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Preparing Pre-Service STEM Teachers in an Emerging Global Environment

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Abstract

The dynamics of Science, Technology, Engineering and Mathematics (STEM) teacher preparation has changed very dramatically in line with present-day realities and the demands of the emerging global environment. This work explores in detail the exigencies of global issues as they influence STEM education with specific attention given to 21st century skills, impact of technology, mathematics competencies, climate change, global competencies, and equity, diversity and inclusiveness. The article canvases for novel approaches to preparing STEM teachers who are skilled and knowledgeable practitioners, culturally aware, know about world events and global dynamics, literate for the 21st century, collaborative team members, effective users of technology and media, and responsible and ethical citizens. Recommendations on the knowledge, skills and attitudes that STEM teacher preparation should project were also given.
Keywords: STEM education, teacher preparation, emerging global environment, pre-service STEM teachers

Introduction

Education is a conscious effort of society to inculcate its existing body of knowledge, values, norms, science and technology into the young generation for the purpose of active participation in society. To achieve this purpose, the society engages the services of educational institutions where children are taken through well-planned structures. Thus, one of the most urgent aims of education is to facilitate social and economic development and expose learners to the scientific and analytical thinking skills they need to understand global issues, build a sustainable world and innovate new

technologies (Iji, Abah & Anyor, 2017). Present-day education that is desirable is one that builds global competence.

The term global competence is used to describe a body of knowledge about world regions, cultures and global issues and the skills and dispositions to engage responsibly and effectively in a global environment (Longview Foundation, 2008). A globally competent student has knowledge of and curiosity about the world's history, geography, cultures, environmental and economic systems and current international issues. Such a student has language and cross-cultural skills to communicate effectively with people from other countries, understand multiple perspectives and use primary sources from around the globe. A globally competent student has a commitment to ethical citizenship.

Obviously, to help students become globally competent, teachers must have the knowledge, skills and dispositions that are first expected of the students. In addition to these capacities, globally competent teachers must have knowledge of the international dimensions of their subject matter and a range of global issues; pedagogical skills to teach their students to analyze primary sources from around the world, appreciate multiple points of view and recognize stereotyping; and a commitment to assisting students to become responsible citizens of the world and of their own communities (Longview Foundation, 2008)

Present levels of digital penetration are evolving as technology advances and making access to and use of Information and Communication Technologies (ICTs) an essential element for the participation in society, democracy and economy. Also, digital equity is the ultimate outcome of ongoing effort towards digital inclusion, with focused action and investments to eliminate historical, systematic and structural barriers that perpetuate disadvantaged individuals and communities. Globalization through digital equity recognizes the moral obligation to harness ICT to address the needs of disadvantaged individuals, communities, neighborhoods, community-based organizations and small businesses (Iji & Abah, 2019).

It follows that training teachers for the global age also requires that teacher educators, who are preparing future teachers in higher educational institutions, need to develop the capacities noted above as well as the knowledge, skills and dispositions to help teacher candidates acquire them (Longview Foundation, 2008). For Science, Technology, Engineering and Mathematics (STEM) teacher educators, these capacities entail knowledge that has been thought of as a kind of meta-knowledge that includes at least some of the knowledge that STEM teachers require, just as teachers of science, technology, engineering and mathematics need to know more than the knowledge that teachers require to help students learn the various STEM subjects (Beswick & Goos, 2018).

Requisite knowledge for STEM teachers will entail a sound grasp of sustainability issues. Sustainability should be understood by STEM teachers as a search and a negotiation within society rather than a tangible goal. The same applies to sustainability education. In academic discourses, maintaining the complexity of sustainability issues and different perspectives is stressed for educational and democratic reasons (Holfelder, 2022). Integrating different perspectives and values is considered necessary. This position is related to teaching methods that make various perspectives of Education for Sustainable Development (ESD) evident and allow students to discuss and reflect on them, particularly with respect to present-day development in digital technology.

The abundant use of digital technology does not only raise the need for skills that complement what computers do, but it also influences what science, technology engineering and mathematics are or will become relevant in our society (Gravemeijer et al., 2017). Preparing STEM teachers that can deliver the change that we are witnessing and that can suit the needs of the future require a concerted effort by all stakeholders in the STEM education ecosystem. This present work takes a holistic view of the challenges of the emerging global environment and the necessary adjustments that can be brought into STEM teacher preparation schemes across different levels. The presentation begins with an overview of STEM education, then a consideration of pre-service STEM teachers in the emerging global environment and followed by the expectation of the curriculum for pre-service teachers. The work also explored the required capacity building needed for current STEM teachers.

The Concept of STEM Teacher Education

STEM education is a conglomerate of different fields of study concerned with the tools, methods and approaches that facilitate the practice of teaching and learning of science, technology, engineering and mathematics. STEM education, particularly at the higher education level, prepares students for quantitative and symbolic reasoning and advanced mathematical skills through general education, services, undergraduate and post graduate programmes. Iji and Abah (2017) opine that STEM education basically prepares students to become innovative STEM instructors, professionally prepared to communicate STEM subjects to learners at all levels.

With focus on teacher education, STEM education considers the design, implementation and effects of curriculum and instructional interventions, and contemporary developments in learning theories and technology as they pertain to the teaching and learning of science, technology, engineering and mathematics as school subjects. Mathematics educators see mathematics not simply as a body of knowledge or an academic discipline but also as a field of practice. Mathematics teacher education is concerned with how mathematics is learned, understood and used. It looks beyond applications to ways in which people think about mathematics, how they use it in their daily lives and how learners can be brought to connect the mathematics they see in school with the mathematics in the world around them (Abakpa, Agbo-Egwu & Abah, 2017).

