AFRICAN CONDITION: TRANSFORMING STEM EDUCATION[1]

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Abstract

The paper explores the evolution of science in Africa against the perceived policy emphasis of the role of Science, Technology, Engineering and Mathematics (STEM) in development. The deployment of STEM in the school curricula and the question of relevance are debated with guiding questions such as *who* and *what* shapes STEM discourse in curricula? What frame of STEM (could) best promote development in Africa? The paper examines a range of factors, issues and arguments in STEM education in Africa, and proposes possible future trajectories of STEM in the education system.

Keywords: Africa and development, science, technology, engineering and mathematics (stem); education, curriculum, teaching and learning.

1.0 Introduction

1.1 *Science in Africa*

Africa is the only major region of the world that has thus far failed to achieve a significant measure of sustainable human development. The results of this failure have been civil wars, political instability, authoritarian regimes, widespread violation of human rights, unacceptable level of poverty, widening gap between Africa and the developed world and increasing marginalization of the continent in an increasingly interdependent world.

Although there is no consensus on an 'optimal' strategy for the successful management of Africa's development crisis, it is widely agreed that investments in people and in science and technology are prerequisites for achieving significant economic growth and social transformation.

Available data show that Africa's stock of human capital is particularly poor, and the science and technology base in Africa is conspicuously weak. These two crucial dimensions of development have been pushed aside by the imperatives of 'crisis management' that has characterized the continent's political and economic policies.

In Botswana for example, the need for investing in STEM is predicated on the urgent necessity of equipping the nation's labour force with the skills and competencies associated with numeracy as well as with the advanced STEM research knowledge and skills required by a global knowledge-driven economy (Government of Botswana Education and Training Sector Strategic Plan (ETSSP), 2015). Such emerging national policy and strategic thrusts demonstrate that Africa can ill-afford to ignore the importance of STEM for today's and future society that is perhaps best captured in the insightful observation by a renowned mathematician, Whitehead (1947), made more than 60 years ago, that for civilization to advance in two thousand years, the overwhelming novelty in human thought will be the dominance of STEM thinking. It is no coincidence that STEM are advocated as prerequisite for modernization and economic development worldwide. Countries recognise importance of STEM and demonstrate their trust in STEM policy provisions that prioritise these subjects and or integrate them across

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national curricula. But has STEM delivered on the claims of modernisation? What has been their impact?

1.2 *The evolution of Science in Africa*

Developments in science and technology have had profound effects on humankind, even in the Africa region. These effects are not limited to the quality of lives, but extend to the ways people think about themselves and others, and in their expectations concerning the future ways of life. STEM increasing play a political role in African society that may often miss recognition. Similarly, it is easy to take for granted the STEM dominated increase in the quality of lives in African communities.

To illustrate this, we can consider life in Africa four centuries ago, around the 1600s. In Europe, this epoch occasioned great explorations, cultural awakening championed by persons like Copernicus, that gave birth to modern science (Jegede and Okebukola, 1991). In Africa, the *mfecane*[2], migrations, tribal wars, and a range of other challenges were widespread. Life was a hazardous enterprise played out as an exercise in survival often in the locality of one's birth; with disease, pestilence and famine as constant threats to survival. Owing to low populations at the time, infant mortality rates and life expectancy left a lot to imagination. Epidemics, such as the bubonic plague, were common. Information was passed through generations by means of oral tradition, and until the mid-1900s, nature dominated African society as it had for all previous ages. There was little to delight in about nature, and little sense about what Francis Bacon foresaw in Europe as the *power over nature* that would come with the use of modern science and technology. People in Africa lived according to cultural norms.

Colonisation wars of the 19th century, and the subsequent formation of states, gave little attention to STEM. In the 1950s-1960s, few schools taught biology, chemistry and physics. In the early 1960s, awakening to STEM was triggered by African states' thrust for independence. At primary school level, science existed as nature study, hygiene, health and rural science. The focus was on rural life for African children. In the few urban schools serving the predominantly white and some elite (including Asian families), objectives for teaching science were not stated as the focus was on overseas exams, such as the Cambridge Examination Certificates in secondary level.

