Chapter

A Theoretical Framework for Implementing STEM Education

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Abstract

Globally, strengthening Science, Technology, Engineering and Mathematics (STEM) education is recognized as embedding solutions to many societal problems like the depletion of natural resources and issues related to climate change. The recognition of STEM disciplines as economic drivers motivated the initiation of STEM education in both developed and developing nations. This is based on the thinking that an effective STEM education is a vehicle for developing in students the much desired twenty-first century competences. Yet, its operationalization has remained a great challenge in many nations. In most nations, educators lack a cohesive understanding of STEM education and are also deprived of an easy-to-understand STEM education framework that informs classroom practices. This chapter proposes a practical theoretical framework that nations may adopt and/or adapt for their STEM education to be successful.

Keywords: classroom practice, STEM education, STEM educators, theoretical frameworks

1. Introduction

Today, it is indisputable that Science, Technology, Engineering and Mathematics (STEM) are strong drivers of competitive national economies. Thus, throughout the world, nations are busy investing in STEM with the hope of grooming innovative minds to spearhead the development and sustainable growth of their economies. In education, strong STEM programmes are regarded as critical in developing students with twenty-first century competences (knowledge, skills and values) [1]. Twenty-first century competences including creativity, problem-solving and entrepreneurial are prerequisite students' further studies in STEM areas, their taking up of related careers and ventures into entrepreneurship and inventions [2]. In this regard, STEM classrooms require teachers who hold knowledge and pedagogies associated with different STEM disciplines and who would be able to construct new identities within their nation and school contexts [3, 4]. The economic development foundation-laying goals for STEM education are quite clear in literature. With all of the possible benefits of STEM education, it becomes imperative to ascertain that teachers teach STEM effectively [5]. Yet, quite often nations introduced STEM education void from context-specific theoretical frameworks and standard operating procedures (SOPs) to guide its understandings and implementations [6, 4, 7]. Logically, the success of STEM education endeavours is largely underpinned by well-defined national conceptions, theoretical underpinnings and SOPs of STEM education. Yet, in many nations, STEM teaching has been left to individual teachers to figure out what it entails and how to do it. The need for nations to clearly define theoretical framework for STEM integration remains [8] and cannot be overemphasized (Lederman & Niess, 1998).

Despite the increasing attention to STEM education worldwide, its stakeholders in particular educational institution managers and classroom practitioners are still grappling to come into terms with what constitutes STEM education and how it can move to classroom settings [9]. No clear-cut answer to these issues can be discerned in the literature and discourses among STEM-related communities of practice. Research findings that STEM education is failing in many nations can be explained from the non-available answer to this question. This problem is aggravated by a variety of STEM education frameworks (Berlin & White, 2010) which often lack consensus of what STEM and STEM education entail. For example, in Zimbabwe, the Primary and Secondary Education Ministry fails to agree with that of Higher and Tertiary Education, Science and Technology on the meanings of STEM education and their implications to its implementations [10]. Currently, Zimbabwe still does not have a clear and accessible national STEM education framework. An obvious and immense need for stakeholders to agree on what STEM education is and how it is to be introduced in educational settings can also be drawn from studies conducted in Turkey, Egypt, and the United States of America [11].

The main argument of this chapter is that in order to break the vicious circle of STEM education reform failures, academics need to examine and consequently collate different theoretical frameworks into easy-to-understand and easy-to-implement practical approaches. Different nations then can adjust such frameworks to their contextual needs. The chapter first discusses the Qualitative-Philosophical methodology adopted to develop the Science, Technology, Engineering and Mathematics Education (STEME) theoretical framework. Second, four approaches selected from literature and from which STEME was constructed are examined in turn. Third, how the theoretical framework was constructed and how it describes STEM education are presented and discussed. Fourth, the chapter discusses the practical applications of STEME model to translate STEM education into a living reality. The chapter ends with a final word after conclusions and recommendations.

2. Qualitative-philosophical methodology

STEM education literatures were Qualitative-Philosophical (QualPhil) studied to develop a STEME model this chapter proposes. QualPhil is a pragmatism-grounded approach that blends qualitative and philosophical research approaches. Pragmatic perspectives untangle epistemological boundaries in knowledge production through the mixing of approaches that are deemed relevant and fitting to the purposes of the study. The knowledge on STEM education was drawn from different sources and perspectives in literatures, and ongoing research works with students under my supervision in STEM education. The philosophical angle guided the synthesis of multiperspectives on STEM education done through the deductive and inductive interrogation of literature grounded in qualitative approaches [12]. The chapter rigor was enhanced by not only broad literature scope drawn across STEM disciplines but also frequent peer debriefs with academics and students doing postgraduate researches in STEM disciplines and STEM education. Procedurally, three phases were iterated. First, the study was informed by three years of student project work in STEM Education. The critical supervision of works in six students to completion phase in Zimbabwe provided insights into the theoretical origins of the conception and implementation of STEM education problems. In the second phase, 10 articles from conceptual and empirical credible sources were selected and analysed. Finally, the STEME model was developed through linking main categories (themes).

