ADEA 2017 Triennale

Education and Training in Africa

Revitalizing Education Towards the
2030 Global Agenda and Africa's Agenda 2063

SUB-THEME 2

Promoting Science, Mathematics and ICT

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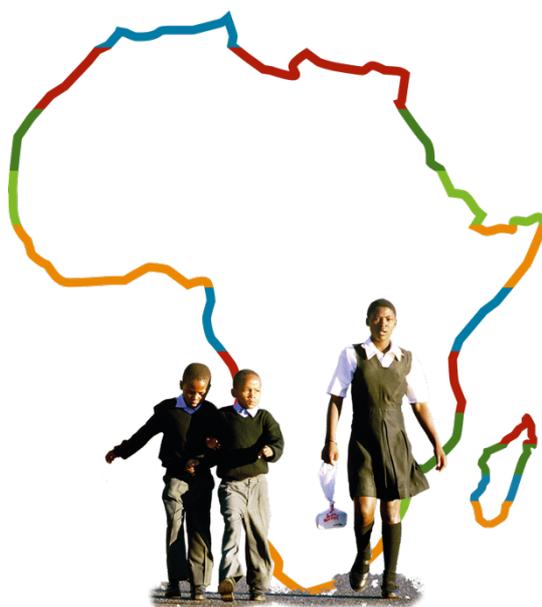
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Ushirika wa Maendeleo ya Elimu Barani Afrika
الرابطة لأجل تطوير التربية في إفريقيا
Association for the Development of Education in Africa
Association pour le Développement de l'Education en Afrique
Associação para o Desenvolvimento da Educação em África

Synthesis Paper

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TABLE OF CONTENTS

ABREVIATIONS AND ACRONYMS

AAAS	American Association for the Advancement of Science
ADEA	Association for the Development of Education in Africa
AfDB	African Development Bank
ASEI	Activity, Student, Experiment and Improvisation
AT	Assistive Technology
AU	African Union
AUC	African Union Commission
CEMASTEA	Centre for Mathematics, Science and Technology Education in Africa
CESA	Continental Education Strategy for Africa
CNTE	National Technology Centre of Education
EFA	Education for All
ELLs	English Language Learners
ESD	Education for Sustainable Development
GeSCI	Global e-Schools Communities Initiatives
ICT	Information and Communication Technology
ICQN	Inter Country Quality Node
ICQN-MSE	Inter Country Quality Node — Mathematics and Science Education
IEA	International Association for the Evaluation of Educational Achievement
INSET	In-Service Education and Training
JICA	Japan International Cooperation Agency
JOCV	Japan Overseas Cooperation Volunteers
MDGs	Millennium Development Goals
MSE	Mathematics and Science Education
OECD	Organization for Economic Cooperation and Development
PDSI	Plan, Do, See and Improve
PISA	Program for International Student Assessment
PRESET	Pre-Service Education and Training
SDGs	Sustainable Development Goals
SMASE	Strengthening of Mathematics, Science Education
SMASSE	Strengthening of Mathematics, Science in Secondary Education
STEM	Science, Technology, Engineering and Mathematics
TCD	Teacher Capacity Development
TCTP	Third Country Training Programme
UN	United Nations
UNESCO	United Nations Education Scientific and Cultural Organisation
WG	Working Group
WGEMPS	Working Group on Education Management and Policy Support

LIST OF FIGURES

EXECUTIVE SUMMARY

Introduction

As articulated in the African Union Commission (AUC) Agenda 2063 document, Africa envisions itself as an integrated, prosperous and peaceful continent: an Africa driven and managed by its own citizens and representing a dynamic force in the international arena by 2063. To achieve this vision, Africa will need human capital that is well prepared through quality education and high level skills in science, mathematics and Information and Communication Technology (ICT). ADEA's 2017 Triennale whose overall theme is *Revitalizing education towards the 2030 Global Agenda and Africa's Agenda 2063* will provide a platform for policy dialogue and sharing of knowledge and experiences that could contribute to the transformation of Africa's education systems for sustainable development. The Triennale is organized around four sub-themes, namely, *Implementing education and lifelong learning for sustainable development; Promoting science, mathematics and information and communication technology; Implementing education for African cultural renaissance and pan-African ideals; and Building peace and global citizenship through education*. This paper provides a synthesis of contributions made under Sub-theme 2, which focuses on promoting science, mathematics and ICT education.

Issues and challenges

Science, mathematics, and ICT education in Africa faces numerous challenges and issues that hinder quality and access at all levels - preschool, primary, secondary and higher education. The issues relate to the preparation of teachers, teacher qualifications, competencies and skills, and teaching methodology; curriculum relevance and availability of appropriate teaching and learning resources; poor access and participation in mathematics and science education; gender disparity in the learning of Science, Technology, Engineering and Mathematics (STEM); the critical role of the language of instruction in the learning of science and mathematics; and the importance of ICT education and ICT in national development. This synthesis paper discusses these issues and highlights experiences and initiatives that have addressed some of these challenges.

Findings

The analytical work has unearthed initiatives and interventions that are designed to address the challenges associated with science and mathematics education in Africa. Although many countries are promoting the acquisition of science, mathematics and ICT skills by learners, progress has been slow. Areas of significant progress include: i) enhancing teacher quality through continuous professional development; ii) enhancing teacher capacity to integrate ICT into teaching and learning; iii) using ICT to expand learning opportunities in higher education; iv) using ICT to build teacher capacity through online teacher orientation programmes; v) relating mathematics content to real life situations and experiences; and vi) connecting students to their environment through science. The following areas however need attention: proficiency in the language of instruction by both teachers and students; integrating indigenous knowledge into school science; increasing the participation of females in STEM subjects; and addressing the needs of persons with learning disabilities.

Key lessons and messages

From the analytical work, the following key lessons and messages stand out:

- Innovative approaches to learning science and mathematics that relate the teaching of the subjects to real life situations can enhance learners' understanding and appreciation of the importance of science and mathematics in national development.

- The language of instruction plays an important role in enhancing students' understanding and performance in science and mathematics. Proficiency in the language of instruction of both teachers and learners has strong influence on learning outcomes.

- The integration of ICT into the learning process can have far reaching effects on learning outcomes. However, ICT application and technology-mediated learning will require availability of the necessary ICT infrastructure and teachers imbued with ICT skills and knowledge.

- ICT can be drawn upon to expand learning opportunities in higher education, while contributing to greater efficiency in the use of resources.

- Indigenous knowledge is as important as school science and should be reflected in the curriculum. Integrating indigenous knowledge into school science enables students to better understand observed scientific phenomena in relation to their cultural experiences and practices. In this regard, there is need to popularise scientific knowledge and its importance among all segments of African society.

- For sustainability, beneficiary governments of donor-funded programmes aimed at strengthening the teaching and learning of science and mathematics should commit to appropriating, institutionalising and expanding such programmes.

- Progress in promoting science, mathematics, and ICT education in Africa will require commitment and investments in teaching and learning infrastructure, the training and continuous development of adequate numbers of teachers, teacher motivation, and experience sharing of best practices and successful initiatives.

- Gender disparities in learning STEM subjects will need to be addressed through targeted interventions that encourage female enrolment in STEM disciplines.

Conclusion and recommendations

The findings show that the issues and challenges associated with effective science, mathematics and ICT education in Africa cut across all levels of education from preschool to higher education. The challenges include: poor quality of teachers and teaching (i.e., teaching methodology, staffing and teacher competencies and skills); curriculum and curriculum materials (i.e., non-contextualised curricula and learning materials, examination centred curricula, and inadequate teaching and learning resources); access and participation in mathematics and science (i.e., gender disparity in participation in STEM subjects and careers; low levels of competency in the language of instruction by both teachers and learners); low levels of competency of both teachers and leaners in the use of ICT in education; and low output of research in STEM and the physical sciences.

It is recommended that all countries prioritise science, mathematics and ICT education within an enabling policy framework; invest significantly in teaching and learning infrastructure and teacher development; design and implement targeted interventions to encourage female participation in STEM disciplines; and address the learning needs of persons with visual and hearing impairment or other learning disability. Finally, the creation of a knowledge sharing platform at the continental level will be helpful in disseminating successful experiences and good practices.

1.0. INTRODUCTION

The overall theme of the ADEA 2017 Triennale is: *Revitalizing education towards the 2030 Global Agenda and Africa's Agenda 2063*. The Triennale is organized around four sub-themes which focus on: equity, quality and lifelong learning as (Sub-theme 1); promoting science, mathematics, and ICT (Sub-theme 2); African cultural revival and ideals for pan-Africanism (Sub-theme 3); and education for peace and global citizenship (Sub-theme 4).

This paper is a synthesis of the current status and efforts aimed at promoting science, mathematics and ICT education in Africa. It is based on the review and analysis of country and transnational case studies and other contributions submitted to the Triennale under the sub-theme, papers presented at two regional consultation forums, the results of an online consultation, as well as a comprehensive literature review. The paper is divided into five sections. The first section gives the background, purpose and scope of the synthesis. The second section gives the status of science, mathematics and ICT education in Africa and summarises the key issues and challenges in science, mathematics and ICT education in Africa. In section three, the methodological approach employed in unearthing the current developments in science, mathematics and ICT education in Africa is presented. The fourth part presents and discusses the main findings emanating from an analytical review of the case studies, research reports, and background papers contributed for the Triennale. The fifth and final section highlights the conclusions from the analytical work and the key recommendations.

