa and its implication for the use of technology: A survey of the experiences and opinions of educators and technology specialists*. Retrieved from elearning Africa: https://www.elearning-africa.com/ressources/pdfs/surveys/The_effect_of_Covid-19_on_Education_in_Africa.pdf

Engineering for Kids. (2020, November 12). *Why is STEM Education So Important?* Retrieved from Engineering for Kids: https://www.engineeringforkids.com/about/news/2016/february/why-is-stem-education-so-important-/

European Union. (2010). *Science, Technology and Innovation in Europe.* Luxembourg: European Union.

Fomunyam, K. G. (2019). Teaching STEM Education in Nigeria: Challenges and Recommendations. *International Journal of Mechanical Engineering and Technology, 10(12)*, 85-93.

Formunyam, K. G. (2020). Massifying Stem Education in Africa. *International Journal of Engineering Research and Technology, 13 (2)*, 253-260.

Garekwe, K. G. (1996). Mathematics performance in Botswana public examination: Implications for girls participation. *Mathematics as a barrier to learning of science technology by girls: Report of a conferences in Ahmedabad, India* (pp. 18-30). Ahmedabad: Commonwealth Secretariat.

Goel, V., & Burton, L. (1996). Mathematics as a barrier to learning science technology by females. *Mathematics as a barrier to learning of science technology by girls: Report of a conferences in Ahmedabad, India* (pp. 6-17). Ahmedabad: Commonwealth Secretariat.

Gonzalez, H. B., & Kuenzi, J. J. (2012). *Science, Technology, Engineering, and Mathematics (STEM) Education: A Primer.* Washington D.C.: Congressional Research Service.

Government of Japan. (2020, 12 10). *Cabinet Office, Government of Japan*. Retrieved from Science and Technology Administration in Japan: https://www8.cao.go.jp/cstp/english/about/administration.html

Gwaza, T. H. (2015). *Investigating factors that lead to underperformance in mathematics, physical sciences and life sciences.* Johannesburg: Unpublished Master of Thesis in Science Education, University of Johannesburg, South Africa.

Hamukwaya, S. T. (2019). *K-12 Namibian teachers' belief on learning difficulties in mathematics: Reflections on teachers' practice.* Utrecht: University of Utrecht Netherlands.

Hanushek, A., & Woessmann, L. (2010). Education and Economic Growth. *International Encyclopedia of Education Volume 2*, 245-252.

Human Rights Watch. (2020, August 26). *Impact of COVID-19 on Children's Education in Africa*. Retrieved from Human Rights Watch: https://www.hrw.org/news/2020/08/26/impact-COVID-19-childrens-education-africa

Ilukena, A. M., Haimbodi, F. N., & Sirinji, R. A. (2018). The historical development of number systems in Namibia. *Reform Forum*, 4-17.

Jamme, M. (2020, November 10). *World Economic Forum*. Retrieved from What STEM can do for Africa: https://www.weforum.org/agenda/2015/01/what-stem-can-do-for-africa/

Kahaawa, J. (1996). Mathematics as a barrier to learning science and technology amongst girls in Uganda. *Mathematics as a barrier to learning of science technology by girls: Report of a conferences in Ahmedabad, India* (pp. 95-105). Ahmeddabad: Commonwealth Secretariat.

Kariisa, H. A. (2015). Perceptions of secondary school mathematics teachers towards Secondary Science and Mathematics (SESEMAT) programme in Mbarara District, Uganda. *International Journal of Recent Multi-Disciplinary Research, 2(12)*, 1092-1096.

Kashu, J. N. (2014). Survey on gender and academic performance in Secondary Schools in Kenya. *Unpublished*, 1-119.

Katiambo, D., Wasike, D. W., & Mutsotso, S. N. (2019). Effects of ASEI-PDSI SMASSE approach on mathematics learning outcomes in secondary schools in Kenya. *International Journal of Science and Research (IJSR), 8(9)*, 1400-1404.

Kedikilwe, P. (1993). *Report of the National Commission on Education.* Gaborone: Republic of Botswana.