The African Primary Science Programme (APSP) for the mainly British aligned states such as Kenya, Ghana, South Africa, Zimbabwe, Zambia, Malawi, Uganda, and Nigeria started with missionary influence and participation of scientists from the US and Britain in 1960. The African Primary Science Programme (APSP), the African Science Programme (ASP), the Nuffield Secondary School Science, the Namutamba Project in Uganda by UNESCO in 1967 (UNESCO, 1978/79) and the Entebbe Mathematics programmes of the latter part of 1960s and early 70s facilitated science teaching and learning from traditional-theoretical discourse to an inquiry-based teaching and learning of science. The intention was to inspire creativity in the learners and innovativeness among the teachers. According to Jegede (1995), the impact of these science programmes was limited by inadequacy of facilities, the resourcing of education in general, including the competencies of the science and mathematics teachers themselves, particularly for schools serving African children.

In the last two decades, Africa has seen a re-emergence of great interest and support for science, technology, engineering and mathematics education, including initiatives such as the African Forum for Children's Literacy in Science and Technology (AFCLIST), funded by the Rockefeller Foundation and the Norwegian Agency for International Development (NORAD), the Zanzibar camps, the Minds across Programme (Uganda), the Science Curriculum

2. A Zulu word for (times of) tribulations, social unrest, particularly triggered by the murderous rule of Shaka Zulu and his expansionist rule in South Africa.

Initiative in South Africa (SCIA) and a range of other STEM projects across African countries. A characteristic of these projects is their central focus on the challenges of transforming science teaching for the better. This hinges on a number of basic principles for changing STEM: a need for systemic change which focuses on human development, orienting STEM to local realities such that curricula, teaching materials, and assessment process that need to be contextual and ensure sustainability. The notion of *context* in STEM is geared towards evolving a critical mass of STEM human capital. This demands that STEM be inquiry-based and focus on scientific skill development. Science and technology teacher education should also address and alter the classroom power relations that make learning collaborative, inclusive and less authoritarian. This is expected to accommodate heretofore excluded groups, especially the girl-child and other socio-economically marginal groups.

2.0 Role of STEM in development

Development is an ideological concept. However, the different interpretations share the perception that significant economic growth is a prerequisite for development. And whereas there is no consensus among economists as to the mix of elements that would cause growth, it is widely accepted that such a mix would necessarily include investments in people and in science technology, engineering and mathematics.

Many economists argue that human capital in the form of educational attainment plays an important role in economic growth (Cf. Schultz, 1961; Denison, 1962; Lucas, 1988; Mulligan & Sala-I-Martin, 1992). Empirical studies of Peaslee (1965, 1969) and Benavot (1985) demonstrate that primary education had a significant positive effect on economic growth of both industrialized and developing countries. A World Bank study of East Asian 'miracle' countries shows that "the single most important factor in launching the miracle countries on a path of rapid, sustained economic growth was universal or near-universal primary school enrolment" (World Bank, 1995, p.34). In the case of South Korea, Soh (1992, p. 163) found that in support of economic development, "Korean education supplied various types of manpower needed for national economic growth, with education given credit for as much as 22.61% of the increase in the country's gross national product over the 1984 – 1986 period." Over the last decade, Goldsbrough (1996, p.86) studied the impact of adjustment policies on growth in eight developing economies and concluded that "the two most important variables contributing to growth are investment in physical capital and the achievement of basic educational benchmarks, as measured by primary school enrolment ratios."

In an influential empirical study, Barro and Lee (1993) present a data set on educational attainment for 129 countries over five – year periods from 1960 to 1985. In this study, human capital is the number of years of completed schooling for persons aged 25 and over. Barro and Lee show that for developing countries as a whole the average of school attainment doubled over the period (from 1.8 years in 1960 to 3.7 years in 1985), while that in Sub-Sahara Africa (SSA) grew by 80% (from 1.5 years to 2.7 years). The results further show that while SSA has made significant achievements at all three levels of education, about half of the adult population in 1985 received no formal education (Barro & Lee, 1993).

How has Africa's stock of human capital evolved since 1985? Adult illiteracy rates may be used to proxy for the no-schooling category. The illiteracy rate for the population aged 15 and over in Africa is 45.6% in 1995, with Uganda's corresponding share being 64%, which is more than double the corresponding rate for Latin America and the Caribbean (UNESCO 1999).