3. STEM education

Different STEM approaches have been adopted in different education contexts even within the same nation [4, 13–15]. Research reveals that this is the main source of confusions and misconceptions/misunderstandings of STEM education among teachers [14]. These confusions and misconceptions are ripple effected by Many other barriers to STEM education [16]. Four approaches that premised the development of the Science, Technology, Engineering and Mathematics Education (STEME) theoretical framework are described. These are pathed, integrated, continuum and STEAM (Science, Technology, Engineering, Art and Mathematics) education.

3.1 Pathed STEM education

The four pathways to STEM education suggested by this framework are isolated and independent (S-T-E-M), duet (e.g. SteM), one into three (e.g. E S-T-M) and all four infused (STEM) approaches [17].

The separatist or silo approach is also discerned in the literature as a traditional approach that holds the isolated instruction of each individual STEM subject [18]. Some symbolize this way of teaching as S-T-E-M to draw attention to its independent subject nature with no to minimal or integration. In schools, this approach manifests as traditional disciplinary list of school subjects like science (chemistry, physics, biology, etc.), mathematics, technology and engineering. It becomes a curriculum movement in that it emphasizes that subjects like technology and engineering which were largely excluded in the school curricula be included. The approach's established history and philosophy of classroom practices currently ground the STEM educators' (teachers in high schools and universities' lecturers) discipline-based training. Teachers informed by this approach tend to teach for subject matter understanding and enhancement of student achievements [19]. They value and conserve their specific knowledge domains [19]. Furthermore, S-T-E-M encourage teachers to adopt lecture-based classroom practices that not only restrict students' academic development and growth [20] but also make students lose interest in STEM subjects [21]. Moreover, the approach supports teachings which are decontextualized from the real world and fail to create opportunities for student to learn through doing, applying and solving problems in real-life situations [22]. This encourages students to maintain separated and parallel views of subject content [6]. In turn, the products of silo teaching-based approaches find it difficult to understand the integration between and among STEM subjects and the real world. This fragmented acquisition of knowledge, values and skills is not in sync with the competences demanded by twenty-first century economies. It is also not aligned to the STEM education form that endeavours to make students realize the integrated or holistic sense of their world living. Conclusively, this approach is limited in capacitating students with the dearly need twenty-first century competences.

The second STEM education path is the integration of two of the four STEM disciplines. This is described in this chapter as the duet STEM education approach. As an example, in schools this duet approach can concentrate on science and mathematics (SteM). Integrating science and mathematics (SteM) seems to be the preferred approach to STEM education in most schools among nations [17, 23]. This duet approach can be thought of as discipline based. The discipline-specific level of the STEAM pyramid [24] can be related to this STEM teaching way. In the pyramid framework, this level is described as where individual fields or disciplines are taught as stand-alone, but the focus becomes the base discipline where the teaching connects with other subjects. This is to say the subject of focus is covered in depth in relation to other STEM subjects. The specific area of academic expertise and related careers is more apparent and significant. This approach is considered more appropriate to secondary education [24]. The approach retains discipline identity and therefore befitting not only to educators but other professionals who have been trained in and associate themselves with specific disciplines like engineering. Within this approach, subject-based connections are done in a way that does not make a subject lose its uniqueness [25].

It is convincing from the definitions of each of the STEM disciplines that excluding one of them most likely creates competence gaps in student which will limit them in handling real-life problems. This is captured in this quote that 'We now live in a world where; you can't understand Science without Technology, which couches most of its research and development in Engineering, which you can't create without an understanding of Mathematics' [24, p. 17]. Thus, an understanding of what each STEM field is makes this assertion clearer. These fields are chronologically described [17]. First, Science (S) focusses of what exists in the natural world. Scientist engages in scientific inquiry, discovery and exploration to understand the world. In schools, colleges and universities, curriculum courses like biology, chemistry and astronomy aim to make student understand the specific aspects of what the world holds. Second, the Technology (T) is concerned with what can be designed, made and developed from materials and substances in natural world to satisfy human needs and wants. It alters the natural world through inventions, innovation and practical problem-solving as well as design processes. Third, Engineering (E) applies mathematical and scientific knowledge to develop ways of economically utilizing the materials and forces of nature in order to benefit mankind. It draws from technology to produce resources such as energy uses through creativity and logic [24]. Technology and engineering disciplines are strongly connected [17]. Finally, mathematics (M) is the science of patterns and relationships [numerically and symbolically expressed] and provides specific language for technology, science and engineering. Actually the practices of scientist, technologist and engineers are STEM integrated [6]. My talk with my children and siblings in architectural, electronic, automotive engineering all confirmed these authors' assertion that practitioners in these fields draw from various science disciplines, mathematics and technology in doing their work.