Kioko, E. N. (1996). Girls, mathematics, science and technology education in Kenya. *Mathematics as a barrier to learning of science technology by girls: Report of a conferences in Ahmedabad, India* (pp. 68-72). Ahmedabad: Commonwealth Secretariat.

Koketso, L. P. (2015). STEM education in Botswana: understanding the gender disparity in enrolment and. *Unpublished Master Thesis, Concordia University, Montreal, Canada*, 1-103.

Komakech, R. A., & Osuu, J. R. (2014). Uganda SESEMAT Programme: Impact and challenges in its implementation. *International Journal of Education and Research, 2(6)*, 133-146.

Lucas, A. M., & Mbiti, I. M. (2014). Effects of School Quality on Student Achievement: Discontinuity Evidence from Kenya. *American Economics Journal: Applied Economics*, 234-263.

Majgaard, K., & Mingat, A. (2012). *Education in Sub-Saharan Africa: A Comparative Analysis.* Washington DC 20433: The World Bank.

Mansfield, J. W. (2020, November 9). *Researchgate.* Retrieved from https://www.researchgate.net/: https://www.researchgate.net/publication/276076320_The_Congressional_Science_Technology_Engineering_and_Mathematics_STEM_Education_Caucus_and_the_Congressional_Academic_Competition_History_and_Current_Practice

Manyiraho, D., Atibuni, D. Z., Olema, D. K., & Wamakote, L. (2020). SESEMAT in-service pedagogical strategies and student achievement in science at ordinary level in Tororo SESEMAT Region. *American Journal of Educational Research, 8(6)*, 309-320.

Matachi, A., & Kosaka, M. (2017). JICA's support to education in Africa in the last two decades: Focusing on mathematics and science education. *Journal of International Cooperation in Education, 19(2)*, 35-53.

Mbugua, Z. K., Kibet, K., Muthaa, G. M., & Nkonke, G. R. (2012). Factors Contributing to Students' Poor Performance in Mathematics at Kenya Certificate of Secondary Education in Kenya: A Case of Baringo County, Kenya. *American International Journal of Contemporary Research, 2 (6)*, 87-91.

Mensah, J. A., Mereku, D., & Ameyaw, A. A. (2004). *Ghanian Junior Seconcary School Students Achievement in Mathematics and Science: Results in the 2003 Trends in International Mathematics and Science Study.* Accra: Ministry of Education, Youth, and Sports.

Mhlanga, D., & Moloi, T. (2020). COVID-19 and the digital transformation of education: What are we learning on 4IR in South Africa? *Education Science*, 1-11.

Mlachila, M., & Moeletsi, T. (2019). *Struggling to Make the Grade: Review of the causes and consequences of the weak outcomes of South Africa's Education System.* Washington DC: IMF.

Mpuchane, S. (2002). Low participation of girls in science programs in Botswana. *AIP Conference Proceedings Volume 628* (pp. 133-134). New York: American Institute of Physics.

Mukhwana, A. M., Abuya, T., Matanda, D., Omumbo, J., & Mabuka, J. (2020). *Factors which contribute to or hinder women in science, technology, engineering, and mathematics in Africa.* Nairobi: The African Academy of Sciences.

Mutisya, B. P. (2010). *The impact of SMASSE project on the teaching methodology and learning in secondary schools in Kangundo and Matungulu districts, Kenya.* Nairobi: Unpublished.

Muyoyeta, N. K., Abah, J., & Denuga, D. (2017). School based factors affecting grade 12 learner's academic performance in Namibia Senior Secondary. *European American Journal, 5(7)*, 9-22.

Mwangi, B. N., Gongera, G. E., & Thinguri, R. W. (2013). Determinants of Girls Low Enrollment in Physics in Secondary Schools: Case of Kajiado North District, Kajiado County, Kenya. *Journal of Education and Practice, 4(13)*, 131-142.

Mwangi, J. K., & Atina, J. O. (2016). The effectivness of SMASSE teacher training programme on KCSE performance in mathematics and chemistry subjects in Kikuyu District, Kenya. *Journal of Education and Practice, 7 (6)*, 156-163.

Namara, F. (2018). Factors affecting provision of quality basic education in Nyagatare District, Rwanda. *Journal of African Interdisciplinary Studies, 2(3)*, 109-119.