School enrolment ratios provide information about flows of education, and the accumulation of these flows is a principal component in the creation of stocks of human capital in the future. Although countries like Botswana, Ghana, Tanzania, Uganda, Zimbabwe and

Zambia have made some progress in all levels of education in a post-independence era – sustaining the attained levels of access to primary, secondary and tertiary education pose a serious challenge in national budgets that are stretched by increasing demands in other sectors of national development such as energy (OECD, 2015, p.49).

Of 13 African countries for which data comparable to that of Barro and Lee are available, only 4 have improved the composition of their respective stock of human capital relative to that of SSA in 1985. These countries are: Botswana, Mauritius, South Africa, and Ghana. It is interesting to note that the first 3 of these 4 countries have higher than average GNP per capita in Africa. However, since economic activity is influenced by, among other things, "the knowledge, skills, competencies and other attributes embodied in individuals" (OECD 1998:9), it is important to consider qualitative aspects of human capital.

Research results show that school quality is an important determinant of pupil achievement in developing countries. In particular, instructional facilities and materials, teachers and textbooks appear to be critical variables. See, for example, Husen et al. (1978), Heyneman et al. (1981), Heyneman & Loxley (1983), Fuller (1987) and Cope et al. (1989).

3.0 Issues in STEM education

The state of STEM education and STEM research in Africa is particularly grave. Teachers of STEM are both under-qualified and poorly motivated; STEM curriculum reform is often inspired by uncritically imported western models; examinations determine the 'worth of STEM knowledge'; memorization and rote learning are the dominant forms of teaching; and the subject's unity and links to science and technology and relevance to student's everyday experience are hardly emphasized. There is less inquiry science learning, more rote learning. Children are less, than more, able to extract meaning from their schooling for relevant application.

There appears to be an assumption that quality teaching is provided and assured by curriculum (read *content*) changes. This has tended to create a temporary and false comfort in education delivery, assessment and management. In the desire to provide quality science education, educators and all the other stakeholders should grapple with questions regarding where quality rests. Is quality in the national education policies? Is it in curriculum documents? Is it in and what are the assessment processes? What *truly* benchmarks quality and relevance in STEM? With present resurgence of long-standing concern about education of scientists and engineers, compulsory sciences in schools and about public understanding of science and technology, the public is pointing to the "failure" of STEM curriculum development. There is advocacy for preparation of 'up-to-date' text materials, hoping that this time the materials will be 'relevant,' 'better' and 'more effective.' Is this the case? Very unlikely, for many reasons, e.g.: curricular materials, however lucid, skilful, and imaginative, cannot 'teach themselves.' The most significant cause of failure in adoption and implementation of contextualised STEM curricula materials in African educational settings lie in what happens in science teacher education and their professional development. A teacher can always negate the intent of the STEM materials by attitude, unpleasant comment, and, most significantly, by what he or she chooses to test for, and how. Another formidable obstacle that must be overcome at all levels in the schools is that of logistical support for teaching, student learning and assessment.

There are a number of consequences of these and other state-based and institutionally intrinsic limitations in STEM. For example, in one report of student characteristics in STEM learning, only 12% of the cross section of university students execute *thinking*, *reasoning* and *understanding*, indicating that they have developed some capacity for abstract logical reasoning at least to rudimentary level; up to 54% or more of the students are unsuccessful in their learning tasks and still use predominantly concrete patterns of reasoning ; the remaining

33% are in transition, exhibiting only partial success; most university students are very much in need of practice in the various modes of *thinking* and *reasoning* in STEM (Oluka, 2006). Sometimes the volume and pace of material thrust on students in the majority of STEM courses preclude the exercise of the time-consuming operations of thinking, reasoning and understanding. The majority of students are thus forced into blind memorization, and they eventually come to see all 'knowledge' and 'understanding' as the juxtaposition of memorized formulae, names and phrases. They are tested almost exclusively on the memorized end-results. It is further noted that "students' evaluations, based on administration of two or more of the now classic Piagentian tasks, are showing, with remarkable reproducibility, important data for debates on STEM curriculum reform" (Oluka, 2006, p. 6).