1.1. Background

One of the milestones of the education for all (EFA) global movement is the increase in student enrolments in schools (UNESCO, 2016). According to the UNESCO Global Education Monitoring Report (2016), 91% of eligible students are enrolled in primary education. While the substantial increase in students' population is commendable, there are concerns over the 9% eligible students who are yet to access education for reasons such as extreme poverty, nomadic lifestyles and displacement due to conflict. This group of students need access, not just to education, but to quality education. Ensuring this access may require innovative approaches and strategies. The global community adopted the 2030 Global Agenda enshrined in 17 Sustainable Development Goals (SDGs) in 2015, with Goal 4 exclusively focusing on ensuring quality education and opportunities for lifelong education for all. Inherent in this goal is the implication of universal access to quality education — one that offers all learners requisite skills needed to function well and to contribute to the development of their communities and society at large. Furthermore, such education should help the youth to develop personal characteristics that are critical to attainment of sustainable development, including the development of an attitude of being less self-interested, doing more with less, and caring for the environment (UNESCO, 2016).

Recently, the African Union Commission (AUC) adopted Agenda 2063, with a vision of building an integrated, prosperous and peaceful Africa – an Africa driven and managed by Africans and representing a dynamic force in the international arena. This was in an effort to continue building on gains made in most countries in Africa in terms of reducing poverty levels, raising incomes, and improving education and health outcomes (African Economic Outlook, 2014). Indeed, the African Economic Outlook reported a Human Development Index growing at a rate of 1.5% per annum for Africa. Recognizing the critical role of human capital in achieving its vision, the African Union commits to ensuring a "revolution of education, skills and active promotion of science, technology, research and innovation in order to strengthen knowledge, human resources, capacities and peoples'

abilities for the African century" (AUC, 2014, p. 14). Through education, Africa hopes to raise the critical mass of human resource as change agents for the continent's sustainable development. As a step towards realising this vision, the Heads of State and Government adopted a ten-year Continental Education Strategy for Africa (CESA 16-25) in January 2016 in Addis Ababa as the framework for transforming education in Africa. The framework is guided by six principles that articulate the vision for education in Africa and seven pillars to provide an enabling environment for the attainment of the vision. Among other areas of focus, CESA places emphasis on science, mathematics, and ICT as drivers in achieving Africa's agenda for sustainable development. Indeed, two out of the 12 strategic objectives in the CESA framework are geared towards building learners' capacities in science, mathematics and ICT, namely: harnessing the capacity of ICT to improve access, quality and management of education and training systems; and strengthening the science and mathematics curricula in youth training and disseminating scientific knowledge and culture in society.

Africa's emphasis on science, mathematics, and ICT is consistent with the global trend of viewing these subjects as central to the rapid global changes that have transformed the way the human race lives and works (AAAS, 1993). Furthermore, ICT is emerging as an important instructional tool globally. There is increasing evidence of a correlation between countries investing in ICT to enhance education performance in the core subjects of mathematics, science and reading, and the high scores in international achievement tests such as PISA (OECD, 2009). Similarly, Thioune (2003) reported that, for the past two decades, most developed countries have witnessed significant changes in almost all aspects of life, notably, economics, education, communication and travel, which can be traced to ICTs. However, in order to draw on science, mathematics and ICTs to grow "the Africa we want", as envisioned by Agenda 2063, Africa needs to take stock of the status of implementation of the strategies in science, mathematics and ICT in education, and to identify experiences that work to address the obstacles and challenges, as well as circumstances under which they work. These can provide important lessons and a framework within which decisions for scale-up and replication elsewhere may be made.

1.2. Purpose of the Synthesis Work

The purpose of the synthesis work is twofold. First, the synthesis paper is an attempt to document the development of science, mathematics and ICT in education in Africa and any inherent implementation challenges. Second, the paper seeks to identify innovative and workable solutions to the challenges from within and outside Africa. In this regard, the synthesis sought to answer the following questions:

1. What are the issues and challenges facing mathematics, science and technology education in Africa?

2. What experiences both African and non-African have successfully addressed these issues and challenges?

1.3. Scope of the Synthesis

The synthesis covers issues, challenges and implementation strategies in science, mathematics, and ICT in education at all levels of education delivery in Africa (i.e., preschool and primary, secondary, and higher education). Mathematics and science education in Africa was examined in the context of teaching and learning. How such education could be restructured and re-engineered to prepare learners for a better service to their communities and society at large in a sustainable manner, was

of great importance. ICTs were considered from the perspective of their use both as tools and means for improving access, quality and management of education and training. In this regard, ICT tools, including computers, tablets, phones, and internet and their use especially in enabling access, delivery and management of education in general, and science and mathematics education in particular, all counted as relevant to the sub-theme. Some examples of the application of ICTs in providing solutions to national socioeconomic development challenges are also highlighted.

2.0. CURRENT STATE OF SCIENCE, MATHEMATICS AND ICT EDUCATION IN AFRICA

2.1. Targets based on UN Agenda 2030 and AU Agenda 2063

Goal 4 of the 2030 Global Agenda for Sustainable Development (SDG 4) is: "Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all." The need for quality science, mathematics and ICT education is implied in four of the seven targets of SDG 4. The four targets are listed below:

Target 4.1: By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes.

Target 4.2: By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education.

Target 4.6: By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy.

Target 4.7: By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development.

Agenda 2063 sets more specific goals and targets for Africa. In effect, Africa hopes to capitalise on human capital that is well grounded in science, mathematics and ICT to achieve its vision outlined in Aspiration 1 of Agenda 2063. One of the goals under this aspiration is to have *well educated citizens and skills revolution underpinned by science, technology and innovation for a knowledge society*. Two priority areas (i.e., literate, creative and adaptive citizenry; and skills revolution for the 21st century global competitive environment) have been identified under this goal, together with targets to address them. For example, under the priority area of literate, creative and adaptive citizenry the following targets have been set:

Target 1: 100% literacy rate by 2030

Target 2: Universal basic school education (including early childhood education) with 100% enrolment rate by 2020.

Target 3: Universal high school education with 100% enrolment rate by 2025

Target 4: At least 70% of high school graduates will go on to tertiary education with 70% of them graduating in science, technology and innovation programmes.

The following targets have been identified to address the priority area of skills revolution for the 21st Century's global competitive environment:

Target 1:   10% of degrees awarded by universities/polytechnics are in computer science and information technology by 2040.

Target 2:   50% of all degrees awarded by universities/polytechnics are in the engineering sciences by 2040.

Target 3:   10% of degrees awarded by universities/polytechnics are in the bio/health sciences and bio-technology by 2040.

Target 4:   100% of secondary school students without access to tertiary education have free access to TVET education by 2030.

2.2. Status on Targets

1. Access and Completion Rates

It is important to note that gains have been made in respect of the EFA goals, especially in terms of increase in enrolment of students in school. However, disparities still exist in terms of access, quality, and equity in education that includes science, mathematics and ICT education among regions in Africa at different levels of education. Regarding access and completion rates, CESA 16-25 noted:

- Access to education at pre-primary school level stands at "about 20% on average in Sub-Saharan Africa (SSA). It is much higher in Northern African countries such as Algeria, Morocco and Tunisia" (p. 14). For lower and upper secondary education in low income African countries, access stands at 44.7% and 23.2% respectively.

- Completion rate at primary level currently stands at only 70% in SSA and 95% in North Africa and the Middle East. At the lower and upper secondary education level, completion rates stand at 29.5% and 13.9%, respectively, in SSA. These data are illustrated in Figure 2.1, provides shows enrolment and completion rates for different education levels in different regions. The data in Figure 2.1 show that less than 10% of students enrolled in school at primary level in Sub-Saharan Africa make it to tertiary education.
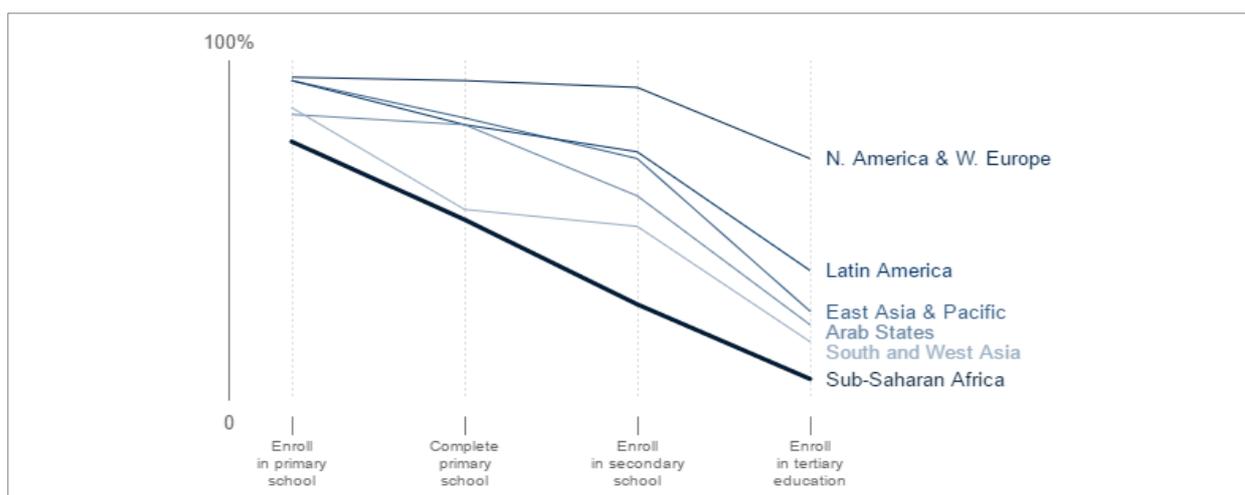
Figure 2.1. Enrolment and completion rates at different education levels in different regions
Source: Centre for Universal Education, Brookings Institute (2012)

Furthermore:

- There is gender disparity in enrolment with girls' enrolment standing at 30% and 35% of the total enrolment at the lower and upper secondary level respectively in SSA. In addition, boys outperform girls in math and science.