The third way is to integrate one of the STEM disciplines into the other three being taught [17]. For example, engineering content can be integrated into science, technology and mathematics courses. This author says this path may be depicted as E S-T-M. This is differentiated from integrating technology into the author by referring to this form as T S-E-M. This approach attempts to address the limitation of the duet way that focusses only on mathematics and science. However, it still conserves the discipline characteristics. One model suggests that STEM integration can be achieved through using engineering or technology designs to create connections of concepts and practices from mathematics or science [5, 26, 27].

Lastly, an infused model of the all four disciplines into each other to teach them as an integrated subject matter [17]. This way of STEM teaching relates to interdisciplinary meaning of STEM education [28]. The different expressions of this form of STEM education all converged to a blended approach that draws classroom practices (purpose, content, context, pedagogy, assessment and interactions) from all four fields and merges the into one field. For example, STEM integration as interdisciplinary involves cutting across subject interconnections into interdisciplinary content and skills [5], in that it mixes STEM content areas into a one subject learning area [29], an interdisciplinary teaching approach that removes the barriers among the four disciplines through incorporation of all the knowledge domains and individual subject skills into one [30]. This form of STEM education requires teachers to hold appropriate knowledge, skills and beliefs of each discipline so that students gain holistic competences for understanding and tackling world problems [31]. This integrated content mirrors the multidisciplinary nature of problems encountered in the real world. Integrated STEM education has promised to equip students with the long sought after skill to link the book with real-life problems and to provide hands-on approach which help motivate students to take up STEM subjects. Research indicates that using an interdisciplinary STEM education provides opportunities for relevant and more thought-provoking experiences for students [32]. Such experiences stimulate higher-level thinking skills and problem-solving. Ultimately, the effective implementation of this approach makes students better problem-solvers, innovators, inventors, self-reliant, logical thinkers and technologically literate [29].

Today, the interdisciplinary approach in STEM education is commonly accepted. It emphasizes on the matching of what it taught and learnt to the real world. Students are to make connections between school and the society [28]. The approach progresses nations towards STEM-literate societies which are compatible with twenty-first economies.

3.2 Integrated STEM education

The integrated STEM education entails 'an interconnected entity [of disciplines] with a strong collaborative connection to life' [31, p. 79]. This STEM education approach directs teachers to diffuse paradigmatic knowledge, skills, values and language differences and teach the integrated discipline as one cohesive entity. In doing so, teacher and student interactions should take the centre stage to enable them to collaboratively construct new knowledge, skills and beliefs at the intersection of more than one STEM subject area. Driving such interactions in the classrooms necessitates that teachers comprehend STEM content and acquire supportive pedagogical content knowledge specific to their subjects as well as working knowledge in another [31].

This integrated approach argues that the 'real-life' application of STEM is naturally integrated. A mathematically rigorous science education (MRSE) argument that disputes the epistemological (paradigmatic) view of mathematics and science as distinct to an extent that they are imposable to integrate illustrates how this model functions [31]. This argument aligns the insightful thinking that desperate epistemological assumptions underlying STEM disciplines detract their integration [33] and the interdependence relevance of science and mathematics to real life [34]. This interdependence of science and mathematics perspective afore their applications into real-world situations. Thus, the application of sciences and mathematics in engineering and technology invalidates their compartmentalized views and brings in an understanding of STEM education as an integrated entity.

STEM teaching can occur at the space where two or more STEM subjects such as mathematics and science intersect. Class interactions draw into this space the content and processes such as problem-solving and quantitative reasoning of both mathematics and science. Mathematics used in science or mathematically rigorous science education brings to the attentions of teachers an interdisciplinary understanding of STEM education that 'does not create an independent meta-discipline while preserving the subject-specific knowledge, skills, and attitudes' [31].

3.3 A continuum approach

The continuum approach borders on four different levels ranging from the lowest level 1 (the disconnected) to the highest level 4 (the integrated) [23]. The other possible ways of STEM integration it provides are the connected and complimentary in levels 2 and 3, respectively. In the disconnected level, individual STEM subjects are taught and learnt separately. These subjects such as chemistry, biology and mathematics exist parallel to one another in school curricula. Each subject is taught by teachers trained to teach it. STEM integration within this level entails introducing the subjects like engineering and technology in the school curricula which are usually excluded in schools. Like the separatist or silo approach of the pathed STEM education approach [17], this disconnected level guides the teaching and learning of specific STEM subjects. This level 1 STEM teaching and learning not only perpetuates the disparateness among multiple disciplines but also decontextualizes learning from real-world activities. It retains the status quo of teaching and learning of each STEM subject which has long been seen as lacking in instilling economic development driving skills such problem-solving, critical thinking, collaboration and creativity in students [35]. Yet, highly ranked infused (see Section 3.2) and integrated (see Section 3.3) STEM education approaches make it clear that this curriculum reform is not only about introducing engineering and technology in the school curricula as stand-alone subjects, but it is about integrating concepts from different subjects into new STEM subject matter, using student-centred pedagogies and assessment approaches in a way that nurtures students' 'inventiveness, creativity, and critical thinking'. Thus, the level 1 approach promotes traditional silo practices rather than integrative (innovative) practices.

