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Framing pre-service teacher preparation in Africa from global STEM education practices

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ABSTRACT

Purpose: This study seeks to review the literature on contemporary science, technology, engineering, and mathematics (STEM) education practices to frame approaches that can be used to prepare STEM pre-service teachers.

Design/methodology: This study used a systematic literature review guided by PRISMA 2020 statement. Following some eligibility criteria 79 studies were selected for synthesis. Data were analysed qualitatively, and Excel spreadsheet was used for the quantitative aspects.

Findings: This synthesis revealed diversity in the conceptualization of STEM education. Despite a lag in global STEM education research, countries such as South Africa and Tanzania have published research areas like STEM education practices, STEM teacher education, and technology adoption for STEM education. The synthesis also showed that aspects of policy, instruction, STEM-teacher professional development, STEM teacher education approaches, student activities, and the nature of support for STEM education are important considerations for developing effective models for framing pre-service teacher preparation.

Originality/value: This study is the original work of the researchers. The study draws from global STEM education practices and assesses the geographical distribution of literature on STEM teacher education practices in African countries to frame a six-point approach that can be used to enhance effective STEM teacher education practices.

Keywords: pre-service teachers, STEM teacher education, STEM competencies, STEM centers, STEM policy

INTRODUCTION

Globally, educational institutions have reformed the goals of the sciences curriculum to align with contemporary trends in science, technology, engineering, and mathematics (STEM) education. The overarching goals for STEM education as provided in the Interdisciplinary STEM education framework by the National Academy of Engineering and National Research Council of the USA in 2014 are two-pronged (Mohr-Schroeder et al., 2015). The first set of goals represents what needs to be achieved for learners, inclusive of the development of STEM literacy, fostering 21st century competencies, STEM workforce readiness, making connections, and cultivating interest and engagement while increased STEM content knowledge and pedagogical content knowledge become the second set of goals designed for the educators (Mohr-Schroeder et al., 2015). Cognisant of such goals, many nations have prioritised STEM education to create scientifically literate populations (Yerdelen et al., 2016). Knowledge of STEM is considered a key pillar for the development of skills for future jobs in the tech industry and modern innovation-based economy (Sarma & Bagiati, 2021). Thus, as Gadzirayi et al. (2016) contend, critical skills needed to champion developments in construction, mining, agriculture, information and communication technology (ICT), and manufacturing industries hinge on STEM education.

STEM education movement has seen relatively more phenomenal growth in global north than in the south (TVERC, 2022). The designation global north or south does not refer to geographical regions but to the economic, political, and cultural power balances (Braff & Nelson, 2022). For instance, Australia and New Zealand together with the USA, the UK, France, Canada, Singapore, Japan, and South Korea are some of the countries of global north. Most of the countries in Africa, Latin America, some countries in the Middle East, India, and Indonesia among others align to the global south and these generally lag on global economic rankings (Braff & Nelson, 2022). The commonly held belief that countries of global north lead in terms of research and publications seems to be losing credence with the advent of contrary empirical evidence. For instance, Zhan et al. (2022) used a citation frequency indicator and found the USA, China, Australia, Turkey, and the UK as countries among 13 others with the most publications in the field of STEM education, in the period 2004-2021. On the contrary, scholars such as Confraria et al. (2017) argue

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that the use of citation indexes introduces a limited view of otherwise complex phenomena because some focused research papers on global south in areas such as Agronomy may be relevant to the local economies, yet researchers elsewhere do not find value in those topics. Confraria et al. (2017) further argue that the use of different indexes may produce different results. The authors note,

> "… Despite some recognized limitations, the use of bibliometric data and indicators has also been rising in the context of global south, where this type of analysis can be particularly relevant to understanding successful processes of closing the S&T gap with the most advanced economies" (p. 267).

While that is the case further research that assesses the geographical distribution of literature on STEM teacher education practices in African countries is needed (Zhan et al., 2022).

On a general level STEM approaches are applicable in diverse settings. Empirical evidence shows that STEM education has been attempted in elementary (English, 2017), junior (Chiu et al., 2015), K-12 classrooms (Holmlund et al., 2018), and teacher education (Akerson et al., 2018). Chiu et al. (2015) say STEM education helps to achieve the goals of K-12 science practices, concepts, and core Ideas that many states in the USA seek to achieve. It has also been applied to technical vocational education, engineering, the medical fields, and other informal settings.

> "Informal STEM learning can take place in varied settings and involves a variety of STEM domains (e.g., engaging in engineering practices in a construction exhibit at a museum; talking about math during book reading at home)" (Hurst et al., 2019, p. 2).

