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Interrogating the Implementation of STEM Education in Zimbabwe

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Abstract:
This paper seeks to unpack the Government initiative dubbed STEM in terms of the implications for its implementation in the schools highlighting, particularly, the issues which need to be clarified or addressed if meaningful implementation is to take place. The issues relate to the policy statements from Government, the meaning of STEM and the pedagogical related issues of STEM Education. Implied in the discussion of these issues are possible suggestions on the way forward. The paper argues that although the success of STEM Education depends on many factors, the major determining factor lies in the ability and willingness of the teachers to teach for the acquisition and use, by the students, of STEM literacy knowledge and skills. These are the 21st century skills which include critical thinking, identification and solving of real life problems, creativity and innovativeness. Teachers will need professional and material support to do this. Examination boards would need to test knowledge and skills acquisition and application in solving real life socio-economic problems.

Keywords: *STEM, STEM Education, Stem literacy, 21st century skills, curriculum issues, policy, programme*

1. Introduction

1.1. Background of the Study

In 2007, His Excellency, the President of the Republic of Zimbabwe made the following statement: *There is need to equip learners with knowledge and values that guarantee economic growth and increased opportunities for employment creation; well-rounded citizens who are relevant nationally and competitive globally.* This statement would trigger the Science, Technology, Engineering and Mathematics (STEM) revolution in Zimbabwe. Lessons from other countries, such as the 'Asian tigers', where the implementation of STEM Education has paid significant dividends in solving socio-economic problems of those countries also influenced the STEM initiative in Zimbabwe. In 2016, the Ministry of Higher and Tertiary Education, Science and Technology Development launched the Advanced level STEM initiative. The initiative seeks to encourage Ordinary level school leavers to take up a combination of STEM subjects at Advanced level. These STEM subjects are: Mathematics, Biology, Physics, and Chemistry. Students who take up such combinations receive funding from the Ministry in terms of tuition, boarding, examination fees and levies (*2016 A-level STEM initiative Report 2*by the Ministry of Higher and Tertiary Education, Science and Technology Development).

In the same year, 2016, the Ministry of Primary and Secondary Education launched a new curriculum for both the primary and secondary school levels. One of the major objectives of that curriculum is to develop, in students, the 21st century skills which include: Problem solving, creativity, innovativeness, and critical thinking (Ministry of Primary and Secondary Education: Zimbabwe Education Blueprint: 2015-2022).

These are the skills referred to in one major objective of the STEM initiative which states that the initiative should train and develop cutting-edge skills to meet Zimbabwe's quest for industrialisation and make the country globally competitive. To create a critical mass of scientific mind-sets that are empowered to create new technologies, new industries, new jobs, new markets and practical solutions to current and upcoming problems. "STEM subjects are the headlights for the country's future. Countries that have overcome extreme poverty, massive disease burdens, unemployment, political turmoil and social disorientation have embraced STEM." (*2016 A-level STEM initiative Report 2*by the Ministry of Higher and Tertiary Education, Science and Technology Development, nd, p. 7).

The organisers of this conference highlight the importance of STEM Education in the editorial when they state:

The level of development of any nation is measured by the extent to which Science, Technology and Innovation are developed and exploited for the benefit of society as a whole. Zimbabwe's mineral and natural resources endowment is not questionable. However, exploitation through value addition of these resources requires skills which can only be derived from effective application of STEM Education-------------. ---- the capacity of any nation to compete in the global market depends on its ability to innovate and apply the relevant technologies to industries and the productive sectors. -------------. Consequently, improving teaching and learning in STEM education is an economic factor in developing countries, emerging economies, and even in long established economies.

One of the greatest challenges faced by this noble initiative is succinctly described by the STEM centre at Bindura University of Science Education, a university mandated to train STEM teachers for the country, when they correctly observe that 'not everyone, including key stakeholders, understand what STEM is and let alone how STEM education should be implemented" The centre goes on to say that "The definition of STEM in terms of what is included and excluded varies from organisation to organisation." The centre admits that there are many ways of defining STEM. Later, in this paper, we shall show some of these different interpretations and meanings of STEM by policy makers and their possible implications on STEM implementation.