The general objective of education and training, according to the National Universities Commission – NUC (2022), needs to be in consonance with the realization of national needs and aspirations vis-à-vis personal and national development. The graduates of teacher education programme will therefore be resourceful, creative, and knowledgeable being able to demonstrate leadership qualities as prospective teachers; exhibit the knowledge, skills and attitudes which will enable them to contribute to the growth and development of their communities and their nation in general; and exhibit sound mastery of their subject areas and the ability to impart such knowledge to their students. Such graduates will professionally show mastery of problem-solving skills; be highly motivated, conscientious and efficient classroom teachers for all levels of the educational system; and fit into the social life of the community and society at large and enhance their commitment to national objectives. Additionally, they will internalize the intellectual and professional background, adequate for their alignment and to make them adaptable to any changing situation not only in the life of their country but in the wide world; demonstrate the spirit of enquiry, creativity and entrepreneurship;

enhance commitment to the teaching profession; and apply their skills in the use of new technologies (NUC, 2022).

The general skill set in any given teacher education effort will then include competencies in computer literacy, quantitative skills, communication skills, interpersonal skills, organization skills, information technology skills and entrepreneurship skills. Education-related cognitive abilities and skills required will emerge. These include ability to recognize and analyze educational problems and evolve strategies for their solutions; ability to recognize and implement good educational policies; computational and data processing skills relating to education, financial and manpower data; and ability to demonstrate knowledge and understanding of essential facts, concepts and principles and apply theories to education (NUC, 2022).

The expected behavioral attributes of graduates of teacher education programmes will include understanding the socio-cultural environment in which they find themselves and how such environment conditions behaviour; being able to understand, explain, predict and influence human behaviour in work organizations; relating the knowledge of human behaviour to the ethics of their relevant professions; and understanding the relationship between culture and behaviour and why a unimodal system of behaviour may not work (NUC, 2022).

Consequently, coming down to the specific field of Mathematics Education, the National Universities Commission – NUC (2022) underscores that the Mathematics Education programme is developed on the fundamental assumption that pre-service mathematics teachers would acquire profound mathematics knowledge and competent teaching skills that will equip them to face the challenges of teaching in schools, be self-reliant, contribute to national development and meet the demands of the global world. In particular, the objectives of the mathematics education programme will develop graduates who are well equipped with the knowledge and competent skills for teaching mathematics at the lower, middle and upper basic education levels; competent and effective mathematics teachers who are skilled in instructional designs, delivery and classroom management as well as in dealing with human learners; graduates with necessary skills, competencies, intellectual and moral training for a career in mathematics education; and mathematics education graduates' capacity to assume responsible and leadership roles in ministries of education, government educational agencies and private education establishments (NUC, 2022).

From the foregoing, it can be seen that within the demands of the present era, both STEM education system and process need to be amenable. This calls for a fundamental transformation of education in terms of its contents, methods and outcomes. STEM teacher preparation must seek to inculcate skills that are aimed at accelerating technological change rapidly accumulating the desired knowledge, increasing global competition and raising workforce capabilities. STEM teachers will be trained to equip students who will ultimately spend their adult lives in a multitasking, multifaceted, technology-driven and vibrant world. The reality on ground has made it imperative for the education system to be more strategic, aggressive and effective in preparing students to succeed and prosper (Abah, Iji, Abakpa & Anyagh, 2021). Educational institutions all over the world need to rethink what, but more importantly, how and where students learn. The goal of STEM teacher education will be to foster pre-service teachers' use of modern technology to solve problems and communicate their thinking and answers as they gain awareness of the capabilities and limitations of technological instruments.

STEM teachers today face the challenge of carrying out teaching that allows STEM education to respond to the challenges of the 21st century. Presently, science, technology and mathematics are characterized by teaching centered on the resolution of decontextualized exercises, leading to a lowered scientific, technological and mathematical competency (Vasquez, Pineiro & Garcia-Alonso, 2022). The expectation for STEM teacher preparation, therefore, is to train teachers who will provide students with tools that enable them to understand the role of STEM in the world, in solving real problems from local and global contexts. In this sense, STEM competence can be seen as an individual's ability to identify and understand the role that STEM plays in the world, to make informed judgments and to be able to use and engage with science, technology, engineering and mathematics.

The imperative for educators involved in STEM teacher preparation is to re-work practices with the focus of supporting pre-service mathematics teachers by providing them with opportunities to realize for themselves the changes necessary for teaching the various subjects for sustainable futures. Helliwell and Ng (2022) describe sustainable futures as practices aimed at meeting the needs of the present without compromising the ability of future generations to meet their own needs. STEM teachers as the principal stakeholders in the implementation of all STEM-based curriculums can thus deliver incremental changes that will prepare students for applying science, technology, engineering and mathematics in all sorts of work-life and everyday life situations.