Literature points to the thinking that introducing engineering and technology as stand-alone subjects will in some way bring awareness of their connections to the science and mathematics. This can be discerned from the definition of each of the four STEM disciplines. Science has three interrelated dimensions: (1) understanding nature which relates to science as the tool for understanding universal patterns of nature, (2) scientific inquiry which relates to the methodology used for generating knowledge and (3) scientific enterprise which relates to the human involvement in generating knowledge [23]. Mathematics is not only the primal language that cuts across STEM disciplines but also a network of practical and theoretical divisions that interact with other subjects as well as within [24]. It is inclusive of numbers and operations, algebra, geometry, measurement, data analysis and probability, problem-solving, reasoning and proof and communication (including trigonometry, calculus and theory) [23]. Both engineering and technology apply science and mathematics. Engineering uses technology to innovate and create products or structures and process that improves quality of life. Research is consistent that integrating engineering practices and engineering design on the learning of science potentially makes learning meaningful, exciting and relevant. Recent research, however, is focussing on pedagogical integration of engineering into other STEM subjects [27, 36].

The integrated approach, in level 4, informs integrative STEM classroom practices. This integrated approach is in synch with both the infusion model [17] and the integrated STEM education model [31]. Though different terminologies are used to describe this STEM education approach, they all converge on its description as an intertwined approach of the four STEM disciplines in a way that makes it impossible to distinguish each of them. Thus at classroom level, integrated STEM education informs development of integrated content (STEM content) [5], designing and adoption of student-centred pedagogies that support integrated learning [35] and adoption of assessment approaches that promote creativity, inventiveness and innovation in solving real problems. Such classroom practices should depart from the discipline-based student-centred pedagogies, real contexts and problem-solving STEM-integrated practices. The paradigm shift, therefore, calls for new pedagogical models, new content, assessment method, contexts and teacher-learner roles. Further, it necessitates higher education institutions (HEIs) to develop new STEM teacher programmes. The movement from level 1 straight to level 4 would be very abrupt, challenging and expensive. The levels 2 and 3 of this continuum approach can provide midway step progressions towards level 4.

The connected perspective in level 2 refers to drawing attention to connection between the areas while still considering them separately. Within this level teaching and learning is subject specific or discipline based. Though not explicitly stated, two options are available in this level. One is the duet approach of connecting the concepts of mathematics and science. This relates to subject matter or content connections. The second option is the one into three (1–3) STEM integration approach. This alludes to the E S-T-M integration of the pathed STEM education. STEM integration at this level is not to say that other subjects are excluded, but rather the focus is on exploring the primary subject more in depth and then the related fields. At this level, the specific divisions of silo are loosened and lessened through connections.

In level 3, complimentary approach informs teachers to explore mutual relationships between and among STEM subjects rather merely connecting concepts drawn from areas. The term complementary implies use of both differences and similarities of two or more things such as role or skills or strengths to create synergies that bring greater efficiency and effectiveness. Thus, the complementary STEM education notions that the four disciplines are different, but share similarities that can be drawn into a common space. In STEM education, STEM subjects may be offered separately, but the teaching of each specific subject should draw from other STEM subjects in order to develop knowledge and skills from combined strengths.

3.4 STEAM education

The STEAM linkages can be drawn from the articulation that 'We now live in a world where; you cannot understand Science without Technology, which couches most of its research and development in Engineering, which you cannot create without an understanding of the Arts and Mathematics' [24]. These ideas can also be drawn from the STEAM education framework for students with disabilities [7]. In simple terms, this approach entails an addition of the arts to STEM (STEM + arts). Considering students' frustration from unpleasant and/or unsuccessful experiences in STEM disciplines, some researchers suggested students' motivation in learning STEM disciplines needs to be additionally considered within the interdisciplinary framework [33]. They argued that STEM education should be expanded to embrace and integrate with the disciplines of the arts in order to facilitate and promote accessibility of STEM learning. The arts domain embeds areas of performing arts (i.e. dance, music and theater), presenting arts (i.e. visual arts) and producing arts (i.e. media arts), as well as languages. It is acknowledged that in real life, people solve problems through integrative thinking and applications. They do not separate aspects of science, mathematics, art, and so on [37], rather they draw from all the disciplines and confront the problem(s) holistically.