If media reports are anything to go by, the two Ministries do not seem to be in much agreement on the STEM initiative. In *The Herald* of February 9, 2016, the permanent secretary in the Ministry of Primary and Secondary Education was quoted as having said: *"We have nothing to do with STEM'*. Recently, on June 21, 2017 *The Herald* had an article titled *"Ministries clash over STEM"*. This was in reference to the war of words between the Deputy Ministers in the two Ministries of Education over the meaning and implications of STEM.

These different perspectives from the two Ministries of Education are worrisome and do not help the practitioners. To implement this programme effectively, the practitioners need to understand it well. To understand it well, practitioners must get one clear message about what STEM Education is from the policy makers. Where differences in meaning or perspectives of STEM Education exist, the implementation of the programme could be compromised if not jeopardised. Because of these different perspectives of STEM, it becomes necessary to interrogate the initiative so that we can come up with implications of the various view points and more importantly, hopefully, come up with a common understanding of the initiative. That is the purpose of this paper.

2. Development

2.1. Issues on the Implementation of STEM Education in Zimbabwe

The paper identifies three issues for discussion:

2.1.1. STEM as a Policy or a Slogan as Compared to STEM as an Innovation in Education

A policy statement or policy document gives direction and guidance to a programme such as STEM. Somebody must translate that policy into a programme. A policy is like a house plan, on paper. A builder must translate the house plan into a house, a building. Clearly, a house plan is not a house. A policy must be clear enough to ensure that it is not open to several different and contradictory interpretations. Policy makers, policy interpreters and policy implementers must sing from the same hymn sheet otherwise there is going to be discord. In Zimbabwe, as we will see later, the policy makers do not seem to be in agreement resulting in several contradictory policy statements. Such a situation makes the implementation of the programme extremely difficult.

It is our view that in Zimbabwe, for now at least, STEM is more of a policy than a clear guidance on the implications for instructional programmes and practice. Bybee (2013) contends that the power of STEM diminishes rapidly as one moves away from national policies towards the implementation of STEM in the schools. This means that while we are very good at policy formulation, the same cannot be said about programme implementation. (Bybee was referring to American schools which had been exposed to STEM more than a decade earlier on.) This is because policies (even clear policies) do not spell out exactly what needs to be done in the classrooms. Telling teachers to develop the 21st century skills in their students without telling or showing them how to do it will not be very helpful. This means that translating policy into practice is not automatic. It requires training. This is where universities and teacher's colleges come inas they implement STEM Education in their courses. They have to show students how to teach the STEM way.

A slogan is a phrase which serves the role of advertising, promoting, branding, marketing a product or programme. It saves as a rallying point that generates a sense of unity and common purpose. For example, in Zimbabwe, our STEM slogan could be:' Stemitize and industrialise and modernise'. 'Ngazviende mberi'. Unfortunately, as we saw in the case of a policy, a slogan does not spell out what needs to be done in the classroom.

The point we are making here is: There is need for one clear national driven policy on STEM Education and to move from policies, slogans, political statements on STEM to STEM as an educational reform. Policy makers, teacher educators and teachers must work together if the implementation of STEM Education is to succeed.

2.1.2. The Meaning of STEM as Given by the Policy Makers and as Understood by the Implementers

The meaning of STEM is very important because how it is going to be implemented will depend on how it is understood.

According to the Ministry of Higher and Tertiary Education, Science and Technology Development, STEM is an initiative for Advanced level students and that the STEM subjects are Physics, Chemistry, Biology and Mathematics (*2016 A-level STEM initiative Report 2*by the Ministry of Higher and Tertiary Education, Science and Technology Development) and yet STEM stands for Science, Technology, Engineering and Mathematics.

In *The Sunday Mail* of April 17, 2016, the Deputy Minister of Higher and Tertiary Education, Science and Technology Development answered that question when he wrote: *"For starters, at Advanced level, STEM means we are focusing on two of the STEM components namely the S (with its Physics, Chemistry and Biology) and the M which are the raw materials for the T and the E for later years at university and for future jobs in the world of T and E.*

The Minister of Higher and Tertiary Education, Science and Technology Development is quoted in *The Chronicle* of June 22, 2017 as having said: *'What's THEMATIC in STEM is not these subjects (Meaning: Physics, Chemistry, Biology and Mathematics). It's the T and E, the Technology and Engineering. That's what STEM is, technology and engineering, not simply Physics, Chemistry and Biology on one hand or mathematics.'*

The STEM centre at Bindura University of Science Education, a university mandated to train STEM teachers for the country, identifies the following as STEM subjects: Biology, Chemistry, Computer Science, Food Science, Mathematics, Physics; Wood technology, Metal work, Technical drawing, and Building technology.