To demonstrate a shift towards engineering, STEM initiatives in the USA focus on transdisciplinary teaching and learning in junior and K-12 settings, next generation science standards, standards for preparation and professional development for teachers of engineering, and national assessment of education progress technology and engineering literacy assessment (Strimel & Grubbs, 2016). Thus, while several research studies have been conducted on STEM education practices for the 21st century teaching in the school curriculum, and other fields such as medicine and engineering, little is found on science teacher education. In a similar fashion reviews in the last ten years have concentrated on STEM education practices in developed countries with very few existing on teacher education in Africa. This is the case despite the realisation that educational developments in the school curriculum that exclude teacher education are bound to meet limited success (Pugach et al., 2020; Rowan et al., 2021). In other words, the skills that teacher candidates possess that they deploy in their work in the schools are honed through teacher education programs.

> "New perceptions of and approaches to existing concepts by school-age children are dependent upon well-informed and well-trained teachers, and without such teachers, quality STEM education is unlikely to be successful" (Liu, 2020, p. 130).

Thus, a systematic review that seeks to fill this gap by establishing the prevalence of STEM education practices in African countries and how the same can be deployed in science teacher education is therefore called for. We, therefore, endeavour to frame contemporary STEM teacher education practices, and specifically, the following questions guide the review:

1. What conceptualisation of STEM education has existed in literature in the last ten years?
2. Which African countries are actively involved in the publication of STEM teacher education literature?
3. What STEM teacher education practices for the 21st century era are reported in the literature?
4. What insights can be drawn by combining and comparing findings from STEM teacher education practices of the different studies?

MATERIALS & METHODS

Sources of Information

This systematic review began with brainstorming on the study focus on the context of our gathered personal experiences as teacher educators and the drafting of the review protocol. "A systematic review protocol specifies the plan for the conduct of the review" (O'Connor et al., 2014, p. 29). To restrict the presence of bias reporting we kept referring to the outlined study objectives, and the methods of the review as contained in the protocol. Guided by O'Connor et al. (2014) we allocated each other responsibilities and delineated the intended search units (search unit=one search phrase) and selection criteria among other aspects. The initial list of search units comprised; STEM teacher education, STEM education, STEM education practices, STEM education integration, integration approaches, designing STEM teacher education programs, pre-service STEM education in African countries, engineering and science education, and ICT and STEM in African countries. To focus the search additional search phrases were used if available data pointed to the need. Search engines used were PubMed, Google Scholar, and Google. PubMed and Google Scholar yielded scholarly articles on STEM education practices and STEM teacher education while Google was used to search for country or regional reports and records. Of the three databases, Google Scholar yielded most of our data.

Eligibility criteria & selection process

Our search focused on journal articles, reference lists of previous reviews, country reports, regional reports, STEM education blogs, book chapters, empirical studies, and sector/department reports that were published in the period 2010-2023 and written in the English language. Studies and reports were grouped according to target research questions. However, for each unit search,

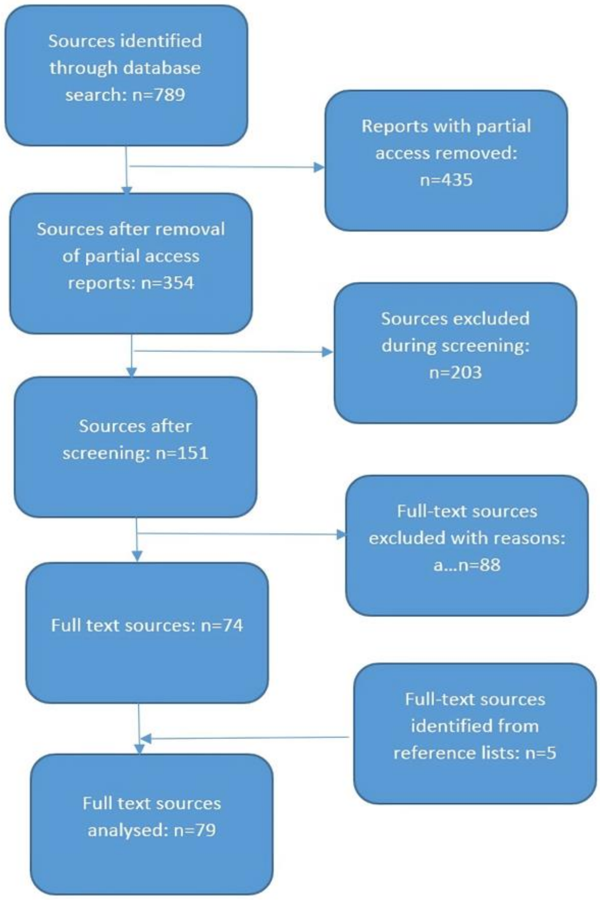

Figure 1. Data source identification screening & sources analysed (Adapted from Mudaly & Chirikure, 2023)