- At higher education level, many more students are enrolling in courses in the humanities as compared to those related to science and technology. In addition, the many students who enrolled in courses in humanities were faced with the challenge of overcrowded classes.

Based on data from CESA 16-25, Northern Africa is ahead of other regions of Africa in access and participation in education. However, it is clear that when it comes to access, participation and quality in education in general, and specifically in science, mathematics and ICT education, Africa is behind other regions of the world.

Factors that hamper access and quality in education delivery include inadequate teaching and learning resources, barriers related to the language of instruction, shortage and quality of teachers, and inadequate teacher and learner support. Regarding resources, data consolidated by UNESCO on areas related to teaching and learning resources that include textbooks and teacher quantity, as well as access to basic services such as water, and electricity (as reported through UNESCO Bulletin No. 9 of 2012), showed disparities access and distribution of resources, not only across different countries but also within countries. For example, while in some countries the textbook to child ratio was 1:1 or 1:2 at most, in other countries the ratio was as high as 1:11. Similarly, the UNESCO Bulletin identified Mauritius as the only African country with where all schools were connected to electricity from the national grid. In other countries, only secondary schools or select primary and secondary schools were connected to the national grid.

2. Barriers Associated with the Language of Instruction

Science and mathematics are cultural in the sense that they have their own cultural tools such as language. For a meaningful learning of science subjects, for instance, students should understand scientific language: to be able to write and "talk science" (Lemke, 1990). Achieving this may be a challenge in contexts such as Africa where the language of instruction is different from the first language of learners and teachers because it involves learning the language of instruction as well as the content and language of mathematics and science. Studies conducted in Africa have shown that learners do not participate in mathematics and science lessons in meaningful ways due to limited proficiency in the language of instruction by both teachers and students (Brock-Utne, 2007; Evans & Cleghorn, 2010; Kembo & Ogechi, 2009).

For example, Brock-Utne (2007) conducted an experimental study in Tanzania where students were taught the same concepts in biology and geography using two different languages: English, the language of instruction and Kiswahili, the first language of learners. The researcher found that in classes taught in English, the teachers talked most of the time and the students talked only when asked to answer questions for which most of them did not know the answers. On the other hand, classes taught in Kiswahili were more lively with the teachers having a difficult time in choosing the students to answer questions because of what Brock-Utne described as a "forest of waving hands" (p. 494) going up whenever a question was posed. Brock-Utne argued that there was more meaningful learning in the classes taught in Kiswahili compared to those taught in English because students brought to the class their experiences with phenomena involving the concepts being taught and

teachers capitalised on them to build new information and introduce new terminology. This study helps to confirm that learning in a language other than the first language can be a hindrance to meaningful learning, especially for students with low competencies in the language of instruction. This situation becomes even more complex when teachers do not have adequate mastery of the language of instruction because it can lead to confusion as a result of miscommunication.

This was illustrated from the findings of a study that investigated teacher-student interactions in preschool through third grade science classes taught by student teachers in South Africa (Evans & Cleghorn, 2010). The researchers found that the student teachers conducted some exemplary lessons. However, there were also incidents of missed opportunities for students to learn in meaningful ways. One such incident involved a demonstration by one of the teachers about a reaction between bicarbonate of soda and vinegar in a balloon. In addition to referring to the reagents as "opposites", the teacher instructed the students "to look at the balloon blow up" (p. 143). According to the Evans & Cleghorn (2010), the balloon did not blow up, rather it got inflated. As a result, the students were left baffled. Similarly, Kembo and Ogechi (2009), who conducted classroom observations of several classes at primary school level for mathematics and science in Kenya, found that the teachers had difficulties teaching due to inadequate mastery of English, the language of instruction. Kembo and Ogechi observed:

> Teachers had difficulty explaining scientific and mathematical concepts simply and clearly because they lacked the appropriate lexical resources to facilitate this. This often led to code-switching to Kiswahili and other local languages, but with very little remedial/developmental consequences. In many cases even code-switching was inappropriately applied and led to even more confusion (2009, p. ix).

While there may be need for more research targeting teachers and their teaching especially at high school level, the findings of these studies may mean that access to meaningful learning of mathematics and science in the African context has an added layer of complexity involving teachers' incompetence in the language of instruction.

3. Gender Disparities in Science and Mathematics Education

There is abundant evidence of gender-based differential participation and engagement in mathematics and science (Asimeng-Boahene, 2006). Achievement in mathematics and science has also been shown to be differentiated along gender lines. For example, Gachukia and Kabira (1991) found that girls performed generally lower than boys in science and mathematics. Reasons that have been advanced for the gender disparity in mathematics and science include, socialisation and societal expectations of boys and girls; gender stereotypes; and teachers' attitudes and teaching methodologies (Asimeng-Boahene, 2006). Clearly, the findings of these studies, especially regarding the influence teachers have on the uptake of mathematics and science by both boys and girls, put into sharp focus the role of teacher preparation and preparedness in addressing the issue of gender-differentiated performance.

4. Teacher Quantity, Quality and Support

It has been argued that teachers are the single most important factor that influences teaching and learning outcomes (Darling-Hammond, 2010; GCE, 2012; Hooker, 2016). There is general agreement that the quality of education in any country is as good as the quality of its teachers (GCE, 2012). However, teachers' quality needs to be supported by teachers' quantity. UNSECO (2016) reported

acute shortage of teachers in many countries in the world with 70% of countries in Sub-Saharan Africa facing acute shortages of teachers, rising to 90% at secondary level. The report further noted that:

> "Improving education quality requires far more than just having enough teachers in the education system: teachers need to be trained, supported through professional development, motivated and willing to continually improve their teaching practices" (UNSECO, 2016, p. 11).

This means that teacher quality in terms of their initial training and capacity development for further acquisition of knowledge and skills are important factors in education delivery. In addition, teacher motivation, especially in terms of appropriate remuneration and working conditions, also requires consideration.

According to UNESCO (2016), 12 out of 31 countries and 16 out of 30 countries with less than 80% of trained teachers at primary and secondary school levels respectively were in Africa. The scenario becomes clearer when the percentages of trained teachers are compared across different levels and regions as shown in Figure 2.2.
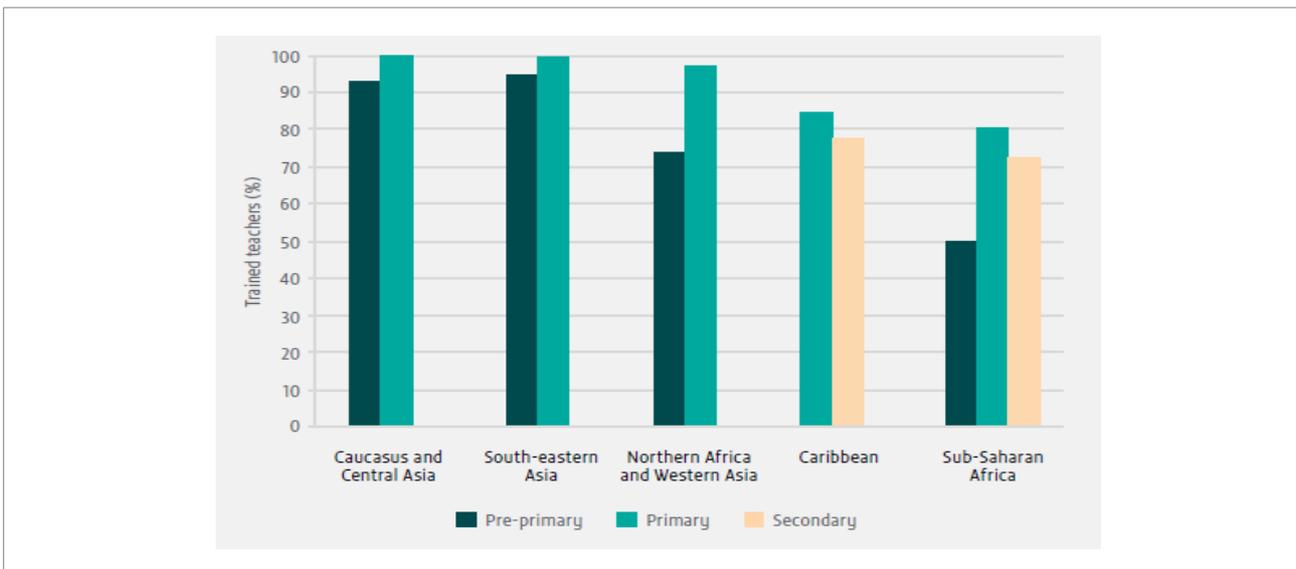
Figure 2.2. The number of trained teachers at different levels of education in different regions
Source: (UNESCO, 2016)

As shown in Figure 2.2, more than half of pre-primary and one-quarter of secondary school teachers in sub-Saharan Africa are not trained. It seems then that Africa and more so, sub-Saharan Africa, has the highest number of unqualified teachers. According to the Global Campaign for Education report of 2012:

> Well-trained teachers can better manage diversity in a classroom, can deal – for example – with the huge range of ages commonly found in schools in post-conflict countries, can reduce violence and manage discipline in a positive way and, through gender training, can better support girls' participation in class in a way that significantly increases their chances of success (p. 2).