National Science Foundation. (2007). *Rising above the gathering storm: Energizing and employing America for a brighter economic future.* Washington D.C: The National Academies Press.

National Science Foundation. (2020, November 12). *What is STEM education?* Retrieved from National Science Foundation: https://www.nsf.gov/news/news_summ.jsp?cntn_id=243502

Obama, H. B. (2009). *Educate to Innovate Campaign for Excellence in Science, Technology, Engineering and Mathematics (STEM) Education.* Washington DC: The White House, United States of America.

OECD. (2016). *Innovating for Education and Educating for Innovation.* Paris: OECD Publishing.

Ohanyido, C. (2018, March 29). *The Pivotal Role of Education in Africa’s Development*. Retrieved from Global Education Conference: http://www.globaleducationconference.com/profiles/blogs/the-pivotal-role-of-education-in-africa-s-development

Oluka, S. (2017). African condition: Transforming STEM education. *Monsendi Journal, 20 (1)*, 57-66.

Omar, H. A. (2017). *Determinants of Student Enrolment in Physics in Kenya Certificate of Secondary Education in Kenya: A Case of Wajir County.* Nairobi: Unpublished Thesis in Master of Education in Curriculum Studies, Univeristy of Nairobi.

PASEC. (2020, 12 10). *Programme d’analyse des systèmes éducatifs de la CONFEMEN* . Retrieved from Programme d’analyse des systèmes éducatifs de la CONFEMEN : http://www.pasec.confemen.org/

Republic of Botswana. (2015). *Botswana Education and Training Sector Strategic Plan (ETSSP) 2015-2020.* Gaborone: Republic of Botswana.

Republic of Botswana. (2017). *National Development Plan 11 Volume 1 April 2017 to March 2023.* Gaborone: Republic of Botswana.

Republic of Ghana. (2014). *Inspiring science and mathematics in basic schools: Report of the committee that reviewed basic science and mathematics education in Ghana.* Accra: Republic of Ghana.

Republic of Ghana. (2018). *Ministry of Education Sector Medium-Term Development Plan 2018-2021.* Accra: Republic of Ghana.

Republic of Kenya. (2018). *Ministry of Education National Education Sector Strategic Plan for the Period 2018-2022 .* Nairobi: Government Printer.

Republic of Rwanda. (2015). *Rwanda Vision 2050.* Kigali: Republic of Rwanda.

Republic of South Africa. (2015). *Department of Basic Education Action Plan to 2019: Towards the realisation of schooling 2030.* Pretoria: Republic of South Africa.

SEACMEQ. (2020, 12 10). *The Southern and Eastern Consortium for Monitoring Educational Quality*. Retrieved from The Southern and Eastern Consortium for Monitoring Educational Quality: http://www.sacmeq.org

Sintema, E. J. (2020). Effects of COVID-19 on the performance of grade 12 students: Implications for STEM Education. *EURASIA JOURNAL of Mathematics, Science and Technology Education 16 (7)*, 1-6.

Ssempala, F. (2017). *Science Teachers Understanding of Practice of Inquiry Based Instruction in Uganda.* New York: Syracuse University.

Stewart, E. B. (2000). *An ecological perspective of science and math academic achievement among African American students.* Ames: Iowa State University.

The African Exponent. (2018, March 29). *The Major Problems That Africa is Facing Today in 2017*. Retrieved from The African Exponent: https://www.africanexponent.com/post/8304-poor-governance-corruption-and-insecurity-major-problems-confronting-africa

The Planet Earth Institute. (2016). Generation Science: Empowering Africa's Future Scientific Leaders. *ScienceAfrica UnConference* (pp. 1-9). London: The Planet Earth Institute.

The World Bank. (2014). *Raising Botswana's Human Resource Profile to Facilitate Economic Diversification and Growth.* Washington DC : The World Bank.

The World Bank. (2019). *Public Expenditure Review of the Basic Education Sector in Botswana.* Gaborone: The World Bank.