only open-access articles from the first five web pages of Google Scholar and the first two pages of PubMed that offered us free downloads were selected for review. The exclusion criteria included articles and reports published before 2010, thesis and dissertations, journal articles that were not fully accessible requiring payments or provided only partial information, and newspapers. To decide whether a study met the inclusion criteria we assessed if the title and abstract matched our study focus and if it answered any of our research questions. The assessment was done at two levels. Firstly, following the review protocol individual researchers conducted and maintained an Excel database for their initial search. Secondly, researchers at the same workstation paired to share work done in level one and further worked on the analysis and synthesis of studies and reports according to the research questions allocated to them. Following guidelines in other literature (Denzin & Lincoln, 2018; Mudaly & Chirikure, 2023), the synthesis process involved compiling the data gathered, sorting the documents into batches based on their focus areas, coding the data, collating codes, merging or refining the codes, where necessary until a saturation level was achieved. We also assessed for trends, patterns, contradictions in the literature, and the contribution of studies to the existing knowledge in the field. The records identified, analysed, screened, and selected are summarised in **Figure 1**.

RESULTS

STEM Education Practices

Diverse views on the meaning of STEM education were found in the systematic review. Our analysis of the literature on STEM education revealed complexity and ambiguity in its definition, trends, and status. It is a movement originally conceived by the USA National Science Foundation in the 1990s to explore knowledge and conduct basic and applied research that is directly beneficial to innovation and economic growth and popularised in some Asian countries such as South Korea. To date, there is no agreement in the literature on its definition. For example, Li et al. (2020a) in an earlier review note diversified interpretations of STEM education that yielded loose definitions. Tan (2020) argues that over the years STEM education has remained ill-defined and retained some level of opacity. Li et al. (2020b) note diverse perspectives about STEM education, arguing that there is no consensus on subjects that should be included in STEM education. However, despite this lack of consensus, a few definitions are discussed. While some scholars (e.g., Kertil & Gurel, 2016; Suyanta, 2019) view STEM education as a learning approach that integrates STEM others, e.g., Tan (2020) views it as a combination of disciplines whose existence is sustained by overlaps among them. Yet on another level, STEM education can be viewed as only referring to interdisciplinary or cross-disciplinary individual STEM subjects. An attempt is made to define and classify STEM education through the application of several models.

The models that were reviewed in the literature showed different approaches that mirror the complexity of STEM education conceptualization discussed earlier. Our analysis revealed the existence of different models and approaches to STEM education integration but for us all of them were dealing with the issue of STEM education integration. The first model discussed in Kertil and Gurel (2016) argues for two basic approaches in STEM education integration-the content and context integration models. In content integration, STEM education curriculum is structured in ways that facilitate coverage of more than one STEM discipline while context models put one discipline into the centre of teaching but select relevant contexts from other disciplines without ignoring the unique characteristics, depth, and rigor of the main discipline. Strimel and Grubbs (2016) proposed three pathways (models):

(1) stick to the fundamental goals of technology education,

(2) bring engineering and science education together and potentially create a core discipline, and

(3) revitalize science through a shift to engineering.

The two basic models place emphasis variously on school subject contexts and technology and engineering curricula, respectively. For instance, Kurtil and Grubbs (2016) cite researchers who indicate that the most important component that mediates STEM education is engineering education with its emphasis on the design process. However, the question of teachers' knowledge and understanding of STEM education integration approaches remains a crucial one even in our study. Thibaut et al. (2018) observe that effective implementation of integrated STEM requires teachers with specialized pedagogical content knowledge and a deep knowledge of STEM content, which is largely and unfortunately lacking.

Viewpoints on integration varied. Sanders (2012), as cited in English (2017), distinguished "integrative STEM education" from "STEM integration" arguing that integrative STEM education represents dynamic and ongoing learner-centered processes while STEM integration implies static, teacher-centered approaches. In the other sections of the literature, integration was explained through a set of approaches. For example, Guzey et al. (2016) advance two STEM education integration approaches by Harley (2001), as cited in Guzey et al. (2016), and Jacobs (1989), as cited in Guzey et al. (2016). Harley (2001), as cited in Guzey et al. (2016), presents five levels of integration, sequential (science and mathematics are taught one after the other), parallel (science and mathematics are taught concurrently), partial (science and mathematics are taught partially together), enhanced (science + mathematics are core, technology, and engineering are peripheral support disciplines), and total (science + mathematics are taught together as major disciplines. According to Guzey et al. (2016), Jacobs' (1989), as cited in Guzey et al. (2016), is a six-level approach; discipline-based (separate subjects taught in separate classes), parallel discipline separate subjects are connected to common themes and topics, multidisciplinary (disciplines are taught together), interdisciplinary (deliberate connections are made between/among subjects), integrated (use cross-cutting themes connected to real-world problems) and complete program (curriculum is based on students' everyday lives). While in Harley's (2001), as cited in Guzey et al. (2016), approach Science and Mathematics play a central mediating role, in Jacobs' (1989), as cited in Guzey et al. (2016), approach focus is largely on connections between and amongst disciplines, the use of cross-cutting themes that are derived from real-world problems, and complete curriculum programs based on students' everyday lives. We raise the same concerns articulated in the literature reviewed (e.g., Thibaut et al. 2018) in connection with the difficulties of implementing such integration approaches in the context of diverse school environments with traditionally compartmentalized curriculum structures. Thibaut et al. (2018) say implementing an integrated STEM approach in an educational system that has a very established segregated and discipline-based structure requires profound restructuring of the curriculum and lessons.