This means that to achieve the desired quality of education, Africa needs trained teachers.

Alongside the issue of teacher qualification is that of working conditions and remuneration. Research shows that there is a correlation between countries that pay their teachers well and learner performance in mathematics (IEA, 2009). According to IEA, countries that paid their teachers well had their students performing better on international assessments, such as Program for International Student Assessment (PISA). Also, well-structured professional career ladder and performance evaluation systems are critical elements that enable teachers to continue growing and delivering quality education to students (Liang, Kidwai & Zhang, 2016). Liang et al (2016) use the example of Shanghai (China) to demonstrate how a high degree of coherence between policy and implementation can ensure the recruitment and retention of the best teachers. Shanghai is guided by the eight-policy goals of the Systems Approach for Better Education Results (SABER) for teachers, as illustrated in Figure 2.3.
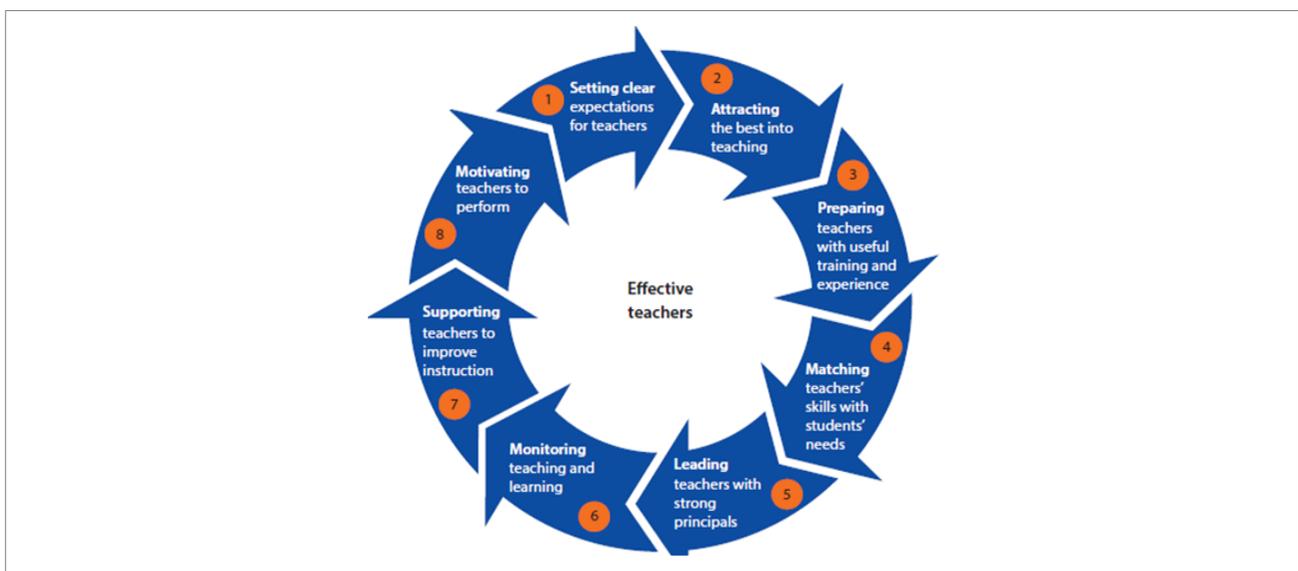
Figure 2.3. Eight policy goals under SABER for teachers in Shanghai
Source: Liang et al (2016)

As can be seen in Figure 2.3, there is a host of actions that have been implemented to ensure that teachers in Shanghai are effective. Effectiveness is a function of a supportive system that includes setting clear expectations for teachers, equipping teachers with necessary skills and knowledge, providing an enabling environment for effective practice, and motivating teachers to perform.

Liang et al. (2016) observed that Shanghai recorded the highest PISA scores in reading, science and mathematics on a global assessment of the educational abilities of15-year-olds. This success was attributed to the effectiveness of the teachers in providing quality education. Shanghai teachers spent the lowest amount of time on non-teaching activities such as classroom management and administrative tasks, compared to teachers from other countries (Figure 2.4).

It seems then that learning outcomes such as high examination scores are positively related to the amount of time spent on activities related to teaching and learning. When teachers spend more time on teaching and learning activities, students learn more and this leads to better learning outcomes.
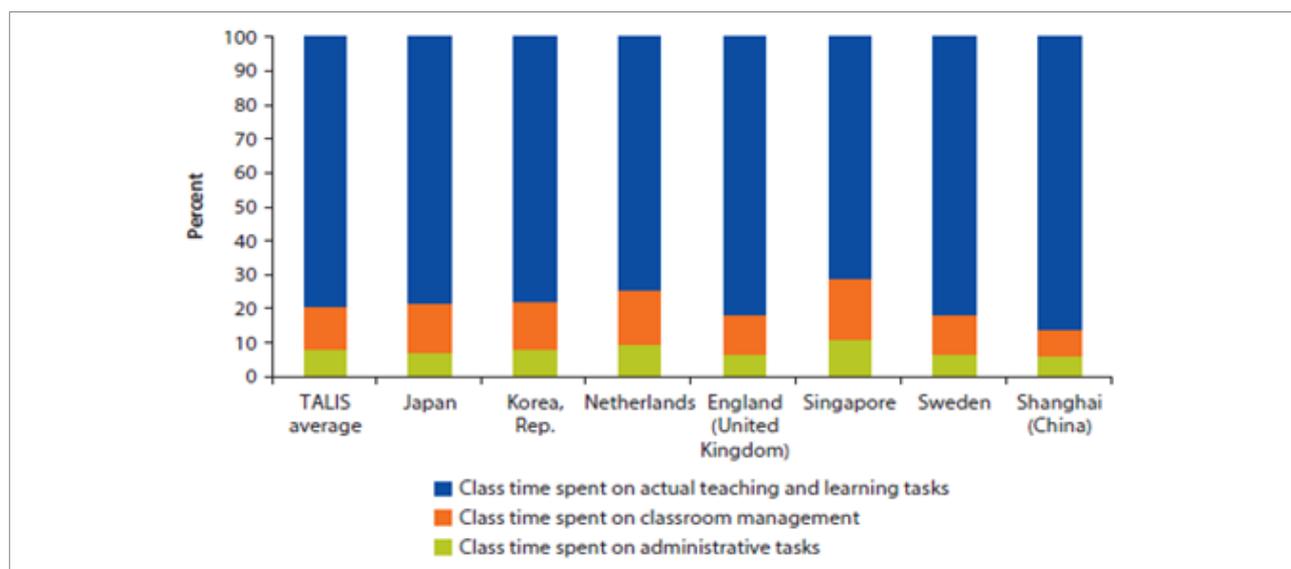
Figure 2.4. Time spent on different tasks in different countries
Source: Liang et al. (2016)
Note: TALIS = Teaching and Learning International Survey

5. Literacy and Numeracy Skills

The Brookings Institute report of 2012 estimates that 61 million African children reach adolescence without basic literacy and numeracy skills based on a Learning Barometer developed by the Institute. The report projects that:

• 17 million children in Africa will never go to school.

• 97 million will enter school on time, but 37 million of them will not learn basic literacy and numeracy skills.

• 14 million will enter school late, and 3.6 million of those students will not learn basic literacy and numeracy skills.

According to UNESCO (2012), basic numeracy and literacy are the most elemental skills requirements for jobs. The high number of learners without basic numeracy and literacy skills signals a reduction in their capacity for decent work and sustainable livelihoods.

6. ICT in Education

According to a 2015 UNESCO report, disparities exist among SSA countries in terms of, not only the quantity of ICT tools (for example, radios, television and computers) accessed in school, but also policy formulation, formal commitments and integration of ICT into the curricula. For example, while only 14%, 1% and 2% of Grade 6 pupils in Malawi could access radio, television and computers respectively in school, 82%, 77% and 62% pupils could access the same tools respectively in Namibia at the same grade level in 2007. The highest percentage on access of these tools was recorded in Seychelles where 100%, 93% and 100% could access the same tools respectively in the same year (UNESCO, 2015).