Pre-Service STEM Teachers and the Emerging Global Environment

The world of the 21st century has changed at an exponential rate, challenging all traditional norms and approaches. Technology has been transforming human life in one way or the other for thousands of years, but in the present computer age, the pace of technological change has been very rapid, altering schooling, work and social lives in ways that have significant consequences for all people. Rapid advances in Information and Communications Technology (ICT) and expanding connectivity to the internet have made today's world increasingly complex, interconnected and knowledge driven. In rethinking education to cope with these changes in the 21st century, innovation in teacher education is indispensable. Failure to innovate implies repeating yesterday's educational programmes and strategies tomorrow. The society which education is meant to sustain is becoming transformed by trends such as automation, globalization and networking, with attendant influence on workplace culture and personal responsibility (Abah *et al.*, 2021).

Presently, economic, social and technological transformations are linking the global environment in unprecedented ways. Today's students will need extensive knowledge of the world and the skills and dispositions to engage with people from many cultures and countries. They will need these to be responsible citizens and effective participants in the global marketplace of the 21st century (Longview Foundation, 2008). Few STEM teachers today are well prepared to educate in this new global context.

Students today are graduating into a world that is interconnected as never before. All the challenges of the emerging global environment, whether in health, environment, poverty or peace and security, require cooperation across borders and boundaries. As Longview Foundation (2008) noted, employees in business, government, community and non-profit organizations who are hiring today's graduates recognize that it is

foolhardy, if not impossible, to work in isolation from the rest of the world. The education system needs to be preparing young people for this new reality. The required system should ensure that students will develop the knowledge of world regions and global issues, languages and cross-cultural skills and values of citizenship and collaboration that are so important to living and working in an increasingly interdependent world. Individual teachers, schools and isolated higher-education programmes have long provided high-quality instruction and a global education to some students. But more needs to be done at a systematic or policy level to ensure that all students in all communities who graduate from school are globally competent.

Though few institutions have created comprehensive internationalization programmes, more are exploring new ways to bring international elements to courses, activities and even requirements. In terms of requirements, the ongoing curriculum review by the National Universities Commission (NUC) in Nigeria is predicated on the need to prepare students at Nigerian Universities for the challenges of the emerging global environment (NUC, 2002). Visionary teacher educators and teacher education professional bodies have begun to recognize that the earlier teachers learn to infuse global knowledge and perspectives into their teaching, the more comfortable and skilled they will become at making this a natural and essential part of their teaching practice.

So, what does STEM teacher preparation for the emerging global environment entail? The Longview Foundation (2008) provides a highly recommended framework for internationalizing teacher preparation, detailing four (4) key components. Firstly, they detail revising teacher preparation programmes to ensure that general education coursework helps each prospective teacher develop deep knowledge of at least one world region, culture, or global issue and facility in one language in addition to English; professional education courses teach pedagogical skills to enable future teachers to teach the global dimensions of their subject matter; and field experiences support the development of pre-service teacher's global perspectives. The second component entails facilitating at least one in-depth cross-cultural experience for every pre-service teacher through promoting study or student teaching in another country, or service-learning or student teaching in a multicultural community within the country; financial support for such experiences; and appropriate orientation, supervision and debriefing to tie these experiences to prospective teacher's emerging teaching practice. The third dimension alludes to modernizing and expanding programme for prospective world language teachers by preparing more teachers to teach less commonly taught languages; updating language education pedagogy based on current research and best practice; and updating language education pedagogy based on current research and best practice. The fourth key component involves creating formative and summative assessments to evaluate the effectiveness of new strategies in developing the global competence of perspective teachers (Longview Foundation, 2008).

In considering mathematics teacher preparation, as a case, for the emerging global environment, arguments from critical mathematics education must be taken seriously. Critical mathematics education has focused on questions of social justice and environmental sustainability, such as the threat of climate change. The planet faces an array of complex, challenging environmental problems, including mass extinctions, pollution, habitat loss, and climate change. Mathematics plays a key role, both in understanding such problems and in making possible the technologies that contribute to them. Critical mathematics education, in combination with a perspective on complex environmental problems called post-normal science, offers a valuable framework with

which to think about the role of mathematics and of mathematics education in response to these problems (Barwell & Hauge, 2021). Mathematics educators are expected to prepare teachers to educate future citizens to participate in the democratic debates these problems will engender.

Hauge, Karcerja, Lilland and Steffensen (2024) used critical mathematics education analytic framework, particularly within ethics and concepts of harm, to demonstrate results which show that discussing and working with socio-political issues in mathematics classrooms evoke teachers' ethical awareness. The outcomes indicate that teachers weigh the importance of working with these harmful issues, where mathematics has different roles, against showing care for the students, as such issues are sensitive for some students. Some teachers express insecurity in facing ethical challenges, which suggests that ethics and techniques to handle challenging situations need to be addressed in teacher education in mathematics. This empirical study further shows results that offer relevant insight and perspectives useful for developing teaching and learning mathematics related to socio-political global issues. Connecting ethical awareness, democracy and critical thinking to mathematics is an essential area of critical mathematics education as its main concerns include letting students get acquainted with critical aspects of mathematics in society and to open possibilities for all students to get involved (Hauge *et al*., 2024).

The Curriculum for Pre-Service STEM Teachers in the Emerging Global Environment

Curriculum is the totality of student experiences that occur in the educational process. Curriculum refers specifically to a planned sequence of instruction through which educational institutions seek to translate societal values into concrete reality (Abah, 2020). Any form of change envisaged for the successful preparation of pre-service STEM teachers in the emerging global environment will therefore need to begin with adjustments to the STEM teacher preparation curriculum in the universities and colleges. STEM teachers need to be prepared for exploring the current and emerging possibilities in terms of content and technology. They need to develop a professional attitude of evaluation and reflection about tools for teaching – a thoughtful visioning that investigates and considers the impact of tools for teaching science, technology, engineering and mathematics (Niess, 2006).