The articles in the data set were also examined for contexts of STEM education. Contexts for STEM education implementation are discussed at various levels-international and national policy, schools/institutional, and theoretical. In the context of international and national levels, studies (e.g., Rampersad & Zivotic-Kukolj, 2018) analyse policy formulation for STEM education and student uptake of both STEM disciplines and jobs. For instance, Baker and Galanti (2017) point out the existence of inconsistency and inequity in the funding and availability of high-quality STEM programs. Baker and Galanti (2017) note that high-quality, culturally relevant, and innovative STEM teaching and learning typically occurs in schools and communities that have the most access to resources, knowledge, expertise, and infrastructure to innovative tools, technologies, and STEM career pathway programs. Jeffries et al. (2020) write about the performance of students in STEM subjects and their uptake. Like elsewhere, they note underachievement trends of the USA students in all the disciplines of STEM and relatively low technology and engineering literacy levels. Suyanta (2019) discusses the integration of STEM education in the context of a specific subject–chemistry. Suyanta (2019) alludes that STEM-based chemistry learning means that chemistry learning is integrated with technology, engineering, and mathematics citing Chemistry integrated with industry, Chemistry integrated with technology, and chemistry integrated with Mathematics as examples. At a theoretical context level, Kertil and Gurel (2016) coin a STEM problem-based learning (PBL) context as having interdisciplinary learning objectives, ill-defined tasks, student-centered interactive group work, collaboration, and other design activities. Sujarwanto et al. (2021) identify contexts for STEM education they call "need to know" and "need to do for engineering". The context of "need to do for engineering" is the process of designing and testing a product. The process requires the use of principles and theories related to materials, processes, and energy while the "need to know" context is when the principles and theories used are insufficient to solve a problem and thus a need arises for new/additional knowledge. Given this diversity in contexts for the implementation of integrated STEM education, a call is made for close cooperation and liaison between science educators and professional scientists/engineers and the deliberate formulation of policy frameworks that support schools and institutions of STEM education.

Competencies for STEM education

We regarded the sub-heading *competencies for STEM education* as a misnomer because the literature that we reviewed indicated some competencies of STEM education as well. That is, while some literature (Hafni et al, 2020; Rahmawati et al., 2021;

Table 1. Theoretical & instructional approaches/pedagogy for development of 21st century STEM competencies

Reference	Approach/pedagogy	Activities/explanation
Thibaut et al. (2018)	Teamwork	-Collaborative learning -Cooperative learning -Communicating information -Working in small groups -Interdependence in group work
Chu et al. (2017)	Social media learning	-Integrating social media technology into mainstream education -Innovative learning -Collaborative web-space
Chu et al. (2017) & Papadakis (2018)	Gamification/games for learning	-Inject game elements in nongame contexts -Science game design projects -Group collaboration -Artifact construction
Chu et al. (2017), Connors-Kellgren et al. (2016)	Project-based learning	-Individual or group activities -Projects with time frames -Product presentation and/or performance
Ali (2019), Ärlebäck and Albarracín (2019), & Fidan and Tancel (2019)	PBL	-Students work together to address open-ended questions -Inquiry & problem resolution -Scaffolded learning
Chu et al. (2017) & Ng and Tsang (2023)	Constructionism	-Creation of complex computational digital artifacts -Collaboration & sharing -An expression of deep conceptual knowledge -Use information resources in a workshop-based environment (hybrid laboratories)
Li et al. (2019) & Thibaut et al. (2018)	Engineering design	-Design-based learning -Developing & using models -Designing solution -Design thinking -Engineering design -Design justification -Opportunities to learn from failure & to redesign-based on that learning
Pellas et al. (2020)	Virtual reality	-Multimedia material -Virtual experiments -Simulation-based exercises -Video games -Self-directed & inquiry-based learning -Real equipment accessible at a distance
Ajit (2021) & Salmi et al. (2017)	Augmented reality	-Mixing real-world & digital illusions -Interactivity with real environments -Online effects -Three dimensional impressions