On the other hand, while some countries had no policy on integration of ICT in education provision, other considered only some levels of the education system, while yet others had national policies covering all levels of education. In addition, disparities were noted among countries' in regard to the integration of ICT into the courses delivered at different levels of the education system. According to the UNESCO (2015) report, Burkina Faso, Comoros, Guinea, Madagascar and Niger had neither learning objectives nor courses in basic computer skills at primary school level, while Djibouti, South Africa, The Gambia and Togo had objectives or courses in basic computer skills, but only at the upper secondary level. Countries that had objectives or courses in basic computer skills at both lower secondary and upper secondary included Ethiopia, Lesotho and Liberia while Angola, Botswana, Cameroon, Cote d'Ivoire. Mauritius, Uganda and Zambia had objectives or courses in basic computer at primary, lower secondary and upper secondary levels. These data are consistent with those reported by ADEA (2014) on the integration of ICT into training systems in various African countries. The ADEA report noted that there was differential uptake of ICT in education at primary and secondary levels in Burkina Faso. While there was evidence of use of ICT in teaching (i.e., PowerPoint, projectors, etc.) at secondary school level, none existed at the primary school level.

There is no doubt that ICT has the potential to revolutionise classrooms, including those involving students with learning disabilities. For example, through Assistive Technology (AT) software, available mainly through tablets, students with visual impairment can do just as much as their peers who are sighted in working on their class assignments (Smith & Kelly, 2014). Similarly, with the help of ICT tools, people with visual impairment are able to carry out tasks that would otherwise prove difficult (Shaw & Kirkham, 2005).

Clearly, the impact of ICT in education and in life in general is both positive and real. However, one of the challenges in realising the benefits of ICT education has to do with teachers' competency especially those involving the use of AT to help learners with visual impairment. A survey by Zhou et al. (2012) showed that 59.3% of the teachers had "some" or "no" confidence in using AT to support teaching. The infusion of ICT courses into the pre-service education of teachers would equip them for the integration of ICT into their teaching and for the use of ICT tools. In a study to determine the impact of infusing ICT into pre-service training, Nix et al. (2004) found positive influence of ICT not only on the pre-service teachers but also their learners during student teaching as well as on the supervising teachers after only one year of infusing ICT into the teacher training programme. Nix et al. (2004) found that:

> (a) Student teachers are dynamically utilizing technology in the classroom, (b) students in the classrooms are literally enjoying education based on the impact the technology has provided, and (c) supervising teachers have individually benefitted from the influence of the student teacher in the classroom (p. 60).

7. Research in STEM Fields and the Physical Sciences

According to a World Bank (2014) report on developments in sub-Saharan African research, there has been a general increase in research conducted in Africa between 2003 and 2012. The report noted however that Africa, more specifically, sub-Saharan Africa, lags behind in research output in Science, Technology, Engineering and Mathematics (STEM). Figure 2.5 shows the percentage of total article output in the Physical Sciences & STEM and the Health Sciences for sub-Saharan Africa regions compared to Malaysia and Vietnam.
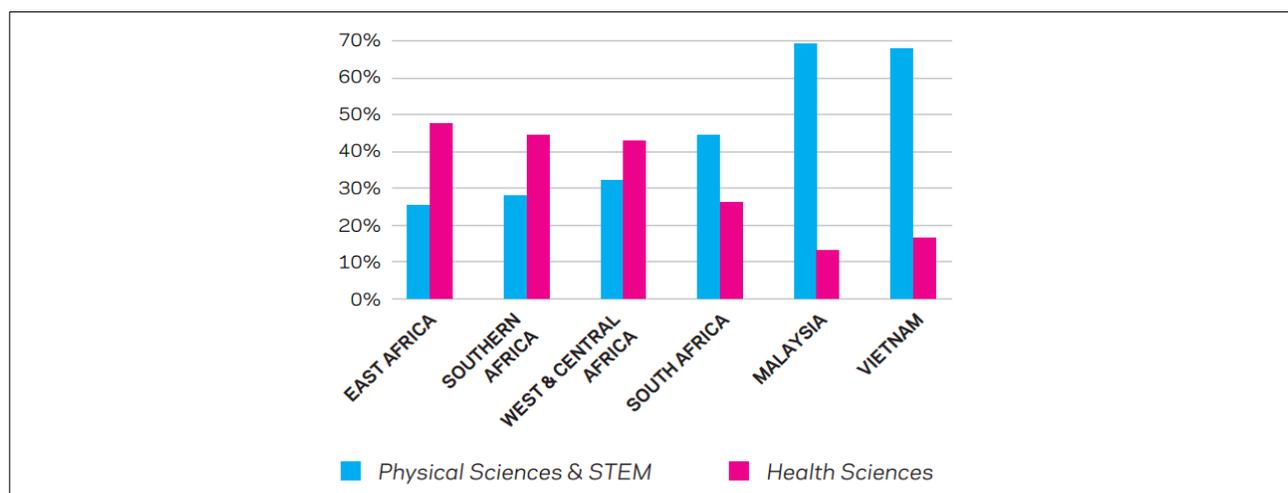
Figure 2.5. Percentage of total article output in the Physical Sciences & STEM and the Health Sciences for sub-Saharan Africa regions compared to Malaysia and Vietnam
Source: World Bank (2014, p. 4)

The World Bank (2014) suggests that the large gap in STEM research could be linked to factors that include: the low quality of basic education in science and mathematics within Sub-Saharan Africa; a higher education system skewed towards disciplines other than STEM, such as the humanities and social sciences; international research funding – which comprises the majority of Sub-Saharan Africa research funding – that prioritises health and agricultural research.

8. Science benchmarks and mathematics standards

Science literacy benchmarks and mathematics standards provide a basis for developing science and mathematics curriculum and assessment and evaluation. Currently, there are no science literacy benchmarks and mathematics standards for Africa. However, the Inter Country Quality Node on Mathematics and Science Education (ICQN-MSE) and the Working Group on Education Management and Policy Support (WGEMPS) are working on a framework for developing science literacy benchmarks and mathematics standards for Africa. Key questions guiding their work include: what constitutes scientific and mathematical literacy for the African child in the African context and what are the attendant essential competencies? What is important for young people to know, value, and be able to do in situations involving science, mathematics and technology?

2.3. Key Issues and Challenges

From the analysis and discussion of the data and information presented in the previous sections, the key issues and challenges facing science, mathematics and ICT education in Africa may be summarised as follows:

1. Limited access to and poor quality of science and mathematics education

   • Inadequate academic and physical resources (e.g., textbooks, and basic services such as water, sanitation and electricity);

   • Large class sizes, especially at higher education level;

   • Low proficiency of teachers and students in the language of instruction;

- Gender disparities in participation and academic performance in science and mathematics;

- Inadequate numbers of science, mathematics and ICT teachers;

- Inadequately trained or unqualified teachers;

- Absence of teacher support mechanisms.

2. Generally poor background of learners in basic literacy and numeracy skills

3. Inadequate ICT infrastructure and policies

- Inadequate availability of ICT tools such as radios, computers, television, and internet facilities;

- Poor teacher and student competencies in the use ICT tools;

- Absence of comprehensive policies on ICT integration into education provision.

4. Low research output in STEM and the physical sciences

5. Lack of science literacy benchmarks and mathematics standards

3.0. ADDRESSING THE CHALLENGES: METHODOLOGICAL APPROACH

How can the challenges of promoting science, mathematics and ICT education in Africa be addressed? The methodological approach involved taking stock of the status of science, mathematics and ICT in education, as well as collating experiences and best practices on what works in addressing the challenges and the circumstances under which they work.

The methodology was based on a concept note developed by ADEA that not only raised some of the issues and challenges of science, mathematics and ICT education in Africa but also the urgency of taking action. Several sources of information for addressing the challenges were identified. These included the ADEA networks such as the Inter Country Quality Nodes (ICQNs) and Working Groups (WGs). Other sources of information gathering and experience sharing included regional consultative forums, online consultations, review of literature, and analysis of academic and research papers, agency reports, as well as country and multinational case studies contributed to the sub-theme. These activities provided information and data needed to prepare this synthesis paper. This section provides a brief description of the actions and activities involved.

3.1. Regional Consultative Forums

Two regional consultative forums were held under the sub-theme in Dakar (Senegal) for the West Africa region and Rabat (Morocco) for the North Africa region. ADEA organised the two forums in collaboration with the ministries of education of the two countries with the support of the Africa Development Bank (AfDB) and the Japan International Cooperation Agency (JICA). The Dakar forum which was held on 13th and14th June 2016 was attended by 47 participants drawn from five countries in West Africa, namely, Mali, Burkina Faso, Cote d'Ivoire, Mali, Nigeria and Senegal. The Rabat forum, held at the same time, brought together participants from three North African countries - Mauritania, Morocco and Tunisia – as well as Ethiopia, Kenya, Senegal and Zambia.

The forums afforded the stakeholders and participants an opportunity to share experiences on workable solutions to the challenges facing science, mathematics and ICT education in Africa. The

proceedings of the regional consultative forums provided invaluable information included in this synthesis paper.