The World Bank. (2020, November 10). *The World Bank*. Retrieved from Population growth (annual %) - Sub-Saharan Africa: https://data.worldbank.org/indicator/SP.POP.GROW?locations=ZG

Tikly, L., Jourbert, M., Barrett, A. M., Bainton, D., Cameron, L., & Doyle, H. (2018). *Supporting Secondary School STEM Education for Sustainable Development in Africa.* Bristol, United Kingdom: University of Bristol.

TIMSS& PIRLS International Study Centre. (2020, 12 10). *TIMSS 2019*. Retrieved from International Evaluation Association: https://www.iea.nl/studies/iea/timss/2019

Tuaundu, C. (2013). *The relationship between teacher-learner interactions and the laboratory learning environment during chemistry practicals in Namibia.* Pretoria: Unpublished Doctor of Philosophy Thesis in Eduction, University of South Africa.

U.S. Department of Commerce. (2020, November 12). Retrieved from STEM Jobs: 2017 Update: https://www.commerce.gov/sites/default/files/migrated/reports/stem-jobs-2017-update.pdf

UN Economic Commission for Africa. (2012). *New and Emerging Challenges in Africa: Summary Report .* 2012: Economic Commission for Africa.

UNESCO. (2017). *Report on the populurisation of sciences using champion teachers in Uganda.* Kampala: UNESCO.

United Nations. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development.* New York: United Nations.

United Nations. (2020, 12 10). *Science, Technology and Innovations (STI) and Culture for Sustainable Development and the MDGs*. Retrieved from United Nations Economic and Social Council: https://www.un.org/ecosoc/en/content/science-technology-and-innovation-sti-and-culture-sustainable-development-and-mdgs

United Nations. (2020, November 10). *Youth Empowerment*. Retrieved from Office of the Special Adviser on Africa of the United Nations: https://www.un.org/en/africa/osaa/peace/youth.shtml#:~:text=According%20to%20the%20United%20Nations%2C%20226%20million%20youth%20aged%2015,three%20quarters%20of%20Africa's%20population.

United Nations Population Fund. (2020, November 10). Retrieved from Population and Development in Africa: https://www.unfpa.org/resources/population-and-development-africa

Watera, W. (2018). *Improving female students' enrolment in STEM demands policies that align the social and technical aspects of the problem.* Kampala: Youth 4 Policy.

White, D. W. (2014). What Is STEM Education and Why Is It Important? *Florida Association of Teacher Educators Journal, 1:14*, 1-9.

White, D. W. (2020, November 29). *What Is STEM Education and Why Is It Important?* Retrieved from STEM BEST PRACTICE: http://stembestpractice.com/what-is-stem-education-and-why-is-it-important/

WHO. (2020, November 10). *WHO Coronavirus Disease (COVID-19) Dashboard*. Retrieved from World Health Organization: https://covid19.who.int/

World Bank. (2018, March 29). *The World Bank in Africa*. Retrieved from The World Bank: http://www.worldbank.org/en/region/afr/overview

Worldometers. (2018, March 29). *African Population*. Retrieved from Worldometers: http://www.worldometers.info/world-population/africa-population/

Yara, P. O., & Wanjohi, C. W. (2011). Performance determinants of Kenya Certificate of Secondary Education (KCSE) in Mathematics of Secondary Schools in Nyamoiya Division, Kenya. *Asia Social Science*, 107-112.

Yawson, N. A., Amankwaa, A. O., Tali, B., Shang, V. O., Batu, E. N., Asiemoah, K., . . . Karikari, T. K. (2016). Evaluation of changes in Ghanians students' attitudes towards science following neuroscience outreach activities: A means to identify effective ways to inspire interest in science careers. *Journal of Undergraduate Neuroscience Education, 14(2)*, A117-A123.

Ushirika wa Maendeleo ya Elimu Barani Afrika
الرابطة لأجل تطوير التربية في إفريقيا
Association for the Development of Education in Africa
Association pour le développement de l'éducation en Afrique
Associação para o Desenvolvimento da Educação em África

Association for the Development of Education in Africa (ADEA)
African Development Bank Group (AfDB)
Immeuble CCIA Plateau, Avenue Jean-Paul II, 01 BP 1387
Abidjan 01, Côte d'Ivoire
Tel: (+225) 27 20 26 39 64
Email: adea@afdb.org - Website: www.adeanet.org