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RESEARCH REPORT

Broadening Perspectives of STEM education: A new Conceptual Framework

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Abstract
This systematic review aimed to uncover the commonalities and divergences in the conceptualisations of STEM education from the literature to develop a framework that depicts how STEM education is framed in various national and global contexts. This study employed a qualitative desktop research methodology to examine the evolution of STEM conceptions over the past decade, focusing on its relevance to the 21st century. It utilised the triangle framing framework to emphasise the three axes of support, that is, the epistemological, psychological, and didactical dimensions. The research was systematically organised into three sequential phases to examine the body of peer-reviewed literature on STEM education. The initial phase involved the identification and retrieval of pertinent studies focused on conceptions of STEM education. This was succeeded by a thematic analysis to develop comprehensive syntheses of the literature. Finally, the synthesised findings were critically analysed to uncover new and nuanced ideas and concepts related to STEM education, pushing the boundaries of current understanding. The themes that emerged from the meta-analysis and synthesis of STEM conceptions were compartmentalised against multidisciplinary and integrated approaches, dominance of disciplines, extending the core disciplines in STEM, policies and practices of STEM education, integrated STEM education, epistemological considerations for STEM education, STEM for employability, and realigning assessment in STEM education. The structured framework, developed from the conceptions that emerged during the meta-analysis and synthesis, is essential for broadening the understanding of STEM education and it opens avenues for future research.

Keywords: *Meta-analysis and synthesis, STEM conceptualisation, STEM education, Triangle framing, framework*

In the ever-evolving landscape of education, the role of STEM has become a subject of extensive debate and research (Yan et al., 2024). STEM-based modalities of instruction, which integrate engineering design, mathematical thinking, scientific inquiry, and technological literacy (Kelly & Knowles, 2016), are crucial to leverage digital advances from the past industrial revolutions (Gleason, 2019) and to prepare a workforce capable of addressing issues and

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challenges related to uncertainty (Penphrase, 2019). The arguments thereof not only point to a need to rethink professional development programmes for STEM teachers and the conventional sciences but also reconceptualise STEM education for 21st century citizens. After all, the compelling arguments concerning STEM education today place it at the heart of the development of 21st century skills and the holy grail - Sustainable Development Goals (e.g., Jakfar et al., 2024). STEM education has become a cornerstone of global political and economic priorities, hence igniting significant discussions and inquiry among pertinent stakeholders who view it as a political tool and economic and educational saviour (Razi & Zhou, 2022). It points to the need to mould the global workforce with academic, technical and soft skills that enable them to fit in the world marked by sophisticated technologies, a globalised economy and social diversity (Kayan-Fadlelmula et al., 2022). It is thus reasonable that such reconceptualisation of STEM education be made sustainable through its national policies that provide coherent frameworks for championing STEM-based strategies and programmes across all education sectors, ranging from pre-primary school to higher education (HE), including research, innovation, employment and industrial development (Marginson et al., 2013). There is a need to develop relevant, clearly articulated and contextualised STEM policies and frameworks based on the community's conceptions and conceptualisations of STEM education.

Clearly articulated and contextualised STEM education policies and programmes are vital. These are shaped by the global need for STEM professionals who can face economic, societal and environmental challenges in a globalised economy (Spikic et al., 2023). Indeed , in countries with a developed industrial base such as the United States, the priority is on moulding future STEM professionals, hence emphases on pertinent aspects of K-12 STEM education, STEM majors and careers of underrepresented populations, STEM education funding and research, and most importantly "recruitment, retention, recognition, preparation, and professional development of STEM teachers" (Bush, 2019, p. 74; emphases added). In the United Kingdom, STEM conceptualisation is equally based on human capital driven by a commitment to the effectual scientific enterprise and innovation investment system. Like the Gulf Cooperation Council states (Middle East) (see Kayan-Fadlelmula, 2022), China hopes to improve STEM education competitiveness. It has prioritised a formidable, innovative STEM workforce (Yan et al., 2024). Kamsi et al. (2019), drawing from Joseph (2018), argue within the context of FIR-STEM (Foundational Integrated and Responsive STEM), on the importance of human capital equipped with not only skills but also education, knowledge, experience, creativity and motivation. The aspect of human capital is also set out in Science, Technology and Innovation Strategy for Africa, which is enshrined in the African Union Agenda 2063 (African Union, 2012). To achieve technical competences, which are a fundamental requirement of the 4.0 Industrial Revolution (González-Pérez & Ramírez-Montoya, 2022), member states are expected to take a systematic and coordinated approach to human capital development and popularising STEM research and innovation as potential career paths at both secondary and higher education levels including TVETs.