3.2. Online Consultations

Besides the regional consultative forums, information was collected from different groups of stakeholders through an on-line consultation. An open-ended questionnaire was posted on ADEA's website to allow stakeholders to respond to questions and make contributions on topical issues under the different sub-themes of the Triennale. Under Sub-theme 2, respondents were required to give suggestions on what needed to be done to allow all students regardless of gender and age to engage and participate meaningfully in the learning of mathematics and science, attract as many students as possible to these subjects, and ensure that as many students as possible graduate from school with strong background in mathematics, science and technology.

The stakeholders targeted for consultations included government ministers and ministry technical staff, development partners, teachers, experts, the academia, the youth and students, parents, and civil society in Africa. Given that the questionnaire was open-ended, qualitative data obtained through it were analysed qualitatively. In particular, the participants' responses were analysed to determine emerging themes and trends. The ideas and suggestions from the online consultations were helpful in assessing the contributions to the Triennale under the sub-theme.

3.3. Review of pertinent literature

This process involved reviewing existing literature, reports and data from websites of organisations such as UNESCO, ADEA, and IDRC and Brookings Institute and online sources such as Google Scholar, for papers focusing on the area of mathematics and science and ICT in education. The purpose of the review was to determine the status of knowledge in science, mathematics and ICT in education and to identify experiences and good practices from Africa and elsewhere that have been successful in tackling the challenges associated with science, mathematics and ICT in education.

3.4. Papers contributed to the subtheme

The ADEA secretariat posted a call for papers on its website towards the Triennale and set 31st July 2016 as the deadline for paper submissions. For Sub-theme 2, contributors were invited to submit papers related to the promotion of science, mathematics and ICT in education in Africa. The contributions could be case studies, research papers or reports. The contributions were evaluated and reviewed against the criteria of relevance to the Triennale, particularly to Sub-theme 2; effectiveness of the contributions in addressing issues and challenges in science, mathematics and ICT in education; and possibilities of replication or scale-up of interventions and experiences reported.

4.0. FINDINGS AND DISCUSSION

The findings and discussion of the findings reported in this section are based on the outcomes of the consultative forums, online consultation, literature review and paper contributions to the sub-theme. Also presented in this section are the key lessons arising from the analytical work.

4.1. Initiatives towards promotion of science, mathematics and ICT in education in Africa

A number of initiatives in different countries in Africa are aimed at addressing some of the issues and challenges in science, mathematics and ICT education. These initiatives include: enhancing teacher quality through continuous professional development; enhancing teacher capacity to integrate ICT in teaching and learning through a partnership approach; using ICT to build teachers' capacity; using ICT to expand opportunities for higher education; relating mathematics content to real-life experiences; addressing teachers' poor competencies in the language of instruction; connecting learners to their cultures through science learning; and integrating indigenous knowledge with school science. Brief descriptions of these initiatives and implementation strategies are provided in the following section.

1. Enhancing Teacher Quality through Professional Development

The need for teachers who are adequately prepared to implement science and mathematics curricula cannot be overemphasised. This is because teachers influence learning outcomes and therefore one way Africa can move forward in building its human capital is to use ICT to enhance the teaching of science and mathematics. In many countries in Africa, initiatives have been undertaken to build teachers' capacity to teach science and mathematics. Some of these initiatives started as projects sponsored by development partners, but have subsequently graduated to programmes that are fully funded by the beneficiary government. One development partner that has been instrumental in building teachers' capacity in Africa is Japan through the Japan International Cooperation Agency (JICA). In addition to sending volunteer teachers under the Japan Overseas Cooperation Volunteers (JOCV) programme to a number of African countries to teach mathematics and science, JICA has supported and continues to support many projects involving capacity development of mathematics and science teachers.

The first of these projects was started in Kenya in 1998 as an in-service education and training (INSET) programme known as Strengthening of Mathematics and Science in Secondary Education (SMASSE). The project, which started with only a few districts, was a joint venture between the Government of Kenya through the Ministry of Education and the Government of Japan. The main aim of the project was to provide train in-service training in teaching methods to secondary school mathematics and science teachers. After a successful implementation of the first phase, the project was expanded to the rest of the country, as well as the primary school level. This led to its name change from SMASSE to Strengthening of Mathematics and Science Education (SMASE). Upon the expiry of the project period in 2013, SMASE became a programme fully funded by the Ministry of Education of Kenya. SMASE has since been institutionalised and regularised as a teacher capacity development programme for mathematics and science teachers at both primary and secondary school levels nationwide. The Kenya Ministry of Education has mandated the Centre for Mathematics, Science and Technology Education in Africa (CEMASTEA) to conduct capacity development for teachers and educators, with the ministry providing full financial support. In addition, mathematics and science teachers and educators from sub-Saharan African countries are trained at CEMASTEA through the Third Country Training Programme (TCTP) fully funded by JICA.

Through TCTP, a number of countries have been able to start and run their own SMASE-type projects. Some of the projects are fully funded by the respective ministries of education. For example, SMASE-Nigeria was started and run as a project between the Nigeria Federal Ministry of Education and JICA, covering only two districts in 2006. As in Kenya, the successful implementation of the pilot phase led

to expansion of the project to cover primary schools in the same regions in 2009. On the expiry of the project period in 2014, the project became a program of the Federal Ministry of Education, which took over the funding of all the programme's activities (Aguiyi, 2016).

Ongoing projects in different countries that continue to receive JICA's support (Matachi et al., 2016) include: enhancing the capacity of teachers to develop item pools for learning assessment in Ethiopia; conducting action research for the improvement of INSET and pre-service education and training (PRESET) curriculum in Malawi; improving academic performance by using diagnostic assessments of learners in Morocco; improving basic mathematical skills by using remedial workbooks for learners in Senegal; teacher capacity development (TCD) through lesson study and intensive study of teaching and learning materials in Zambia and TCTP for teachers and educators in sub-Saharan African countries.

2. Enhancing Teacher Capacity to Integrate ICT into Teaching and Learning

A number of countries in Africa have made considerable effort to ensure ICT takes centre stage in education at all levels. They have done so through capacity building for teachers, including equipping them with basic ICT skills for teaching or for use in management and administration in education. However, such efforts are often piecemeal and benefit isolated groups of teachers. Because they are not harmonised, the efforts end up not yielding the desired results. The framework that can address this gap is the UNESCO ICT Competency Framework for Teachers (ICT-CFT2011)., In a paper published by UNESCO, Hooker (2016) explains that the framework serves to align national and local initiatives and programmes into a continuum approach for building teacher capacity systematically through different levels of ICT competency from pre-service to in-service programmes. It allows teachers to move through the three stages of ICT competencies and ICT integration: applying (which is the basic technology literacy level) to infusing (where the teachers deepen their ICT knowledge) to transforming (where they start to apply ICT skills to create knowledge and tools for their teaching). The framework is clear on what teachers should know and be able to do with technology in STEM teaching. With the support of Global e-Schools and Communities Initiatives (GeSCI), the framework has been applied in the development of a roadmap for enhancing teacher competencies, including curriculum for teacher capacity development in ICT integration. In its first phase, the course associated with the framework was implemented in Kenya and Tanzania. The initial evaluation of the impact of the course has shown positive effects, which include enabling teachers to build "confidence with and utilization of ICT in the classroom and school management adjustments to support the use of ICT across the curriculum" (Hooker, 2016, p. 116). A key contributor to the success of the programme is the involvement of stakeholders at all levels, especially in policy support, at all levels.

3. Using ICT to Expand Opportunities in Higher Education

One of the important issues in higher education in Africa is the low enrolment of students in science and technology programmes as well as the large classes associated with courses in the humanities. In order to address the challenge of large classes, Cadi University in Morocco runs and manages UC@MOOC, a digital platform implemented to help deal with large numbers of students at university level (Khalid, 2016). The platform also serves students from other countries in and outside the region, notably, Algeria, Tunisia and Senegal. It was designed to enable university students to learn even without face-to-face interactions with the professors. . Using digitised content made available to them through ICT tools such as CD-ROMS and DVDs, the students are able to play back and listen to or watch lectures at will or at their convenience. They can also stream live lessons on smart phones and

tablets through the platform. Besides giving opportunities to students who would otherwise have had no opportunities to attend universities, the platform has several positive effects. These include: collaboration between lecturers for the development of digitised content; cost effectiveness in delivery of lectures, as students do not have to travel to campus for face-to-face classes; availability of content, which students can access online and played back or at will.

4. Using ICT to Build Teachers' Capacities Online

In most countries, whenever changes are made in curricula, teachers are taken through an orientation programme on the changes through face-to-face interactions with curriculum developers. The success of this method is dependent on both the effectiveness of the organisation of the field meetings with the teachers and the skills of the curriculum officers facilitating the sessions. A novel idea, the Elimika online teacher orientation programme for providing teachers with new information about curricula, has been developed by the Kenya Institute for Curriculum Development (KICD). The programme, which has been piloted with Kenyan primary school teachers, allows teachers to gain new knowledge and skills without having to travel or leave their job to attend face-to-face training workshops. The programme has helped to minimise teacher absenteeism. At the same time, it has succeeded in minimising face-to-face meetings with the teachers, thereby "saving resources both financially (travelling and accommodation costs, license cost) and man hours (personnel needed for the training)" (Gacicio, 2016).