4. The STEME integration framework

The Science, Technology, Engineering and Mathematics Education (STEME) model in **Figure 1** was developed with full recognition that education is contextual,

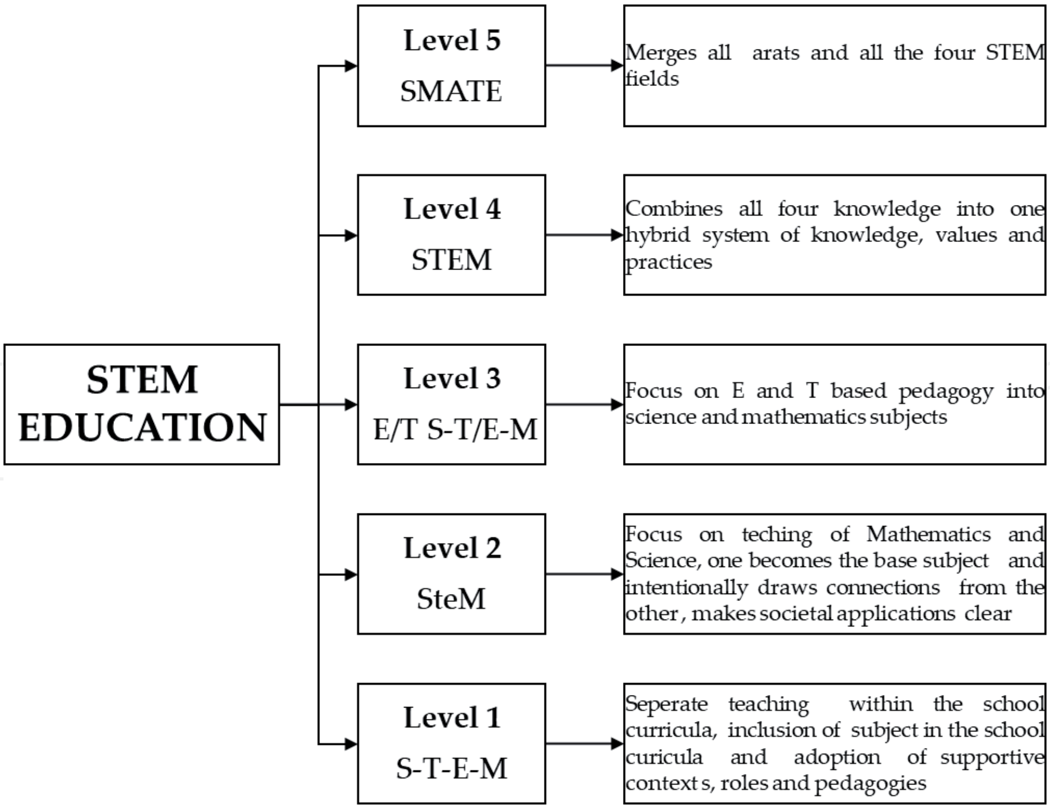

Figure 1.
STEME model.

so STEM education cannot be spared. My mission was to awaken nations into realizing the dire need for providing guidelines. The model was built through comparing and contrasting the four approaches to STEM education discussed in Section 3. Established connections among the four approaches were linked and ordered into a four-leveled STEME model. This framework elucidates on both paths and degree of integration.

Levelling of these approaches was based on their complexity and easiness to comprehend and implement. The lowest level 1 is the separatist approach, abbreviated S-T-E-M. The hyphens between the letters symbolize the side-by-side teachings of STEM subjects. Within this approach, integration is arrived by adding the STEM subject to the school curricula. Literature provides that this is one option for integrating technology into the school curricula [35]. In a simple understanding of STEM education as technology, engineering and mathematics, schools to include the missing discipline, usually technology and engineering to their curricula. This is a simple form of STEM education which is easy to implement [36]. All it requires is to train engineering and technology teachers. The traditional identity of the separatist approach brings not only its history and philosophy of subject specificity but also that of its separate disciplines. The current use of this approach can be inferred from policies that aim at increasing the number of STEM subjects or courses or academic programmes in educational institutions. Such policies also focus on addressing the dwindling enrolment problems and gender disparities in STEM fields. But STEM pedagogical integration can be effected in the teaching of specific STEM subjects. Many nations like Zimbabwe are advocating for shifts in pedagogical practices within the teachings of these disciplines. In Zimbabwe, 'new' STEM curriculum framework encourages teachers to adopt research, discovery and problem-based approaches in teaching specific STEM subjects. The adoption of these student-centred approaches in teaching subjects like chemistry should be able to develop creative and innovative minds in students. Classroom practices emanating from pedagogical STEM integration should be able to meet the criteria for an effective STEM instruction. Students in a pedagogic STEM integration classroom should be able to: (1) solve problems, (2) innovate, (3) invent, (4) logical think, (5) self-rely and (6) technological literacy [22]. Research has shown that by and large pedagogical STEM-integrated classrooms address problems related to subject conceptual understanding, poor achievements and loss of interest and enrolment declines. Other research findings teach us that teachers' subject based trainings and teaching experience support traditional teacher centred approaches and make the pedagogically limited implement STEM education. The need to professionally develop teachers for STEM teaching therefore needs no emphasis.