Rampersad & Zivotic-Kukolj, 2018) regarded STEM as key to some competencies needed for industrialization in the 21st century the other literature (Strimel & Grubbs,2016; Whorton et al., 2017) identified them as competencies for the promotion of STEM education. In the literature, the term competency was used interchangeably with skill. Li et al. (2019) identify design thinking, critical thinking, innovation, and creativity as important cognitive competencies for the 21st century. Lafifa et al. (2023) postulates that 21st century skills as competencies that emphasise process skills in the discovery of knowledge utilising: investigations, argumentation, analysis, inference, organization of information, communication, decision-making, problem-solving, and drawing up conclusions. Chu et al. (2017) view creativity, critical thinking, problem-solving, collaboration, language skills, digital literacies, inquiry mindset, and productivity as examples of 21st century competencies. They further note that although some of the skills have been in existence for quite some time the proliferation of technologies and globalisation has given them currency. A number of the reviewed articles used broader categories or domains of the skills. Li et al. (2019) used three domains-cognitive, interpersonal, and intrapersonal domains. Rafiq and Hashim (2018) identified nine categories inclusive of simulation and augmented reality. Chu et al. (2017) identified communication, information and ethics, and social impact as crucial categories for 21st century skills while Suyanta (2019) suggested learning and innovation skills, information, media and technology skills, and life and career skills. From the broad categories of human social skills (soft skills) of the intrapersonal domain, ethical social skills and life skills stand out despite research showing that these do not receive adequate attention in both school and higher education science learning.

A majority number (33.00%) of articles reviewed identified theoretical frameworks and pedagogy for the development of either the competencies of/for STEM education or the 21st century skills (n=79). In earlier reviews, Thibaut et al. (2018) provided an overview of categories of instructional approaches. The authors identified nine categories (integration of STEM content, focus on problem, inquiry, design, teamwork, student-centered, hands-on, assessment, and 21st century) that branched into several instructional approaches. For example, integration of STEM content had forms of integration (e.g., multi-, inter-, and cross-disciplinary) cited as instructional approaches while posing questions, planning and carrying out investigations, discovery learning, inquiry-based instruction, and authentic scientific practices were designated as instructional approaches under the scientific inquiry category. Other approaches to instruction that emerged from our search are given in **Table 1**.

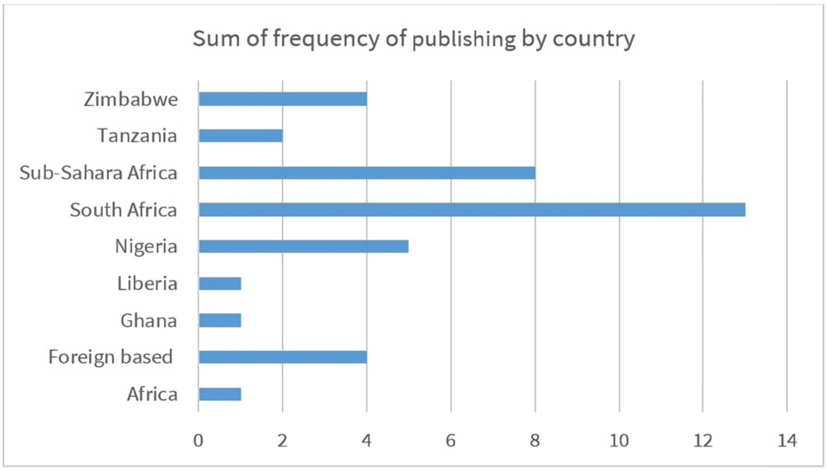

Figure 2. Sum of frequency of publishing by country in period 2015-2023 (Source: Authors' own elaboration)

Context for & Distribution of Publication of STEM Education Literature in African Countries

Previous reviews that have looked at country or regional distribution of STEM education in general were found. These have highlighted countries in which research and publications on STEM education are most prevalent. The USA has been cited as the global leader in STEM education publications, achieving 69.25% of the world's total publications in the period 2011-2022, with Australia, Netherlands, Israel, and the UK coming in the second, third, fourth, and fifth positions, respectively (Irwanto et al., 2022). Zhan et al.'s (2022) review got almost similar results with the USA at the top followed by China, Australia, Turkey, and the UK in that order. However, it is noteworthy that in both reviews the concentration of publications on STEM education was in global north countries suggesting the countries in global south were lagging and in a league of their own. In some literature, global technological dominance, and neoliberal versus massification agendas are cited as the reasons for this concentration (Amano et al., 2021; Christophers, 2020; Mbiti, 2016). Mudaly and Chirikure (2023, p. 1) say:

> In global north, STEM education is historically driven by ambitions of political dominance, the need to curb economic slumps and address critical skills shortages, and growing desire for extra-terrestrial colonization. Within this context, we argue that a neoliberal agenda drives STEM education enterprise. In global south, massification with equity dominates policy formulation and implementation as countries battle to redress past colonial imbalances. Global south countries generally sign up to regional and global STEM education agendas, but financial constraints compounded by an unabated brain drain result in stagnation in policy adoption at the vocational level.