5. Relating Mathematics Content to Real-life Experiences

Mathematics is often viewed as an abstract subject, with little relevance to everyday life experiences. However, it is possible to change this view, as demonstrated through a learning programme of the National Higher School of Mining, Rabat in Morocco (Najib, 2016). Through the programme, mathematics is taught and related to real life experiences and solutions to problems in real life situations that include population growth, management of resources (water, energy, minerals, etc.), demand for energy, climate change, new epidemics and health, security, disaster management, and terrorism. Computer simulations and mathematical modelling contribute to a better understanding of such human development issues and natural phenomena.

6. Addressing Teachers' Competency in the Language of Instruction

In many African countries in Africa, the problem of teacher shortage is real, and often leads to the recruitment of unqualified people to alleviate the shortage. However, such decisions end up compromising the quality of education delivery, especially if such teachers have low competencies in the language of instruction. Research conducted mainly in the African context has shown teachers with a limited competence in the language of instruction as a hindrance to the learning of science and mathematics (Brock-Utne, 2007; Evans & Cleghorn, 2010; Kembo & Ogechi, 2009).

Preliminary findings of a research conducted in three South African provinces, Eastern Cape, Limpopo and KwaZulu-Natal, point to a correlation between teachers' language competency and their performance in mathematics (Tshuma, 2016). Teachers with higher scores in the language competency test performed better in the mathematics test. Furthermore, it was found that on average, the teachers exhibited a lower proficiency in mathematics than what is expected of a 7th Grade learner. The study involved 55 unqualified teachers recruited in an Intermediate Phase (IP) or 4th – 6th Grade programme to alleviate teacher shortage. The findings of this study highlight the relationship between linguistic barriers in teaching science and mathematics with the English

language competency of both teachers and pupils. Teachers' proficiency in the language of instruction and their knowledge of content are key components in teaching and learning.

7. Connecting Students to their Environment through Science

Education for sustainable development should mould individuals who do more with less and respect the environment (UNESCO, 2016). The Aga Khan Academy of Mombasa, Kenya, has been practising an innovative environmental science education curriculum where 3rd Grade pupils learn about ecosystems, using both Kiswahili (primary language) and English (Gordon, 2016).

The learning experience involves a field trip to a game reserve where the pupils interviewed the game park rangers about animals in the park in Kiswahili and noted down their observations in both Kiswahili and English. The learning of science in a real-life situation, using language the in which the students are proficient, has led to a deeper understanding of concepts. In addition, the students developed a variety of skills that include, observation, data collection and analysis, and recording skills. The success of the programme depended on teachers' careful planning and implementation of the curriculum, especially with regard to what science vocabulary to introduce at what level, as well as how the two languages would be incorporated into the course content.

8. Integrating Indigenous Knowledge into School Science

Some scholars have argued that students from non-Western cultures, especially students in Africa, come to science classrooms with cultures and language that may make them to understand science in ways that are significantly different from those in Western cultures (Aikenhead, 2001; Akpanglo-Nartey et al., 2012). Akpanglo-Nartey et al. noted, for example, that such students view phenomena in terms of meaning rather than causes, a perception that leads to a potential conflict between the two forms of knowledge (indigenous or cultural knowledge and scientific knowledge). They argued that, science learning for such students may only become meaningful and relevant if students are given an opportunity to experience what Cobern & Aikenhead (1998) referred to as "autonomous acculturation" or "a process of intercultural borrowing or adaptation of attractive content or aspects of another culture and incorporating them or assimilating them into those of one's indigenous or everyday culture" (p. 42). This may be achieved if school science is integrated with indigenous knowledge. According to Cobern & Aikenhead (1998), this integration helps to ease tensions or conflicts that may exist between the two forms of knowledge.

Aikenhead (2001) used the idea of "rekindling traditions" (p. 341) to illustrate how indigenous knowledge can be integrated into school science. He described a project in which he collaborated with six teachers, together with the Aboriginal elders from northern Saskatchewan, Canada, in developing and using content units that integrated indigenous knowledge (IK) into school science. According to Aikenhead (2001), an important aspect of the units used in the teaching was the presence of themes significant to the Aboriginal community, including respect for the Aboriginal knowledge. He noted that the teaching was practice-oriented and included activities such as finding indigenous plants with medicinal properties. Aikenhead observed that one of the key elements in the successful integration of IK into school science is the ability of the science teacher to adopt the identity of a "cultural broker" – a person who "identifies the culture in which students' personal ideas are contextualized, and then introduces another cultural point of view" (2001, p. 340). In that role, a teacher could help students move back and forth as they learn ideas touching both on IK and scientific knowledge.

The idea of incorporating indigenous knowledge in school science also featured in responses obtained from the online consultations. The respondents acknowledged the importance of indigenous knowledge (IK) as a tool for cultural continuity, and proposed for the integration of IK into curricula to create a link between IK and modern knowledge. One respondent suggested the use of community members as resource persons in incorporating IK into curricula and emphasized the need to "draw on community members as resource persons on IK during curricula development and review".

4.2. Key Lessons and Messages

From the analytical consideration and discussion of the contributions to the sub-theme and the review of related literature, promising initiatives for promoting science, mathematics, and ICT education in Africa were identified. The key lessons and messages are summarised below:

1. Innovative approaches that relate the teaching of science and mathematics to real-life situations can enhance learners' understanding and appreciation of the importance of science and mathematics to national development. In this regard, improved teaching methods and content knowledge by science and mathematics teachers are critical.

2. The language of instruction plays an important role in enhancing students' understanding and performance in science and mathematics. The level of teachers' and students' proficiency in the language of instruction has strong influence on learning outcomes. Educational authorities should therefore give careful consideration to the stage in the learning process at which the mother tongue or second (often foreign) language is used as the language of instruction. Possibilities for bilingual instruction exist and have been successfully demonstrated in some African countries.

3. The integration of ICT into the learning process can have far reaching effects on learning outcomes. However, ICT application and technology-mediated learning will require necessary ICT infrastructure and teachers imbued with ICT skills and knowledge.

4. ICT can be drawn upon to expand learning opportunities in higher education, while contributing to greater efficiency in the use of resources.

5. Indigenous knowledge is as important as school science and should be reflected in the curriculum. Integrating indigenous knowledge into school science enables students to better understand observed scientific phenomena in relation to their cultural experiences and practices. In this regard, there is need to popularise scientific knowledge and its importance among all segments of African society.

6. For sustainability, governments receiving donor-funded programmes aimed at strengthening the teaching and learning of science and mathematics should commit to appropriating, institutionalising and expanding such programs.

7. Progress in promoting science, mathematics, and ICT education in Africa will require commitment and investments in teaching and learning infrastructure, the training and continuous development of adequate numbers of teachers, teacher motivation, and experience sharing of best practices and successful initiatives.

8. Gender disparities in learning STEM subjects will need to be addressed through targeted interventions that attract girls to STEM disciplines.

5.0. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The analytical work on the promotion of science, mathematics and ICT education in Africa has identified initiatives and practices that have successfully addressed the issues and challenges involved. This synthesis paper has documented the findings of the analytical work. The findings were drawn from several sources, including two regional consultative forums, online consultations, and literature review and paper contributions to the Triennale sub-theme. The findings show that the issues and challenges associated with effective science, mathematics and ICT education in Africa cut across all levels of education from pre-school and primary to secondary and higher education. They include: teachers and teaching (i.e., teaching methodology, staffing and teacher competencies and skills); curriculum and curriculum materials (i.e., non-contextualised curricula and learning materials, examination centred curricula, and inadequate teaching and learning resources); access and participation in mathematics and science (i.e., gender disparity in participation in STEM subjects and careers, competency in the language of instruction by both teachers and learners), and competency of both teachers and students with regard to ICT in education, as well as the output of research in STEM and the physical sciences.

However, the findings also show that some important initiatives have been undertaken and are ongoing in a number of countries in Africa and other parts of the world where the same challenges have been effectively addressed. Lessons can be drawn from those successes for replication and/or scale up. Most of these initiatives have focused on addressing the issue of teacher competencies through professional development programmes such as INSET and lesson study. The purpose of such programmes has been to enhance teachers' skills in science, mathematics and ICT education. ICT has also been shown as an important tool in enhancing the quality of education delivery and management and expanding learning opportunities in higher education through the creation of virtual learning platforms and digital content.

Although the learning of science and mathematics has been embraced by Africa and many countries are on the path of transformation for enhanced learning of these subjects, there is need for a mechanism to ensure the inclusion of all countries in the transformation. This is important because if some countries are left behind, progress towards achieving Africa's vision of the Africa we want by 2063 will be greatly compromised.

Furthermore, the findings show that there are areas where no initiatives in the learning of science and mathematics have been reported. These areas include initiatives that target learners at preschool level and those involving learners with special needs (i.e. learners with visual and hearing impairment, and learning disabilities). There is need therefore to ensure that all learners are included in initiatives that promote effective science, mathematics and ICT education.

Another gap that emerged was the absence of science literacy benchmarks and mathematics standards. In the absence of such benchmarks and standards, it would be difficult to tell the progress being made by Africa with regard to science, mathematics and ICT education. It would also be difficult to develop and implement an effective system of assessment and evaluation of science and mathematics curricula on the continent.