On a wider Africa frame, about 40% of Africa's universities do not have a department of STEM; the Bachelor's degree programs in STEM is unpopular among students and are least subscribed to; undergraduate STEM curricula of many departments emphasize traditional areas of the subject; and the demand for graduate education in STEM in most African countries remains limited. This is an education that would not suit an industrial age, let alone an information age society. As such the current status of STEM in education badly fails Africa's youth upon whom the continent's future depends. We need genuine understanding of basic concepts that can perfectly well be developed in elementary and secondary school, and enhancement of capacities for abstract logical reasoning at secondary and university levels as important ingredients to accompany STEM curriculum reform. In this framework, students would enter post-primary with levels of knowledge and understanding that would make discussion of philosophical, historical, ethical and societal questions fruitful and meaningful. They would be able to penetrate aspects of modern STEM that are now hopelessly unintelligible. With such improved background in STEM, our mass production system of lecturing to large classes might be substantially more effective, if still not ideal. Such progress is impeded at the present time, not by lack of adequate curricular materials at elementary, secondary or tertiary levels, but by inadequate teacher education in the sciences.

The standard approach adopted by most African countries for developing STEM human capital is to send students for postgraduate studies in STEM in western countries. This approach is expensive, risky, and ignores the fact that STEM research and STEM education are organically linked: a weakness in either will undermine the other as well as the STEM base itself. Studying STEM in an industrialized context raises questions of relevance to the localization of the knowledge and skills gained to one's context back home in Africa. In order for Africa to be able to come to grips with its serious difficulties and to meet the challenges of the future, it must urgently develop strategies that would significantly enhance the quality of her human capital and strengthen her STEM base. Given the nature of the unfolding future (sustainability, equity, respect of human life and harmony in diversity), it should be evident that any nation that does not strive for excellence in education, in general, and for STEM, in particular, would do so to her own peril.

4.0 Rethinking STEM: Who shapes the discourse on science and technology education?

As Volnick (1998) critically observes, dominant trends in various aspects of science and technology education in African nations are shaped and determined by particular interest groups with conscious or unconscious agendas. As social constructs, discourses are roles that govern how to create meaning and ascribe value. Two key players in the science, technology engineering and mathematics discourse environment are teachers and learners.

Ideologically, a scientific and technological world-view is guided by need to classify, label, asses and measure all that is animate and inanimate. In this regard, STEM are driven by a desire to control and dominate. It is for this reason that critics of science and technology like Feyerabend (1981) and Longino (1993) see STEM as divorcing fact from value in favour of fact, leading to devaluation and marginalization of people and to the creation of otherness. According to National Research Council (2014) and Adas (1989), science and technology are uncritical adoptions of dominantly western views, technologies and methods.

The analytical criticism of STEM in relation to what is included and excluded, what STEM discourse render marginal, render inferior and make invisible, calls for critical reflection. It is this process of reflection that will generate opportunities for the two key players in STEM, the teachers and the learners, to recognize the delicate connections between all humanity, STEM and our environment, and to identify the various forces and relations that prevent us from optimally benefiting from the complex web of interconnectivity and interdependence of life.

In the context of education practice, policy and priorities, what is of concern in African context relates to who is involved in STEM education, who directs its goals and activities and whose interests the STEM education discourse perpetuates.

As Ernest (1991) has documented, there are multiple interest groups in society with contending ideologies to a STEM curriculum. In an emerging paradigm shift from STEM for career to STEM for all, the current arguments in STEM education calls for openness to possibilities of discourse that embraces the complexity of issues that humanity faces in the contemporary world. Making science relevant implies that experiential, outcome-driven learning is of prime importance and that learning is contextualised within the local realities of the learners.

Ogunniyi (1985) decried the continued regression of science education in Africa. When we extrapolate his concerns of almost three decades ago to the current situation, we note that the general poor performance is STEM has further disturbing characteristics of boys, girls, race and socio-economic variations, as well as concerns about relevance, academic rather than applicable knowledge and skills focus.

The significance of STEM education stretches beyond the honoured objective of white-collar career paths. The brazen inequity, coupled with irrelevance, stifled economic and social potential for all strata of our society call for holistic approaches that take into consideration the individual, society, family, learning institution, and the workplace. A common feature in STEM in African nations includes large, overcrowded and poorly resourced classes. This further compounds the challenges faced in realizing effective science discourse.