The Curricula of STEM subjects needs to be amenable. The context of the current school STEM curricula is one whose causal relationship with national assessments is indicative of a nostalgia for days of certainty (as opposed to the uncertainty that now characterizes the world) that exacerbates an already prescriptive, linear progression of STEM concepts and techniques (Helliwell & Ng, 2022). STEM educators are now interested in how to innovate STEM education curricula by providing pre-service teachers with opportunities to question the assumptions that are embedded within school science, technology, engineering and mathematics curricula and to support them in developing practices they view as consistent with sustainable futures. On this basis, students at the basic and secondary education levels can also experience the world in classes that are now intuitively global. Consequently, mathematics teachers can use global data for problem solving, or art and architectural designs from various cultures in the study of geometry and algebra as demonstrated by Abah (2017). As with science, students can learn about the worldwide origins of mathematics and the contributions of many cultures to the development of the field as we know it today (for instance, see

Abah, Iji, Abakpa & Anyagh, 2021). The curriculum of pre-service mathematics teacher preparation will therefore include courses in ethnomathematics and will encourage teaching mathematics in diverse cultures with attendant study tours of indigenous artifacts and institutions in various nations (Longview Foundation, 2008). These kinds of activities are part of what is needed to bring a global perspective to mathematics.

With the advocated curricular considerations, one may ask, if, perhaps, students need to be able to understand phenomena such as growth and decay, spread of disease, and population growth; will they need to understand exponential functions sooner than they would in a typical secondary school mathematics sequence? Or, if it is important for students to study trends and patterns in large populations, does this imply that some understanding of inferential statistics needs to be an integral part of the secondary school mathematics sequence? These kinds of contemplations should permeate the consideration of mathematic curriculum in the emerging global environment. Similar questions can be thought up in the other fields of STEM.

Barwell and Hauge (2021) identify three principles that they provide to inform discussion about bringing climate change into mathematics teaching. The principles, organized into three groups are: forms of authenticity, forms of participation, and reflecting on and with mathematics. Forms of authenticity emphasize that it is important for students to engage with climate change authentically, so that they understand its concrete impact in their own current or future lives. In the mathematics classroom, students will need to be able to use problems about climate change that students find relevant in their lives, as exemplified in local climate concerns and issues such as flooding, local biodiversity, or commercial interests. Students will then be able to work with real data as much as possible. Since mathematics is a human activity, students' own ideas and values will have a central role, and investigating topics like climate change will enable students to understand the nature and effect of human mathematizing. They can consider what important aspects of their climate-based problem are difficult to mathematize, such as psychological or aesthetic impacts. In authenticating climate knowledge for students, students will be provided with the opportunity to engage in meaningful debate relating to climate change, based on their mathematical investigations.

On the principle of forms of participation, Barwell and Hauge (2021) suggest that students need to be exposed to the communication of mathematical ideas and the use of mathematics in debate and deliberations. These principles relate to aspects of critical mathematics education that emphasize the importance of dialogue in the development of critical awareness. Students are required to actively participate first in mathematics, next in their classrooms and then in their communities. Investigating climate change is not simply an interesting context for learning mathematics; the result of student's works can inform many aspects of school life and that of the surrounding community, in relation to energy consumption, traffic patterns or local political action (Barwell & Hauge, 2021). All these will drive students to actively participate in public debate about climate change.

In terms of reflecting on and with mathematics, Barwell and Hauge (2021) opine that students have opportunities to reflect on how mathematics is useful. By working on authentic task and engaging in various forms of participation, students will have opportunities to reflect on the limits of mathematics as observable in the inability of mathematics to model emotions such as what it feels like when your house is flooded. Students will then consider the role of values in mathematics, in shaping their choice of project, their choice of data and their interpretation of their findings. As an example, in

a project on climate impacts on farms, some students might be motivated by economic considerations, such as loss of income for farmers, while others might be motivated by a concern for biodiversity. The final reflection principle is that students will have opportunities to reflect on uncertainty and consider different ways to deal with it. Through their authentic activities, students are likely to encounter various kinds of uncertainty, including an inherent level of imprecision in their data, the absence of some kinds of data, and the possibility of unrecognized factors influencing a situation.

Using mathematics as a fulcrum of STEM to conceptualize what curriculum of STEM education may prepare students for the society of the future, Gravemeijer *et al.* (2017) primarily look at the use of mathematics with an eye on employability, as this is where there is the biggest impact of the digitalization of the modern society. As mathematics at the workplace differs significantly from school mathematics, Gravemeijer and colleagues chart the characteristics of mathematics at the workplace, to get an image of what mathematical activity the students will need preparation. Such characteristics include the informal nature of workplace mathematics; the meaning of context in the workplace; workplace tools, practices, and discourse; and change over time. If it is acknowledged that one of the goals of mathematics education is to prepare students for life and work, then these characteristics of the workplace will have to be considered in mathematics education curriculum design. The curriculum should reflect calls for modeling and applications and for the use of authentic problem situations in education. This dimension for integrating such aspects into teaching formed the basis for Lopes (2024) characterization of the manifestation of critical mathematics consciousness (CMC) in the modelling process and the relationships that are established between mathematical modelling as a teaching methodology and the development of critical consciousness.