5.2. Recommendations

In light of the findings of the analytical work, the following recommendations are proposed:

- **Concerted effort by all countries in Africa**

  Not all countries are actively involved in implementing initiatives addressing the challenges and issues in science, mathematics and ICT education. Implicit in the vision of a united Africa, which is an integrated, prosperous and peaceful continent, an Africa driven and managed by its own citizens and representing a dynamic force in the international arena, is the need that all countries should be seen to be making progress towards the achievement of the vision. Mechanisms need to be devised at the continental level to enable all countries to benefit from initiatives for improving science, mathematics and ICT education. Leaving some countries behind will hamper the achievement of this vision of Africa. In this regard, the African Union Commission should support the development of science literacy benchmarks and mathematics standards to enable effective monitoring of progress being made.

- **Investment in teaching and learning infrastructure**

  Governments should allocate adequate resources to the improvement and upgrade of the facilities required for effective teaching and learning of science and mathematics.

- **Teacher development and motivation**

  Initial and in-service teacher development is a critical success factor, and should be prioritised by African governments. Teacher motivation is also shown to enhance learning outcomes and learner performance.

- **Language of instruction**

  The language of instruction is a key component in the learning process. The understanding of the subject matter is enhanced if learning takes place in a language understood by learners. The teacher's proficiency in the language of instruction is therefore as important as content knowledge

- **Policy support**

  Implementing initiatives and programmes within a policy framework ensures the involvement and support of all stakeholders. Most of the successful initiatives undertaken to address challenges in science, mathematics and ICT education, especially those supported by development partners succeed, partly as a result of being situated within an agreed policy framework.

- **Creation of a knowledge sharing platform**

  From the findings of the analytical work, evidence has emerged of a number of successful initiatives and interventions aimed at addressing issues and challenges in science, mathematics and ICT education in Africa and elsewhere. For others to learn from these successful initiatives and innovative interventions there is need to create a "space" (probably virtual) for sharing such good practices at the continental level under the auspices of ADEA and the African Union Commission.

REFERENCES

AAAS. (1993). *Science Literacy Benchmarks. American Association for the Advancement of Science*. Retrieved from http://www.project2061.org/publications/bsl/online/index.php?intro=true.

ADEA. (2014). *The integration of ICT into education and training systems in Africa: The Cases of Argentina, Burkina Faso, Côte d'Ivoire, Paraguay, Senegal, Tunisia and Uruguay*. Association for the Development of Education in Africa.

Aguiyi, C. (2016). *Institutionalized regular INSET stronghold for improving teaching and learning mathematics and science: The Nigerian experience*. A paper contributed to the ADEA 2017 Triennale: Dakar, Senegal.

Aikenhead, G. (2001). *Integrating western and Aboriginal sciences: Cross-cultural science teaching*. Research in Science Education, 31, 337-355.

Akpanglo-Nartey, R. K., Asabere-Ameyaw, A., Sefa Dei, G. J., & Taale, K. D. (2012). *Children's indigenous ideas and the learning of conventional science*. In A. Asabere-Ameyaw, G. J. Sefa Dei, & K. Raheem (Eds.), *Contemporary issues in African sciences and science education* (pp. 63 -72). Netherlands: Sense Publishers.

Akyeampong, K. (2016). *Relevant mathematics and science education in the transformative shift of Africa*. A Keynote Address during the Regional Conference of Mathematics and Science Education in Africa on 15-17th, March 2016. Nairobi, Kenya.

Asimeng-Boahene, L. (2006). *Gender inequity in science and mathematics education in Africa: The causes, consequences, and solutions*. Education, 126 (4), 711-728.

AUC. (2014). *Agenda 2063: The Africa we want*. Addis Ababa: The African Union Commission.

Ballenger, C. (1997). *Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom*. Language and Education, 11(1), 1-14.

Brock-Utne, B. (2007). *Learning through a familiar language versus learning through a foreign language: A look into some secondary school classrooms in Tanzania*. International Journal of Educational Development, 27, 487-498.

Cobern, W. W., & Aikenhead, G. S. (1998). Cultural aspects of learning science. In B. J. Fraser, & K. G. Tobin (Eds.), International handbook of science education (pp. 39-52). Dordrecht, Netherlands: Kluwer Academic Publishers.

Darling-Hammond, L. (2010). *The flat world and education: How America's commitment to equity will determine our future*. New York: Teachers College Press.

Evans, R., & Cleghorn, A. (2010). *'Look at the balloon blow up': Student teacher-talk in linguistically diverse foundation phase classrooms*. South African Linguistically and Applied Language Studies, 28 (2), 141-151.

Gachukia, E., & Kabira, W. N. (1991). *The identification of elements in African culture hampering the integration of women in development process.* UNESCO : Paris, France.

Gacicio, E. (2016). *Addressing inadequate human capacity/skills in primary schools: A case of Elimika online primary teacher orientation course.* A paper contributed to the ADEA 2017 Triennale: Dakar, Senegal.

Gordon, I. (2016). *Using Bilingual inquiry-based pedagogy to support scientific learning in multilingual African contexts.* A paper contributed to the ADEA 2017 Triennale: Dakar, Senegal.

GCE. (2012). *Every child needs a teacher: closing the trained teacher gap.* Johannesburg: South Africa: Global Campaign for Education.

Hooker, M. (2016). *Cultivating synergies in enhancing ICT competencies: A partnership approach.* In UNESCO, Diverse approaches to developing and implementing competency-based ICT training for teachers: A case study (pp. 88-118). UNESCO: Paris, France.

IEA. (2009). *Do countries paying teachers higher relative salaries have higher student mathematics achievement? Cross-country analysis of teacher salaries and student achievement.* International Association for the Evaluation of Educational Achievement. Amsterdam: Netherlands.

Kembo, S., & Ogechi, N. O. (2009). *Linguistic human rights and language policy in the Kenyan education system.* Addis Ababa, Ethiopia: Organization for Social Science Research in Eastern and Southern Africa.

Khalid, B. (2016). *UC@MOOC, une innovation pédagogique pour faire face aux effets de la massification et à l'échec universitaire.* A paper contributed to the ADEA 2017 Triennale: Dakar, Senegal.

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Norwood, NJ: Ablex.

Liang, X., Kidwai, H., & Zhang, M. (2016). *How Shanghai does it: Insights and lessons from the highest-ranking education system in the world.* Washington, DC: World Bank.

Matachi, A., Tefera, B., Toyomane, N., Nkhata, J., Takahashi, T. Ghouli, A. Chaibi, A., Okukawa, H., Diop, A. B., Kunieda, N. Tembo, B., Nakai, K., & Kosaka, M. (2016). *JICA's support to education in Africa: Focusing on mathematics and science education.* A paper contributed to the ADEA 2017 Triennale: Dakar, Senegal.

Najib, K. (2016). *L'enseignement des mathématiques dans les universités marocaines, enjeux et perspectives.* A paper contributed to the ADEA 2017 Triennale: Dakar, Senegal.

Nix, B. C., DeBella, J., Gierhart, G., Gill, S., Harader, D., Richerson, G., & Tomlinson, D. (2004). *Integrating technology with teaching and learning at Murray State University.* Contemporary Issues in Technology and Teacher Education, 4 (1), 55-63.

Shaw, M., & Kirkham, M. (2005). *Visual impairment and new technologies*. Journal of Epidemiology and Community Health, 59 (12), 1101-1101. Retrieved from http://www.jstor.org/stable/25570932.

Smith, D. W., & Kelly, S. M. (2014). *Assistive technology for students with visual impairments: A research agenda*. International Review of Research in Developmental Disabilities, Volume 46. Retrieved from http://dx.doi.org/10.1016/B978-0-12-420039-5.00003-4.

Supovitz, J. A., & Turner, H. M. (2000). *The effects of professional development on science teaching practices and classroom culture*. Journal of Research In Science Teaching, 37(9), 963-980.

Thioune, R. (2003). *Information and communication technologies for development in Africa. Opportunities and challenges for community development*. Volume I. Ottawa: IDRC. Retrieved from http://idrc.ca.

Tshuma, L. (2016). *Relationship between language competency and intermediate phase mathematics instruction: A case of the Eastern Cape Province*. A paper contributed to the ADEA 2017 Triennale: Dakar, Senegal.

UNESCO. (2014). *Teaching and learning: Achieving quality for all*. UNESCO : Paris, France.

UNESCO. (2015). *Information and communication technology (ICT) in education in sub-Saharan Africa: A comparative analysis of basic e-readiness in schools*. UNESCO : Paris, France.

UNESCO. (2016). *Education for people and planet: Creating sustainable futures for all*. UNESCO : Paris, France.

UNSECO. (2016). *The world needs almost 69 million new teachers to reach the 2030 education goals*. UNESCO : Paris, France.

Zhou, L., Ajuwon, P. M., Smith, D. W., Griffin-Shirley, N., Parker, A. T., & Okungu, P. (2012). *Assistive technology competencies for teachers of students with visual impairments: A national Survey*. Journal of Visual Impairment & Blindness, 106, 656-665.