Despite the geographical differences between the countries in Africa, the similar challenges that they encounter as a block regarding STEM education gave impetus for the current study's focus. The review showed that it was only the scale of publications that differed but to some extent, research work on STEM education and STEM teacher education is prevalent in countries in Africa. In other words, although African countries were missing in the reviews citing global distribution of STEM education publications substantial research was going on in some. **Figure 2** shows the frequency of publications by country in the period 2015-2023. **Figure 2** shows that South Africa topped the list. Sub-Saharan countries, as a block, came in the second position. Sub-Saharan countries are the non-Mediterranean African countries such as Angola, Benin, Burkina Faso, Burundi, Cameroon, and others. This grouping was made up of review articles that did not specify one African country but included three or more of the Sub-Saharan countries in their study. Similarly, the designation foreign-based or African, as shown in **Figure 2** was about research or articles about Africa or some African countries but carried out by institutions or authors of non-African origin. Thus in terms of countries, without bunching, Nigeria, Zimbabwe, and Tanzania came second, third, and fourth, respectively after South Africa.

In terms of article focus our review showed a diversity of topics. Research work covered a wide range of STEM education topics. We codified the various topics and grouped them under three themes-STEM education in Africa, Transforming STEM education through ICT, and STEM teacher education. The frequency of occurrence of the themes is shown in **Figure 3**. Research on STEM education was found to be high with general topics such as challenges of STEM education in Africa, perceptions of and attitudes toward STEM education, and the evolution of STEM education in Africa. **Figure 3** shows that there was a paucity of literature on STEM teacher education while publications on STEM education and ICT integration came in second position. Although publications covering technological adoption in STEM education were in second place in terms of frequency of occurrence, they were the most read and cited. **Figure 4** shows the number of times topics were cited.

The citation of articles depended on, among other things, the year of publication. Recent articles, particularly those published in 2023 had received no or very few citations. The graph in **Figure 4** therefore did not show the publications that had very few citations (10 or less). In terms of frequency of citation, the top five publications were Transforming STEM education through ICT (151 times), ICT use in science and mathematics teacher education (135 times), pre-service teacher education in Africa (80 times), teaching STEM disciplines in higher education (78 times) and improving quality STEM in sub-Saharan Africa (47 times). The first and second most read articles were from Tanzania while the third and fourth was research carried out in South Africa with the fifth publication coming from sub-Sahara Africa.

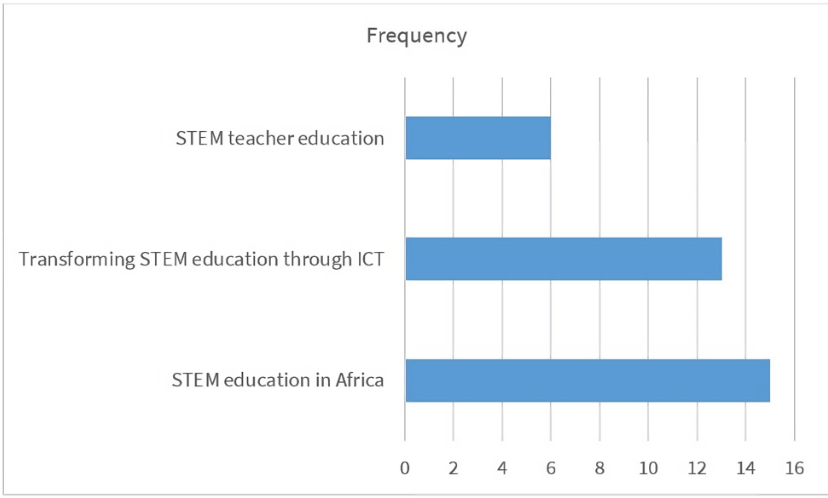

Figure 3. Frequency of occurrence of STEM education themes in Africa (n=34) (Source: Authors' own elaboration)