The science, technology, engineering and mathematics learned in school will allow for flexible use and adaptation. When considering STEM education for the future, beyond anticipating workplace characteristics, teacher preparation programmes require analyzing what is involved in doing science and mathematics in the real world. Broadly, this entails recognizing where mathematics is applicable, translating practical problems into mathematical problems, solving the mathematical problem, and interpreting and evaluating the outcomes. Prioritizing checking calculations over executing standards procedure (which are now carried out by computers) has significant consequences for the content and structure of the curriculum.

Gravemeijer *et al.* (2017) offer three categories for discussing what mathematical competencies are required for the digital society: applying/modeling, understanding, and checking. The motivation for creating and interpreting models in the workplace is to mathematize a realistic situation for the purpose of answering a practical question, not to learn a mathematical idea. In connection to the transition from reality to mathematics, the curriculum needs to model and seek to inculcate capabilities such as decoding and interpreting information, structuring and conceptualizing the problem situation, making inferences and assumptions, and formulating a model. Adopting modeling and applying as goals therefore has implications for the character of the mathematics being taught. While teaching mathematics at the school level, teachers with a conceptual orientation strive for conceptual coherence and focus on supporting students in coming to grips with the role and meaning of the numerical values in the situation and how this translates in numerical operations. Gravemeijer *et al.* (2017) note that the implication is that a conceptual orientation to mathematics is more conducive to understanding mathematical modeling.

With the modern workplace becoming highly automated, employees at many levels must understand what is going on to be able to communicate with both colleagues and customers. STEM Curricula efforts will acknowledge the notion of techno-mathematical literacies that generally points to the need for understanding the hidden, idiosyncratic mathematics that is shaped by tools and the practices developed by others. These literacies consist of a combination of mathematical knowledge and contextual knowledge, making it self-evident that understanding the underlying concepts will be more useful than mastery of rigid procedures (Gravemeijer *et al.*, 2017). This creates room for working on the conceptual mathematical understanding that is needed to grasp the mathematics that is hidden in the digital tools that are abundant in our technological society.

Some studies have provided concrete suggestions and examples of possible curriculum adaptations that can make the argument for a globally responsive STEM education more tangible. Steffensen (2024) focused on how pre-service teachers used important societal issues to engage school students in developing responsible citizenship. Theoretical perspectives from critical mathematics education were used to investigate the experience of a group of pre-service teachers during their practicum with seventh grade students. These teachers used the refugee crisis to raise the students' awareness and enable them to become critical, responsible citizens. Three situations from their practicum were used to discuss how responsible citizenship developed within an integrated STEM curriculum approach. In the first situation, involving boat refugees, students estimated the number of refugees in a boat. In the second situation, involving refugees in Europe, students used technology to identify and process relevant information. In the third situation, involving refugees worldwide, students interpreted information in statistically empathetic ways to develop an informed understanding of the refugee crisis as responsible citizens. The results from Steffensen (2024) indicate that integrated STEM curriculum approaches could include challenging societal issues emphasizing their ethical, social, and cultural aspects to foster responsible citizenship. Similar efforts by Creel and Paz (2018) demonstrated how sustainability issues could be addressed within Accounting, with faculties helping students learn not only accounting but how to be better citizens with a global perspective on sustainability.

Capacity Building for Current STEM Teachers in the Emerging Global Environment

It has been established that STEM teachers of the current and future era require a commensurate level of global competence and mathematical competence that can prepare students for the emerging global environment. Approaching STEM education from this learner-centered perspective will not only allow the development of these competencies but will also provide the necessary scaffolding to form change-agents citizens with whom to achieve progress towards a sustainable world of sustainable, democratic lifestyles and well-being for all (Vasquez, Pineiro & Garcia-Alonso, 2022). This scenario demands that STEM teachers promote their professional competencies and that these competencies enable them to develop in their students what is expected by today's societies.

In this context, a teacher's professional knowledge becomes a central element in what is understood as the STEM teacher competence. In addition to developing knowledge linked to science, technology, engineering and mathematics as teaching

objects, today's societies advocate focusing teaching on the development of key competences for sustainability which by their nature, involve problem-solving that addresses diverse issues. Citing UNESCO 2015, Vasquez, Pineiro and Garcia-Alonso (2022) identify eight key competences and skills that teachers need to develop and implement in educational settings with their students in order to move towards a sustainable world:

Systems Thinking Competence: recognizing and understanding relationships, analyzing complex systems; thinking about how systems are integrated across domains and scales; and dealing with uncertainty.

Anticipatory Competence: Understanding and evaluating multiple future scenarios, creating one's own versions of the future, applying the precautionary principles, assessing the consequences of actions; and dealing with risks and changes.

Normative Competence: Understanding and reflecting on the norms and values that underlie our actions; and negotiating sustainability values, principles, objectives, and goals in a context of conflicting interests and trade-offs, uncertain knowledge, and contradictions.

Strategic Competence: Collectively develop and implement innovative actions that promote sustainability at the local level and beyond.

Collaborative Competence: To Learn from others; to understand and respect the needs, perspectives, and actions of others (empathy), to understand, identify with, and be sensitive to others (empathetic leadership); to deal with conflict in groups; and to facilitate collaborative and participatory problem solving.

Critical Thinking competences questioning norms, practices, and opinions; reflecting on one's own values, perceptions, and actions; and taking a stand in the sustainability discourse.