This is one Ministry but listen to what they are saying! So, what is STEM? It is like a choir where each member is singing a different song from the rest of the choir members.

The *2016 A-level STEM initiative Report 2*by the Ministry of Higher and Tertiary Education, Science and Technology Development (nd) talks about STEM. The STEM centre at Bindura University of Science Education talks of STEM Education. And so, is it STEM or STEM Education? This question is important because, if it is STEM then the emphasis would be on what the teachers and learners in these four disciplines must teach and learn. In other words, the emphasis would be on the content. If it is STEM Education then the emphasis is on how the four disciplines are taught and learnt. In other words, the emphasis would be on the pedagogy. (Of course, there is no content without pedagogy just as there is no pedagogy without content. It is a question of emphasis.)

The *2016 A-level STEM initiative Report 2*by the Ministry of Higher and Tertiary Education, Science and Technology Development (nd) talks about taking up a combination of STEM related subjects separately while the STEM centre at Bindura University of Science Education talks of the integration of STEM related subjects. So, which is which?

As we saw above, according to the Ministry of Higher and Tertiary Education, Science and Technology Development, STEM is an initiative for Advanced level students. The Minister stressed this point again recently on 22 June 2017. The Ministry of Primary and Secondary Education views STEM as a programme which begins at infant level (Ministry of Primary and Secondary Education: Zimbabwe Education Blueprint: 2015-2022).The Ministry of Higher and Tertiary Education, Science and Technology sees reason in what the Ministry of Primary and Secondary Education says but defends its position by saying 'but we hope that those with that view also respect the division of labour' meaning that the two Education Ministries had different roles and mandates to carry out (Minister of Higher and Tertiary Education, The Chronicle, June 22, 2017.). The Higher Education Minister goes on to say 'In that scheme of division of labour, under which the tasks are assigned by his Excellency, the President, ours are to plan, train and develop human capital skills. We can't do that by going to the infant level, that's not our job.'

The above scenario should remind us of the various interpretations and meanings which were attached to a philosophy called ***Education With Production*** which was introduced in the Zimbabwean education system in the early 1980s and the confusion that arose as a result of those various interpretations. As a result of that confusion and lack of national understanding of that philosophy, it died a natural death. Is history repeating itself? It would be very sad if a meaningful and potentially powerful educational reform as STEM would also die a natural death.

2.1.3. A Discussion of Pedagogical Issues in STEM Education

All students who take up STEM related subjects must learn STEM knowledge and skills, processes, principles, values etc. and then apply these to identify and solve the socio-economic problems of society. Experience has shown that not many of the students are capable of learning these science concepts and skills easily. To make the task even bigger and more complex, just learning about these knowledges, skills etc. in STEM would not necessarily result in students and future citizens with competencies to apply that knowledge and those skills to situations they encounter in life. The transmission model (Peterson, Fennema, Carpenter & Loef, 1989), through which teachers transmit factual knowledge to students, will not result in the acquisition and development of the 21st century skills (Organisation of Economic Co-operation and Development, 2009a).

The 21stcentury skills demand that students apply knowledge and skills they gain in one discipline to another and what they learn in school to other areas of their lives within and outside the school. This is called transfer of learning. This means that knowledge and skills gained must be used in new, uncharted contexts (Saavedra & Opfer, 2012). The authors further contend that ordinary instruction does not prepare students well to transfer what they learn. They maintain that through the transmission model, students have the opportunity to learn information but do not have much practice applying the knowledge to new contexts. Such a model does not result in transfer of learning.Transfer is hard, and students need support from teachers and practice at school to ensure that it happens (Forgaty et al., 1992).In other words, there is no such thing as automatic transfer of learning. It has to be taught and learnt and practised.