The STEME level 2–4 approaches allude to STEM integration that involves more than one subject. Generally, this integration approach is more difficult to both understand and implement as compared to the separatist [36]. The ordering of the three approaches was based on the logic that establishing connections between and among STEM subjects positively correlates with the number of the subjects involved. The more the subject to be integrated, the more complex it is to conceptualize and implement STEM education. The more the complex and cognitively demanding the subject involved in the integration, the more difficult the integration is to achieve. The duet integration in level 2 focusses on the teaching science and mathematics and making connections between them. The argument is that science leads to the understanding of nature that holds resource for sustaining life. So it would be difficult to effectively use such natural resources without understanding what the world has in store for humankind. The compartmentalization of science disciplines into chemistry, physics and biology aligns with the discrete approach to their study. 'Mathematics is not just a primal language for knowledge disciplines, but also a network of practical and theoretical divisions that interact both with other subjects' [24, p. 18]. This makes not only its linking it to any of the scientific disciplines practical, but also it can be used to mediate connections among science subjects. In fact, the 'real-life' application of sciences and mathematics in engineering and technology is practically integrated [31]. However, this level remains discipline based and directs teachers of chemistry, physics and biology to integrate mathematic in their teaching. Those of mathematics are also required to make connection to one or more scientific subjects. Like in level 1, the effective implementation of this approach requires teacher knowledge and knowledge of teaching in mathematics and a science subject.

The one into either three E/T S-E/T-M integration approach is in level 3. It describes the integration of either technology or engineering into one of the other three STEM disciplines. This approach suggests that engineering or technology reasoning, decision-making and practices can be integrated in science or mathematics or either engineering or technology classrooms depending on which subjects is being moved into the other. This type of integration is pedagogically based where engineering- or technology design-based pedagogy is adopted in science classrooms [30]. The US states, such as Texas, Oregon and Massachusetts, consented adding engineering to improve STEM education not as a stand-alone subject but rather pedagogically [5]. This curriculum movement lends the support of many researches that have shown that use of engineering designs in science classrooms effectively develops in students the much-desired twenty-first century skills [26, 37]. The same goes for integrating technology.

The STEM education level 4 depicts interdisciplinary or multidisciplinary integration. Though some studies attempt to distinguish these two constructs [9, 24], in this model they are collated to mean the same. The phrase interdisciplinary is used to entail an approach where STEM teaching integrates all the four disciplines into one cohesive teaching and learning paradigm [28]. I use the term parading from its description as a set of interrelated beliefs about reality, knowledge, methodology, values and language

(Mpofu et al. 2016) in relation to STEM teaching. The main aim of interdisciplinary integration is to shift traditional paradigmatic barriers existing among the four disciplines to STEM [38]. Within this interdisciplinary approach, teachers are expected to guide students to make connections between school, community, work and the global enterprise through coupling the learning academic science, technology, engineering and mathematics concepts with real-world lessons [28, 26]. Moreover, interdisciplinary learning impacts lifelong learning habits, academic skills, personal growth [39] and development of knowledge management skills [40].

The last level 5 approach described in this model as Mathematics, Science, Art, Technology and Engineering (MSATE) has been modified from the STEAM approach. STEAM education for students with disabilities can also be adapted to all students. In simple terms, STEAM education means an addition of the Arts to STEM (STEM + Arts). In a level 5 approach in SEME, it is abridged MSATE to depict its integration of all knowledge bodies into one holistic knowledge, values, skills and practice system. This letter arrangement taps arguments proffered by indigenous scholars that science is cultural and language is central to every culture and development of its knowledge. The art domain in this context embraces both languages and social sciences. It is positioned in the centre to depict that inherent in it are knowledge development, representation and communication. Mathematics and Science come before Arts to reflect the connecting role Mathematics plays across STEAM disciplines and the understanding of nature fundamental role Science plays. Thus, the language understanding of both sciences and mathematics enables their combined applications in technology and engineering. Thus, MSATE takes cognisance that language use is integral to activities (e.g. classroom teaching) that are placed within social contexts [37].

5. Practicalizing the STEME theoretical framework

This section presents one way a nation can apply this framework. The framework should be used on an understanding that the actual implementation of STEM education is a mammoth task and process. Therefore, its implementation is a responsibility for all: academics, policymakers, schools and industries as well as communities.

The first step is to build a collaboration team composed of critical STEM education stakeholders. Among the team members should be renown scholars in STEM education drawn from the nation's universities, Ministry of officers in research and technology departments, policy makers, teachers of different STEM subjects, parent or guardians representatives, student representatives industrialist. This team should be selected based on competence, relevant experience and context as well as passion. Time should be taken to capacitate the team through workshops, seminars, symposiums and exchange programmes.

The collaborating team in the second step involves a critical and holistic analysis (CHA) of the status of STEM education in their nation through various researches that use the STEME theoretical framework. This CHA should include the nation's STEM education rationale, goals, intended outcomes, components and how the components interact as well as the implementation challenges. In the STEME framework in **Figure 1**, this activity pertains to the cell—/box-labelled STEM education. The CHA findings should lead to the conclusion that describes the national status of STEM education within or between levels of STEME. This is shown by the direction of arrows. For example, from CHA it can be concluded that our STEM education is largely at level 1. Implications of the finding in relation to the rationale, goals and intended outcomes and impacts are then discussed.