Self-Awareness Competence: reflecting on one's role in the local community and in (global) society; constantly assessing and driving one's own actions; and dealing with personal feelings and desires.

Integrated Problem-Solving Competence: apply different problem-solving frameworks to complex sustainability problems and devise equitable solution options that promote sustainable development, integrating the above competences.

These capacities in Education for Sustainable Development (ESD) aim to develop sustainability – literate learners, who are empowered to make conscious decisions and act responsibly for environmental integrity, economic viability and a fair society for present and future generations. To advance ESD capacity building, it is essential to make ESD - literate STEM teachers so that they value and pay attention to its incorporation in the school context. The aim is for STEM teachers to contribute to the transition to a sustainable society by being able to promote their student's constructive and responsible participation in the world they live in (Vasquez, Pineiro & Garcia-Alonso, 2022).

A vision for implementing lesson processes that improve STEM instruction is possible through reflective practice. Neiss (2006) observes that for the pre-service programmes, though, much more research needs to clarify essential conditions for the development of technology pedagogical content knowledge (TPCK) through content courses, methods courses, assessment courses, and pedagogy courses as well as in student teaching. STEM teacher preparation programmes need to focus on strengthening the pre-service teacher's knowledge of how to incorporate technology to facilitate student learning of STEM subjects through experiences that allow teacher candidates to explore and learn STEM using technology in ways that build confidence

and understanding of the technology and subjects; model appropriate uses of a variety of established and new applications of technology as tools to develop a deep understanding of STEM in varied contexts; help teacher candidates make informed decisions about appropriate and effective uses of technology in the teaching and learning of STEM; and provide opportunities for teacher candidates to develop and practice teaching lessons that take advantage of the ability of technology to enrich and enhance the learning of STEM (Neiss, 2006).

Many resources are available within higher education that can be harnessed to internationalize STEM teacher preparation. In the context of the emerging global environment, internationalization has been identified as the process of infusing an international or intercultural dimension into the teaching, learning, research, and service functions of higher education (Longview Foundation, 2008). This requires many different institutional strategies and multiple leaders. Efforts to develop new or scale up existing activities in pre-service education programmes can benefit when they are linked to other sector-wide efforts, championed by regulatory educational agencies and professional educational associations. Longview Foundation (2008) provides an overview of strategies to prepare globally competent STEM teachers which include:

Engage Leadership and Faculty and Develop a Plan: Deans and heads of educational units/directorates can provide access to resources, amplify messages, and create a climate that supports the preparation of globally competent teachers. Faculties need to discuss what "Global" or "International" means in their teacher education programmes and agree on what they expect as an end product. Then they can build assessments and teaching/learning experiences to meet those goals. Ensuring systemic change that will result in an international education for all pre-service teachers requires vision and a plan within a school, college or department of education. Developing a plan maximizes resources and helps ensure that activities are coordinated and sustainable.

Create a Globally Oriented General Education Programme: Preparing those who will educate the next generation about the world is a vital task that will be shared by all who instruct future teachers. The recent opportunity (in Nigeria) with the 30% institution-based course contents in the NUC's Common Core Minimum Academic Standards (CCMAS) should have been a gateway to bring in the tenets of global competences into Nigeria's STEM teacher preparation programmes. Time will tell if faculties of education across the country peeped into the future in this vital curriculum development exercise

Recruit Students with International Interests and Experiences into Teaching: Increasing numbers of students come to today's teacher preparation programmes with experience of the world and enthusiasm to learn more. Migration and international exchanges bring students from around the world into previously homogenous communities and classrooms. Popular culture is drawing on international influences, celebrities are becoming involved in global causes, and students from immigrant families are entering higher education in greater numbers than ever before. Admissions officers and other advisors play a key role in helping students with these interests and experiences consider a teaching career.

Faculty Development for Global Teaching and Learning: Once pre-service teachers begin taking professional education courses at their institutions, learning from faculty members who bring global expertise to their own teaching is key. Investing in faculty increases the long-term impact and sustainability of any new strategy. Building a globally oriented faculty requires a multi-pronged approach.

Internationalize Professional Education Courses: An important goal of any faculty development activities describes so far is to ensure that the coursework for all pre-service teachers includes a global perspective, either by integrating such content into existing courses required for graduation, or by creating one or more required courses that provide an overview of key global issues. Weaving International knowledge and skills into individual education courses, especially those that are required of all candidates, provides opportunities to address pedagogical issues related to teaching global knowledge, skills, and dispositions as well as to teach international content.

Offer International Experiences at Home, Abroad, and Online: Interacting first -hand with people from another country or culture is an invaluable component of a good global education. Limited time and resources have traditionally prevented teacher candidates from taking advantage of studying abroad, but this is beginning to change as the value of such experiences becomes increasingly evident. STEM Education programmes require us to explore innovative ways to ensure that their students have international experiences during their teacher preparation.

For developing countries across Africa, the ideals of capacity building put forward so far for preparing pre-service STEM teachers in the emerging global environment may be too lofty to follow, given the institutional and funding challenges that are prevalent. The opportunities for faculties to experience global competences first-hand via international collaborations across implementing institutions are scarce. Except if the funding model for higher education is updated in line with present realities, the inherent challenges will remain.

Propositions for capacity building for current STEM teachers in the emerging global environment can take into consideration the following salient arguments raised by Gravemeijer *et al.* (2017):

21st century skills will be adopted as goals of STEM education for the future, while considering that specific attention will have to be given to STEM as it is being influenced by data science, automation and digitalization.