To be effective, any curriculum must be relevant to the students' lives (Perkins, 2010). STEM education lessons must focus on real-world issues and problems where teachers must give students experiences in applying knowledge and skills in real life situations. The 21st century skills of problem solving, creativity and innovation cannot be taught theoretically. STEM Education can only achieve this STEM literacy by providing students with experiences where they apply knowledge and skills in relevant life situations. Biox-Mansilla and Jackson (2011) recommend that teachers should ask questions such as: *How does this topic connect to the reality of the students' lives and interests? How can I make the topic more interesting and engaging for the students?* Lack of relevance leads to lack of motivation, which leads to decreased learning (Schiefele & Csikszentmihalyi, 1995). Unfortunately, these authentic real-life tasks students should engage in are not 'heaped' in some textbooks for the teachers to select from. Teachers must create these tasks.

To teach for the 21st century skills, we would need teachers who can come up with these authentic/life related experiences. Teachers must come up with case studies of authentic tasks where students are taught how to identify and solve real life problems, how to be creative and how to integrate knowledge and skills from different subject areas including those outside STEMS. This calls for a teacher whom is a jack of all trades and master of all of them. Students must then be challenged to identify similar problems which they must research on in order to identify a multiple of possible solutions to the problems (Jolly, nd). These solutions are tried and promising solutions are identified. A situation where none of the suggested solutions is a solution to the problem, that is, a situation where the students fail to get a solution is framed or taken as part of learning. They learn from what went wrong, correct it and try again.

Higher-order thinking skills, which is another term for the 21st century skills (Saavedra & Opfer, 2012) take time to develop and teaching them requires a trade-off of breadth for depth (Schwartz & Fischer, 2006). This means that teachers cover less material but cover it in depth which enables the students to master and use the mastered material effectively. How would this work in an education system which is examination driven? Would students pass the examinations if they fail to cover the entire syllabus even if they understood very well what they covered?

Is the current crop of teachers capable of teaching this STEM way? Teachers generally teach the way they were taught. The teachers in the schools, at least most of them, were neither taught nor trained in the STEM way. They would need to have that new orientation. The majority of the current crop of teachers would need to be staff developed to be able to do this. The big question though is: Who staff develops them? Universities and teacher's colleges would need to train their students to teach the STEM way. How successful this could be would depend on the ability and willingness of the university and college lecturers to do that job.

What seems to emerge from the above discussion is that statements on STEM are fairly clear on **inputs**(Students being taught the 21st century skills) and on **products** (Production of cadres with cutting-edge skills needed to meet Zimbabwe's quest for industrialisation and global competitiveness and students who can identify and solve real life problems in their communities). What we are not very clear about is the **process** which will, for example, transform this high school student into the kind of citizen who would solve the socio-economic problems in Zimbabwe. The question is: What exactly happens in the process box, which is the classroom, which will transform these students into the kind of cadres STEM Education aims to produce? It is this question which needs well thought out answers for STEM Education to succeed.

There is yet another big challenge to the implementation of STEM Education. Do examination boards stress these life related experiences in their examinations? As long as such questions are not asked, teaching for application and production (of ideas, of solutions to socio-economic problems) would not receive much attention. Teachers teach for examinations (Taba, 1962) and they do so for good reasons. This means that for STEM education implementation to be successful there must be paradigm shift at the national examination boards which would then cascade to the testing systems in the schools. At tertiary level we must come up with examination questions where students create, design, identify and solve real life problems. Examinations at tertiary level must be such that two students sitting next to each other may not be able to copy from each other.

The paradigm shift referred to above should take place at other levels and areas of education as well. For example, it is no longer enough to teach Physics well. The Physics teacher must do that and help his students to transfer and use what they learn in Physics in other disciplines and other areas of life. That kind of teacher has to have knowledge and skills in other disciplines as well. Universities and teacher's colleges must produce teachers who are as described above. This requires a paradigm shift from the traditional way of training teachers.