In the third step, the STEM education team identifies their nations' desirable STEME level. I recommend three ways to identify this level. One is to draw it from the goals and intended outcomes and impacts established in step 2 above. For example, on one hand national agenda that seeks to develop and grow its economy through capacitating a critical mass of skilled manpower in STEM-related careers might be aiming at operating at level 3. On the other hand, a nation that seeks to develop and grow its economy through industrialization and entrepreneurship might be at achieving either STEM level 4 or 5. The other one is to consider the best-fitting level to the needs of the nation based on the comparative analysis of the disadvantages and limitations of each level of operation. Finally, a blended approach of two ways can also be adopted.

The fourth step is assessing national needs and constraints in relation to the status and desired STEM level gap. Let's say the status and desired levels were established as 1 and 3, respectively. The team identifies the needs and constraints to move from the status level to the desired level. In step 5, the STEM team develops a STEM implementation plan to take the nation to the desired level including strategies to address the identified obstacles for effective STEM teaching at that level. The last step is to implement the plan.

6. Conclusions and recommendations

This chapter responded to the globally growing calls for an urgent need to put in place clear national frameworks to inform in developing and implementing STEM education at classroom level. There are four main conclusions drawn from the discussion in this chapter. First, the starting point to realize the endeavours of STEM education is for nations to clearly define their theoretical framework. The chapter suggests a STEME (Science, Technology, Engineering and Mathematics Education) integration framework as a starting point for better understanding and operationalizing STEM education. It orders a variety of STEM integration approaches from level lowest level to highest level 5. Second, collaborative engagements of experts are to be used in a six stepwise implementation of STEM education process. These are building a national STEM education collaborating team, critical and holistic analysis of the status of STEM education, identification of the desirable level of STEME level, assessment of the STEM education needs, developing an implementation plan and implementing the plan. Third, the idea of driving STEM education from a well-defined national theoretical framework like STEME can be an effective mechanism for facilitating innovative STEM education practices at classroom level. Lastly, the strength of theoretical framework such as STEME is in systematically contextualizing STEM education from a research and well-defined context. This is of critical importance in light of the significant variation across individuals, nations and disciplines with respect to current understandings of STEM education and its core components. The framework underscores that implementing STEM education requires correct interpretations and deep understandings of its endeavours from national level that cascades down to classroom level. The paper recommends that the developments of national STEM education approaches inform not only STEM teaching but also the development of teaching materials such as textbooks. The strength of this STEME theoretical framework is not only in its adaptability to different contexts but also in its easy to operationalize. The chapter further recommends researchers to use STEME as a springboard for further communication and research exploring the successful implementation of STEM education in their nations and beyond.

Final thoughts

While the success of STEM education relies on many factors, the most important factor of this reform is teachers' classroom practices that foster the development and use of the twenty-first century competences. This hinges on the quality of the teachers and their understanding, marriage to and competencies in STEM education. The teachers will require a lot of support in terms of guiding frameworks, professional development, material development and many other resources. The theoretical framework such as STEME is the key that guides training and retraining, research and monitoring and evaluation of STEM teaching. But above all, the STEME theoretical framework brings about a shared meaning and spirit of STEM education among stakeholders. This chapter motivates me to initiate the practilization of STEM education in Zimbabwe.

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References

[1] Bashman JD, Israel M, Maynard K. An ecological model of STEM education: Operationalizing STEM FOR ALL. Journal of Special Education Technology. 2010;**23**(3):10-19

[2] Holmes K, Gore J, Smith M, Lloyd A. An integrated analysis of school students' aspirations for STEM careers: Which student and school factors are Most predictive? International Journal of Science and Mathematics Education. 2018;**16**(4):655-675

[3] Furner JM, Kumar DD. The mathematics and science integration argument: A stand for teacher education. Eurasia Journal of Mathematics, Science & Technology Education. 2007;**3**(3):185-189

[4] Pimthong P, Wiliams J. Preservice Teachers' understanding of STEM education. Journal Of Social Sciences. 2018:1-7. [Online first]

[5] Stohlmann M, Moore TJ, Roehrig G. Considerations for teaching integrated STEM education. Journal of Pre-College Engineering Education Research (J-PEER). 2012;**2**(1):28-34

[6] Breine J, Harkness S, Johnson C, Koehler C. What is STEM? A discussion about conceptions of STEM in education and partnerships. School Science and Mathematics. 2012;**112**(3):3-11

[7] Hwang J, Taylor JC. Stemming on STEM: A STEM education framework for students with disabilities. Journal of Science Education for Students with Disabilities, Art. 4. 2016;**19**(1):39-49

[8] Asunda PA. A conceptual framework for STEM integration into curriculum through career and technical education. Journal of STEM Teacher Education. 2014;**49**(1):3-15