Preparing students for mathematics in the workplace is one of the goals of mathematics education. Issues that are at play here concern the use of tasks that resemble authentic workplace problems, mathematics that is taught to be useful, and balancing canonical and non-canonical forms of mathematics.

21st Century digitalization of society requires a focus on mathematical competences that complement the work of computers. This points to modeling and applications as goals for mathematics education. This overlaps with the previous point, with a note that apart from gaining experience with authentic like problems, partial skills may also become the focus of attention.

An important element of competencies that complement the work of computers concerns understanding the mathematics underlying the mathematical work computers take over. What is needed here is a conceptual understanding on a generic level; students will come to grips with the key ideas underlying the relevant mathematics. This begs the question of how to attain such understanding. More specifically, how much, and which routine skills are needed to reach more sophisticated goals? And how can tailor-made software applications facilitate this process?

Choosing for 21st Century skills and high-level conceptual understanding requires a significant effort in teacher professionalization, STEM curricula design, and test design.

General education must lay the foundation for a wide variety of levels and types of work. Foundational education will note that digitalization especially affects jobs at the middle and the bottom of the labour market and to make sure that students that may leave school at an early age get a sound preparation. Further education may take care of specialization but more importantly, the world of work changes so fast that specific skills may lose their significance.

Where there is a large overlap between preparation for work or for everyday life, the latter will of course get special attention. Important goals here are self-reliance and self-confidence when dealing with science, technology, engineering and mathematics in everyday life and active citizenship. In relation to this, the 21st century skill of critical thinking is of utmost importance.

All attention for mathematics that has practical relevance outside school should not marginalize the importance of preparation for further education, or the value of mathematics as part of our cultural inheritance.

Recognizing individuality among students and the relationship between student's participation in the practices of STEM classrooms and of their communities are necessary for effective capacity building of current STEM teachers. STEM teachers are to be retrained on the need to be open-minded on issues of race/ethnicity, gender, socio-economic status and cultural diversity (Katwibun, 2013). This understanding will bring current STEM teachers to respect and appreciate cultural differences among their students, being consciously aware of students' expectations, attitudes and beliefs, within the ambit of cultural sustainability in education.

Ongoing research deliberations on cultural sustainability (CS) in education uses a three-role approach to defining CS by viewing culture as, in and for sustainable development (Laine, 2016). The "culture as sustainable development" approach defines culture as the basis or core of sustainability, an approach which generates sustainability. Culture is utilized in finding a new understanding of the human place in the world and highlighting one's human role as a potential initiator of change. Within this framework, change towards a culturally sustainable way of living is achieved through familiar educational themes with various titles relating to STEM education. The "culture for sustainable development" approach sees culture as the "glue" which combines ecological, social and economic pillars. The approach views culture as having a separate, independent role as part of sustainable development. This approach is appealing from the point of view of educational sciences and education as practice, because it highlights such themes as multiculturality, cultural rights, local culture and cultural identity, and other themes that are strongly present in core curricula (Laine, 2016).

Conclusions

This work has extensively argued for new dimensions in preparing pre-service STEM teachers in an emerging global environment. Emphasis has been laid on the need for the pre-service STEM teacher to have a deep understanding of science, technology, engineering and mathematics contents and successfully engage students through a demonstrated passion for STEM by connecting it with their lives. Such pre-service STEM teachers continue to be intellectually curious and demonstrate the habits of minds that lead to lifelong learning about their craft, their students, and their STEM content. Pre-service STEM teachers of the emerging global environment will need to have the capacity to integrate international contents, issues, and perspectives into their

implementation of the STEM curricula. The use of inquiry-based model of teaching has been underscored to enable learners to actively manipulate ideas in order to construct knowledge, solve problems and develop their own understanding of science, technology, engineering and mathematics. Teaching approaches suitable for the emerging global environment will ask students to analyze and reflect on their own learning and will deploy multiple forms of assessment to evaluate ongoing student learning.

As proficient thinkers and problem solvers, pre-service STEM teachers understand and engage complex problems; collect, analyze, and synthesize information from a range of sources; tolerate ambiguity and uncertainty; and produce potentially viable solutions as they deal with student learning. Thoroughly bred pre-service STEM teachers are to use problem solving skills to recognize and act on the needs of individual students, colleagues, and the school community. They ask reflective questions about their practice, use new strategies to reach every student, and find resources to maximize student learning. They advise students and advocate on their behalf to support their success and to help them overcome their challenges. STEM teachers in the emerging global environment are professionals who recognize, value, and respect the broad spectrum of ethnicities and cultures in the school environment, and teach students to collaborate effectively with individuals from different backgrounds. Such teachers use instructional strategies to understand the contributions of different cultures and recognize and draw upon the diverse cultural assets within their classrooms. They also recognize the levels of students' literacy in academic and social language and help them build meaningful bridges between the two.

STEM teachers that are prepared for the current and future age of globalization are effective users of technology and media. They are proficient in the use of essential computer and communication technologies. They can evaluate, critically choose, and use various forms of media and technology in lesson design and implementation to maximize student engagement. Similarly, pre-service STEM teachers that are prepared for the emerging global environment use technology to communicate and work across national and regional boundaries. These teachers understand and stay current on world events, international issues, and global debates, and help students gain understanding through daily interactions. They connect STEM contents to authentic global issues and perspectives. In their classroom practice, prepared STEM teachers present balanced viewpoints on global issues and assist students in viewing issues from multiple perspectives.