In constructing a relevant STEM in Africa, there is need for reflective analysis on conflicting views on questions such as: What counts as science? Whose knowledge are we advancing Science and/or indigenous knowledge? What spaces do curricula accommodate and promote? Why? Through critical examination of questions such as these and more, STEM teachers have opportunities to identify new, innovative and holistically conceived avenues for their personal and professional growth and the quality of STEM learning of their students. The endemic plight Africa finds itself economically, socially, educationally demands that teachers revitalize their teaching, increase laboratory based participatory learning and research experience in their classrooms by grounding their students' learning in the discourse of science, beginning with what is around them. At higher levels of education and curriculum planning, there are demands to explore how strategic connections among education researchers, policy makers, professional development scholars, and ministries of education might catalyse new avenues of teacher preparation and professional development, integrated curriculum development and comprehensive assessment of knowledge, skills and attitudes about science, technology, engineering and mathematics.

5.0 Conclusion: How does Africa change?

The science, technology and society movement of the past few decades has generated interest and flexibility in STEM curricula to accommodate varying views and interests both socially and educationally. The matter of overwhelming endemic dominance of positivist motions of science, guided by a strict adherence to positivism regarding the methods of science call for adjustment to accommodate emerging philosophies about knowledge and learning. As Loving (1995), Jegede, (1995) have argued, science and technology are now increasingly seen as evolving ways of coping with the world within specific contexts and cultures. Sensitivity to these contexts and cultures demand responsiveness of STEM discourse to alternative world views: a disentanglement from defensive, mainstream western science. Similarly, as Jegede and Aikenhead (1999); Jegede and Okebukola (1991) and Lee (2007) put it, consideration of science as per interpretations within indigenous action has potential to align STEM with the tenets of educating for sustainable development. Five principles are implied here.

First, STEM should be biographically contextual, embracing change and transformation of the status quo, because the existing education systems in Africa support the reproduction of dominant social practices and ideologies which need to be questioned and challenged if the transmission of unsustainable systems and ways of life has to be checked. Second, STEM should engender critical thinking so that questions about which STEM, STEM for what purposes and interests, alongside the examination and questioning of roots of unsustainability in the society are critically addressed. Third, STEM should embody holistic approaches to accommodate the broad, complex interconnections between science, technology, society and development. This interconnectivity requires an all-round understanding and dialogue to make STEM future-oriented, with a long-term perspective because STEM should equally be concerned about long term survival. Fourth, STEM should embrace international understanding and global citizenship by integrally addressing globalisation issues that affect all humanity. Such an outlook should expose learners to global issues and problems of STEM and development beyond the confines of national agendas of economy, society and ecology to include problems of hunger, poverty, water, HIV/AIDS, pollution, nuclear power problems, etc., and how these affect us all. The fifth is an important aspect of "ecosystems" approach in design and implementation of STEM programmes. Ecosystems have external drivers, which in the case of the STEM learning system would include funding providers, policies and community attributes (contexts that would be resource sites or bases for indigenising STEM curricula). Ecosystems also have internal drivers; for STEM these would embrace such elements as strategies, assessments and features of an education system that make it more robust (institutional vision, facilities for learning, quality assurance measures and inherent learning and teaching frameworks). An analysis and subsequent commitments that focus on these external and internal drivers could help shape approaches and outcomes.

In Africa, for STEM to be seen as ways to shower-up social and economic development, and in ways that also assure sustainability, their programmes of study across levels of education would need to pursue at least the following three main goals: (a) Define the barriers to achieving more strategic, integrated approaches to STEM learning across the informal, afterschool and formal learning platforms; (b) Identify challenges and opportunities associated with developing a STEM learning "ecosystem." And (c) Identify key attributes and characteristics for possible prototypes of strategic collaborations to move forward.

Furthermore, an ecologically conscious society could be generated through STEM curricula that integrate learning with the world outside the learning space of a classroom to acknowledge the existence of two world views: the pure scientific/technological and the ecological perspectives. These considerations have major implications on curriculum review, packaging and implementation. Science teachers as facilitators in STEM discourse need well conceptualized and articulated teacher education programmes that assure coherence between goals and needs of holistic STEM.

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