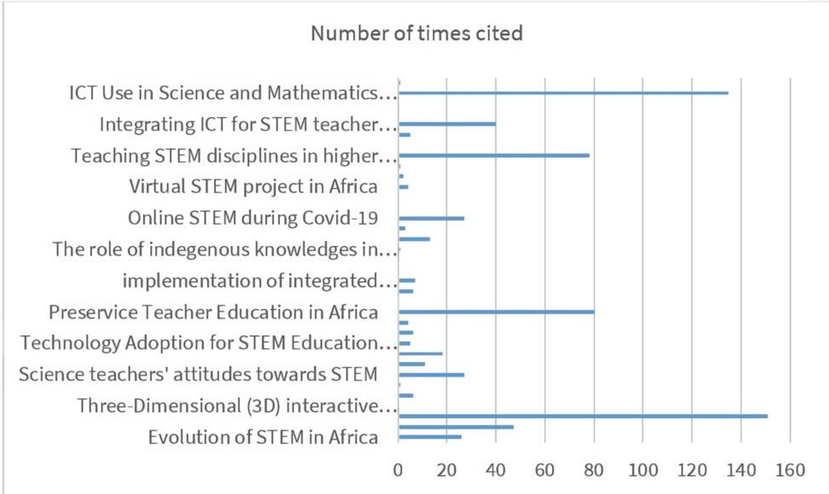

Figure 4. Number of times a publication was cited (n=34) (Source: Authors' own elaboration)

The most cited article that was authored by Barakabitze et al. (2019) showed several typical aspects of a quality literature review such as well-defined scope, robust content, authoritative sources, applicability to diverse contexts, and distinct contribution to existing knowledge in the field.

Framing Pre-Service Teacher Preparation for STEM Education in Africa

A few scholars are critical of STEM teacher education. In their effort to disentangle the meaning of STEM, Akerson et al. (2018) raise several arguments that cast a dark shadow on STEM teacher education movement. Akerson et al. (2018) question how teacher educators could be asked to teach about STEM when it is an aggregate of disciplines and not a discipline itself. They argued people get degrees in disciplines that are part of STEM. Although acknowledging the need for pre-service teachers to understand the nature of the disciplines, that is, the nature of science, nature of technology, the nature of engineering, nature mathematics, and the nature of STEM education, and their connections, as a pre-requisite, Akerson et al. (2018) further question the logic of adding more requirements to a science pre-service teacher who seemed to be struggling already with the nature of science. Despite this hesitation shown in other literature, a majority of studies and reports reviewed demonstrated the value of STEM education to sustainable global economic development.

Implementing STEM teacher education for sustainable development in Africa was perceived as having several challenges. The majority of studies reviewed cited challenges such as inadequate preparation of pre-service teachers for STEM integration, lack of resources, inadequate incentives, large classes, lack of STEM dedicated infrastructure, uncertified STEM teachers, increasing population, and poor conceptualization of STEM education approaches (Association for the Development of Education in Africa [ADEA], 2021; Bardoe et al., 2023; Liu, 2020; Mutseekwa, 2021; Shernoff et al., 2019). Several regional and country reports seemed to concur that reforming teacher education to incorporate contemporary trends in STEM education was urgently needed to counter these challenges.

> "A strategic response to these challenges is to take decisive actions and accelerate investment for improving the quality of STEM education at the basic learning levels and equip the youth with relevant STEM skills to take up emerging opportunities in STEM careers in Africa" (ADEA, 2021, p. 2).

Table 2. Six aspects to consider to improve pre-service teacher preparation for STEM education

Important aspects for STEM teacher education improvement	Explanation & activities	Source/authors
Policy	Formulate STEM education-specific policies on educational equity, community engagement in STEM education activities, equitable distribution of resources, articulated & strengthened multi-sectoral approaches to STEM, promotion, & relevance of STEM offerings in schools & colleges	ADEA (2021), GO-GA (2020), Liu (2020), & Zhan et al. (2022)
Curriculum & instruction	Reform & align teacher education to elementary & high school curriculum, engage STEM pedagogical practices such as gamification, PBL, constructionism, engineering design, & others (see **Table 1**) -Re-design & re-think pre-service courses & in-service workshops -Create STEM documented standards -Explore online teaching approaches inclusive of virtual & augmented reality	Bardoe et al. (2023), Chu et al. (2017), Connors-Kellgren et al. (2016), Grace (2023), Shernoff et al. (2017), & Zhan et al. (2022)
Approaches to pre-service STEM-teacher professional development (TPD)	-STEM-TPD is carried out as outreach, where teacher education institutions collaborate with schools & engineering graduate schools in community outreach programs -Can introduce new learning courses/ modules on STEM education or a STEM general course -Can be taught in existing courses, infusing it through methods courses or educational technology	Cheng et al. (2022), Liu (2020), Mutseekwa (2021), Suryadi et al. (2023)
Student teachers' activities for STEM education	-Real school teaching, micro-teaching, presenting STEM learning designs, critiquing existing STEM learning designs, learning theoretical foundations about STEM, engaging in STEM activities, & trying out various STEM integration approaches	Guzey et al. (2016), Suryadi et al. (2023), & Thibaut et al. (2018)
Models/approaches to STEM teacher preparation	-Offer compulsory courses that foster STEM literacy -Offer STEM education as part of compulsory courses -Can be offered as elective courses covering STEM historical development, pedagogy in STEM education, etc. -Can be done as extra-curricular activities including STEM camps, workshops, exhibitions, seminars, & collaboration with STEM stakeholders	Cheng et al. (2022)
Supports needed for STEM teacher education	-Avail time for STEM activities such as collaboration, work visits to museums, manufacturing plants, & others -Create supportive STEM ethos/cultures -Create supportive STEM infrastructure inclusive of investments in ICT resources & pedagogy -Establish STEM centers of excellence	ADEA (2021), APET (2021), Barakabitze et al. (2018), GO-GA (2020), Oladele et al. (2023), & Shernoff et al. (2017)