References

Abah, J. A. (2017). Viewing basic math through the lens of history: Undergraduates' reflective learning in a history-augmented mathematics classroom. *Waikato Journal of Education, 22*(4), 33-48. doi:10.15663/wje.v22i4.557. http://www.wje.org.nz/index.php/WJE/article/view/557

Abah, J. A. (2020). *Teaching computational thinking*. Makurdi, NIGERIA: Network for Grassroots Science and Mathematics Education (NGSME), 228-244. https://doi.org/10.5281/zenodo.4734343

Abakpa, B. O., Agbo-Egwu, A. O. & Abah, J. A. (2017). Emphasizing phenomenology as a research paradigm for interpreting growth and development in mathematics education. *ABACUS: The Journal of the Mathematical Association of Nigeria, 42*(1), 391-405. Doi: 10.17605/OSF.IO/SGBZT

Barwell, R. & Hauge, K. H. (2021). A critical mathematics education for climate change: A post-normal approach. In A. Anderson & R. Barwell (Eds.), *Applying critical mathematics education*, 166-184. Brill. doi: 10.1163/9789004465800_008 https://brill.com/downloadpdf/book/9789004465800/BP000016.pdf

Beswick, K. & Goss, M. (2018). Mathematics teacher educator knowledge: What do we know and where to from here? *Journal of Mathematics Teacher Education, 21,* 417-427.

Creel, T. & Paz, V. (2018). Teaching sustainability in an accounting classroom. *Discourse and Communication for Sustainable Education,* 9(1), 79-85. doi: 10.2478/dcse-2018-0006

Hauge, K. H., Karcerja, S., Lilland, I. E., & Steffensen, L. (2024). Layers of ethical awareness: Mathematics teachers' concerns on including socio-political issues. In P. Ernest (Ed.), *Ethics and Mathematics Education*, Advances in Mathematics Education (pp.415-439). https://doi.org/10.1007/978-3-031-58683-5_20

Helliwell, T. & Ng, O-L. (2022). Imagining possibilities: Innovating mathematics (teacher) education for sustainable futures. *Research in Mathematics Education, 24*(2), 128-149. doi: 10.1080/14794802.2022.2079553

Holfeder, A-K. (2022). Teaching sustainability: A study of teachers and conceptual tension. *Discourse and Communication for Sustainable Education, 13*(1), 77-87. doi: 10.2478/dcse-2022-0007

Iji, C. O. & Abah, J. A. (2017). Exploring gender differences in graduation proficiency in mathematics education using a Markov Chain Model: Implications for economic growth in Nigeria. *International Journal of Educational Excellence, 3*(2),75-86. doi: 10.18562/IJEE.028. http://www.anagmendez.net/cupey/pdf/ijee_onwu_abah_3_2_75_86.pdf

Iji, C. O. & Abah, J. A. (2019). Internet skills as a measure of digital inclusion among mathematics education students: Implications for sustainable human capital development in Nigeria. *International Journal of Education and Knowledge Management (IJEKM) 2*(1),1-16. https://rpajournals.com/wp-content/uploads/2019/02/IJEKM-01-2019-06.pdf

Iji, C.O., Abah, J. A. & Anyor, J.W. (2017). Impact of cloud services on students' attitude towards mathematics education in public universities in Benue State, Nigeria. *International Journal of Research in Education and Science (IJRES), 3*(1), 228-244. http://dergipark.ulakbim.gov.tr/ijres/article/download/5000202010/5000179858

Katwibun, D. (2013). The need for preparing mathematics teachers for diverse classrooms in Thailand. *Procedia – Social and Behavioural Sciences, 93*, 756-761.

Laine, M. (2016). Culture in sustainability: Defining cultural sustainability in education. *Discourse and Communication for Sustainable Education, 7*(2), 52-67. doi: 10.1515/dcse-2016-0016

Longview Foundation (2008). *Teacher preparation for the global age: The imperative for change*. Silver Spring, MD: Longview Foundation for Education in World Affairs and International Understanding, Inc.

Lopes, A. P. C. (2024). Mathematical modelling: A methodology favourable to the manifestation of critical mathematical consciousness. *International Journal of Mathematical Education in Science and Technology*, 1-30. https://doi.org/10.1080/0020739X.2024.2378191

National Universities Commission – NUC (2022). *Core curriculum and minimum academic standards for the Nigerian university system: Education*. Abuja: National Universities Commission.

Niess, M. L. (2006). Guest editorial: Preparing teachers to teach mathematics with technology. *Contemporary Issues in Technology and Teacher Education, 6*(2), 195-203.

Salīte, I., et al. (2024). Editorial: Kaleidoscope of sustainable practices: Developing minds and shifting patterns, *Journal of Teacher Education for Sustainability, 26*(1), 1-4. https://doi.org/10.2478/jtes-2024-0001

Steffensen, L. (2024). Developing responsible citizenship through integrated STEM education activities. In J. Anderson and K. Makar (eds.), *The contribution of mathematics to school STEM education* (pp. 295-311). https://doi.org/10.1007/978-981-97-2728-5_17

Vasquez, C., Pineiro, J. L. & Garcia-Alonso, I. (2022). What challenges does the 21st century impose on the knowledge of primary school teachers who teach mathematics? An analysis from a Latin American perspective. *Mathematics, 10*, 391. https://doi.org/10.3390/math10030391

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