[9] Holmlund TD, Lesseig K, David S. Making sense of "STEM education" in K-12 contexts. International Journal of STEM Education. 2018;**5**(32):3-18

[10] Moyo PV, Berdut IR. Interrogating the implementation of STEM education in Zimbabwe. The International Journal Of Humanities & Social Studies. 2017;**5**(11):332-337

[11] Ahmed HOK. Strategic future directions for developing STEM education in higher education in Egypt as a driver of innovation economy. Journal of Education and Practice. 2016;**7**(8):127-145

[12] Burbules NC, Warnick BR. Philosophical inquiry. In: Handbook of Complementary Methods in Education Research. New York, NY: Routledge; 2006. pp. 489-502

[13] Johnson CC. Implementation of STEM education policy: Challenges, Progress, and lessons learned. School Science and Mathematics. 2012;**112**(1):45-55

[14] English LD. STEM education K-12: Perspectives on integration. International Journal of STEM Education. 2016;**3**(3):2-8

[15] Bybee RW. The Case for STEM Education: Challenges. Arlington, Virginia: NSTA Press Book; 2013

[16] Ejiwale J. Barriers to successful implementation of STEM education. Journal of Education and Learning. 2013;**7**(2):63-74

[17] Dugger WE. Evolution of STEM in the United States. In: 6th Biennial International Conference on Technology Education Research. Gold Coast, Queensland, Australia; 2010

[18] Gerlach J. "STEM: Defying a simple definition," NSTA reports; 2011

[19] Herschbach DR. The STEM initiative constraints and challenges. Journal of STEM Teacher Education. 2011;**48**(11):197-222

[20] Deslauriers L, Schelew E, Wieman C. Improved learning in a large-Enrollment. Science. 2011;**332**:862-864

[21] Dickstein M. STEM for all students: Beyond the silos. 2010. [Online]. Available from: https://www.creativelearningsystems.com/files/STEM-for-All-Students-Beyond-the-Silos.pdf [Accessed: 01-06-2018]

[22] Morrison J. TIES STEM Education Monograph Series, Attributes of STEM Education. Baltimore, MD: TIES; 2006

[23] Akaygun S, Aslan-Tutak F. STEM images revealing STEM conceptions of pre-service chemistry and mathematics teachers. International Journal of Education in Mathematics, Science and Technology. 2016;**4**(1):56-71

[24] Yakman GG. ST∑@M Education: An Overview of Creating a Model of Integrative Education

[25] Barlex D, Pitt J. Interaction: The Relationship between Science and Design and Technology in the Secondary Curriculum. London: Engineering Council; 2000

[26] Sanders M. STEM, STEM education, STEMmania. Technology Teacher. 2009;**4**(20-26):68

[27] English LD, King DT. STEM learning through engineering design: Fourth-grade students' investigations in aerospace. International Journal of STEM Education. 2015;**2**(14):1-18

[28] Tsupros N, Kohler R, Hallinen J. STEM Education: A Project to Identify the Missing Components. 2009

[29] Morrison J, Bartlet R. STEM as curriculum. Education Week. 2009;**28**(23):28-29

[30] Wang HH, Moore T, Roerig G, Park M. STEM integration: Teacher perception and practice. Journal of Pre- College Engineering Education Research. 2011;**1**(2):1-13

[31] Corlu S, Capraro RM, Caprar MM. Introducing STEM education: Implications for educating our teachers for the age of innovation. Education and Science. 2014;**39**(171):74-85

[32] Furner J, Kumar D. The mathematics and science integration argument: A stand for teacher education. Eurasia Journal of Mathematics, Science and Technology. 2007;**3**(3):185-189

[33] Willimas J. STEM education: Proceed with caution. Design and Technology Education: An International Journal. 2011;**16**(1)

[34] Başkan Z, Alev N, Kara IS. Physics and mathematics teachers' ideas about topics that could be related or integrated. Procedia Social and Behavioural Sciences. 2010;**2**:1558-1562

[35] Capuk S. ICT integration models into middle and high school curriculum in the USA. Procedia-Social and Behavioural Sciences. 2015;**191**:1218-1224

[36] Vasquez JA. STEM--beyond the acronym. Educational Leadership. 2015;**72**(4):10-15

[37] Guzey S, Ring-Whale EA. Negotiating science and engineering: An exploratory case study of a reform-minded science teacher. International Journal of Science Education. 2018;**43**(7):723-741

[38] Morrison A. A contextualisation of entrepreneurship. International Journal

of Entrepreneurial Behaviour and Research. 2006;**12**(4):192-209

[39] Jones ML. A study of novice special educators' views of evidence-based practices. Teacher Education and Special Education. 2009;**32**(2):101-120

[40] Biasuti M, El-Deghaidy M. Interdisciplinary project-based learning: An online wiki experience in teacher education. Technology, Pedagogy and Education. 2015;**24**(3):339-355