Office of the Special Adviser on Africa (2022, p. 17) avers,

> "Curriculum reform at the primary, secondary and tertiary levels is necessary to align with policy expectations, enhance quality and learning in STEM and to disabuse people of the notion that STEM subjects are too difficult. Curricula for teacher training and continuous professional development need to accompany overall curriculum reforms and require stakeholder participation".

The line of argument in these reports is that current teacher education preparation programs are not producing innovative, competent teachers with skillful thinking relevant to motivate students to be agents and active participants in STEM subjects (Moyo & Hadebe, 2018).

Framing pre-service teacher preparation for STEM education in Africa therefore received a lot of attention in the literature. Our synthesis revealed six areas that governments, STEM teacher educators, science teachers, curriculum specialists, and higher education institutions needed to consider improving pre-service teacher preparation for STEM education, as shown in **Table 2**.

DISCUSSION & IMPLICATIONS

Several aspects of STEM education and STEM teacher education have been raised in this review. The conceptualisation of STEM education, models in STEM education, integration approaches in STEM education, competencies of STEM education, and how these could be adopted to improve pre-service teacher preparation programs have been analysed. The current review's output was premised on three assumptions. Firstly, the review provides a theoretical basis for interpreting core issues of STEM education. Secondly, the provision of and a grounding in the African context for framing pre-service teacher preparation is a prerequisite for effective future programs in the continent. Lastly, despite challenges, STEM teacher educators are ready and prepared to learn/adopt new strategies that can assist frame STEM teacher education for sustainable development in Africa. Other studies have dealt with similar issues although with different foci. According to English (2017), core issues of STEM education include perspectives on STEM education, approaches to STEM integration, STEM discipline representations, equity in access to STEM education, and competencies for STEM education.

Zhan et al. (2022) posit that four key themes–educational equity, pedagogy, empirical effects, and career development are found in the literature. The authors further assert that a regional bias on major STEM topics can be discerned with Western countries maintaining a focus on publications that deal with educational equity and disciplinary integration while developing countries focus more on pedagogical practices, and humanistic leadership in STEM education, technology adoption, teachers' ability for integration being the focus for Eastern countries (Zhan et al., 2022). This current review had somewhat different results. Contrary to the assertion from other literature that developing countries were more focused on STEM pedagogical practices in this review more focus in most countries in Africa was on technological adoption. Besides receiving high citation rates, foci areas such as blended learning, online STEM, models for ICT use in STEM education, and transforming STEM education through ICT were largely common (see **Figure 4**).

The thrust of this review that has also received attention in other literature is STEM education practices for pre-service teacher preparation. Strategies for effective STEM teacher education programs were found in studies from different countries such as Indonesia, Thailand, South Africa, Tanzania, and Nigeria. According to Cheng et al. (2022), the four approaches that Thailand uses for the implementation of integrated STEM pre-service teacher education are the use of STEM compulsory courses, infusing STEM education in existing courses, STEM education elective courses, and STEM education in extra-curricular activities. While the other literature presented these approaches disjointedly, this review's synthesis presented six areas to consider when framing a pre-service STEM teachers' preparation program. These six areas were presented in **Table 2** as policy, curriculum and instruction, approaches to STEM-TPD, STEM activities for student teachers, approaches/models to STEM teacher preparation, and supports for STEM teacher education. These aspects considered together provide direction for future STEM teacher education programs. Despite this contribution to the theory of knowledge, this review had its limitations. Firstly, the reports that were selected for the study were mainly open-access articles whose empirical findings could have been complemented by articles that were locked and not readily available. Secondly, a focus on pre-service teacher preparation in the context of Africa may exclude other contexts outside the continent. Lastly, it was the first time the researchers engaged in this genre of research making it possible that some aspects important to credible reviews could be missed. Future reviews can focus on a larger audience by providing a global context on the framing of effective STEM teacher education programs and include larger samples of reports from diverse databases.

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