2.1.4. Some Examples of STEM Education Related Tasks

To teach for problem solving, transfer of learning, and other higher-order thinking skills, teachers could engage their students in tasks such as the following:

Task One: Teachers could borrow the Finland and Singapore (Finland and Singapore are among the leading giants in quality education in the world) approach where instead of getting content from teachers at school and doing problems as homework, students are given content to read at home and work on problems at school with teachers posing thought provoking questions and coaching the students to develop higher-order thinking skills (Schwartz & Fischer, 2006). This is what some educationists would refer to as the flipped classroom i.e. a classroom where there is a reversal of traditional teaching where students get exposure to new content through reading or lecture videos as part of their homework and where class time is used to apply the learned content to solve real life problems through the facilitation of the teacher. For example, after learning at home about the relationship between distance, time and speed (distance = time × speed), the students are asked to use that relationship to draw and interpret life based distance-time graphs. Another example: Having learnt that the relationship between mass, velocity of light and energy is given by the equation $e = mc^2$, students would begin by plugging in numbers in the equation to calculate the unknown given the other two variables (These are lower-order thinking skills). Students can then move on to higher-order thinking skills by answering searching questions such as: *Could we use weight instead of mass in the equation? Why or why not? Would this equation apply on the moon? Why or why not?*

Task Two: The general topic: *Transformation of matter and energy in organisms, ecosystems, global systems: The case of carbon*

Suggested content:

- Creating organic carbon as in photosynthesis
- [$6CO_2 + 6H_2O$+ Energy↔ $C_6H_{12}O_{6+}$ $6O_2$]; Energy conversion: light to chemical.
- Transforming organic carbon as in biosynthesis, digestion, food chains and food webs, chemosynthesis as in industry (e.g. organic compounds, their production, their properties and uses).
- Oxidising organic carbon as in cellular respiration, combustion and different types of fuels including fossil fuels; complete and incomplete combustion; Energy conversion: Chemical to kinetic, heat, light.
- Application of learnt concepts:
- Using real case studies, students learn about:
- Dangers of exploitation of resources (flora and fauna in the natural world; material resources in the home). In addition to the usual teaching methods, students could be involved in role playing and games to illustrate this concept.
- Dangers of overpopulation of some species in an ecosystem e.g. eutrophication.
- Suffocation in poorly ventilated spaces such as rooms, mine shafts. [Incomplete combustion, haemoglobin and its affinity for oxygen and carbon monoxide).
- Global climate change as a result of an imbalance in the above three processes and how it would affect the students' natural environment.

No effort has been made to relate these tasks to any particular level of education in Zimbabwe. Using these examples, a STEM teacher should be able to come up with relevant examples at their level of operation.

3. Conclusion and Recommendations

We strongly believe that while the success of STEM Education relies on many factors, the most important factor, the core of this initiative, is the act of teaching i.e. how teachers will interact with students and how the students will interact with the carefully selected authentic learning materials in order to foster the development and use of the 21st century skills. The pivot of all this is the quality of the teachers and their understanding, marriage to and competencies in STEM Education. Of course, the teachers will require a lot of support. They will need training and retraining, in-service workshops to renew and expand their teaching knowledge and skills. They will need material support. But above all, they will need to understand and share the same meaning and spirit of STEM Education among themselves and with the other stakeholders such as the policy makers.

Since solutions to real life problems have to borrow from a number of disciplines, STEM Education should be about the integration of the STEM disciplines rather teaching the disciplines in isolation. It must, however, be accepted that this is a big paradigm shift from current practice.

Because everybody has to deal with life problems, the ability to identify and solve these problems should be taught to everybody from primary school upwards. Also, the transition from one education level to the next must be smooth. This means that there must be a seamless alignment of the components of the education system from Early Childhood Development stage up to University level. Levels of education must speak to each other. The primary school curriculum should lay a solid foundation for the secondary school curriculum which should lay a solid foundation for tertiary education. As the STEM centre at Bindura University correctly observes: Introducing STEM education at infant level 'is intended to give students a through grounding in STEM at an early age so that they become acquainted with the range of STEM related fields and occupations'. One could add: so that the students become acquainted with the STEM way of learning.

Examination boards must begin to examine the acquisition and use of the 21st century skills. This requires a paradigm shift in all the relevant stakeholders. Without that paradigm shift, the success of STEM Education cannot be guaranteed as teachers always teach for examinations.

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