We acknowledge the diversity in conceptions and conceptualisations of STEM education in different national contexts, which include environmental, political, economic, social and technological specificities. We contend that these aspects thereof backdropped our argument that they are key in the development of STEM policies and frameworks. That said, this review is important. It is part of conglomerate projects concerning not only the broadening of the scope of STEM, specifically concerning its global conceptualisation but also critical analysis of how it is currently measured in the world, and situational analysis and the contextual factors that present barriers and opportunities in Mauritius and South African contexts. The researchers' meta-analysis and meta-synthesis approaches, in this case sought to examine existing literature on STEM education. The approaches enabled the researchers to uncover how the conceptions of STEM education have evolved over time, aiming to develop a framework that different educational stakeholders, especially policymakers can utilise in crafting effective STEM Education policies and strategic STEM plans. This is important as it will map out the way forward on how STEM education may be conceptualised at national and global levels in a quest to developing a competent workforce that can enable own institutions to stay competitive in the evolving technology-laden landscape.

The research sought to address the following research questions:

1. What are the commonalities and divergences in the conceptions of STEM education found pertinent in peer-reviewed literature?
2. What are the key themes that emerged from the thematic analysis of the literature on STEM conceptions?
3. What are the new and nuanced concepts about STEM education that emerged from the analysis of the syntheses that were prepared for each identified theme?

Literature Review

This section focuses on an overview of the (i) origins of STEM education, (ii) evolution of the STEM education conceptions, (iii) implementation of the interdisciplinary, integrated, and holistic STEM education, and (iv) STEM education in the North and the South.

Origins of STEM education

The United States government recognized the urgent need to bolster its scientific and technological capabilities in the wake of the Sputnik launch and the space race with the Soviet Union (Vought, 2018). The focus of STEM at that time was on the development of discipline-related specialists in (i) science to engage in intellectual and practical scientific activities to systematically study structure, behaviour and phenomena of the physical and natural world, (ii) technology to invent and innovate to improve the world and quality of life, (iii) engineering to control, modify, or design materials, processes, and systems, and (iv) mathematics to use and develop symbolic language for representing reality and making sense of the world with numbers (Bybee, 2011). For Gonzalez and Kuenzi (2012), STEM became the most rapidly growing industry in the U.S. economy as the associated companies continued to ramp up technological innovation to remain competitive across the globe and maintain the dominance of the global North across the world That led to strengthening STEM education, with the ultimate goal of cultivating a robust pipeline of skilled professionals capable of driving innovation and maintaining the country's technological edge. Thus, the conceptualisation of STEM moved from mostly an enactment and interprets orientation to an educational orientation, officially giving rise to STEM education (Feola et al., 2023). The movement around integrating STEM into educational frameworks gained a lot of traction and countries began to recognise that STEM education will help students of all ages develop the 21st century skills they will need to be successful, and to play an effective role, in the future workforce (Payton et al., 2017). This led to the development of STEM-focused curricula in many countries of the world (Barcelona, 2014; Kenedy & Odell, 2023).

Evolution of the STEM education

According to Shirey (2018), education systems have traditionally presented science, technology, engineering, and mathematics as separate disciplines. The focus has been on the improvement of teaching and learning of the sciences, technology, engineering, and mathematics as discrete disciplines to provide the best scientists, doctors, engineers, and ICT specialists to cater for the needs of the economy. However, during the late half of the 20th century, a growing recognition of the limitations of siloed STEM education brought about concerns about workforce readiness and the need for innovation. This fuelled a call for a more integrated STEM approach (Bybee, 2010; Hwang et al., 2024; Lee, 2024). Thus, the interdisciplinary and integrated STEM education emerged to break down the silos between disciplines.

Today’s STEM education advocates for the shift towards an approach to teaching where the traditional barriers erected between the four disciplines are removed (Hwang et al., 2024). It should be noted that, as a first step in the transformation from the siloed to an interdisciplinary approach, the latter explored teaching and learning that bring together two or more STEM subject areas to provide students with a cohesive and practical education that mirrors the interconnected nature of real-world problems and industries (Sanders, 2009). Glancy and Moore (2013) proposed a STEM Translation Model as a framework that makes provision for integrated STEM lessons and activities to encourage students to make translations between the ideas of multiple disciplines. That has since been followed by a gradual movement towards a more synergic approach, termed the integrated STEM (iSTEM) approach where all the different STEM related disciplines work together to create more powerful and impactful learning experiences (Bybee, 2010; Hwang et al., 2024; Lee, 2024). Project-based learning, where students apply their knowledge of science, technology, engineering, and mathematics to solve real-world problems, became a key aspect of this new approach, fostering critical thinking, problem-solving skills, and collaboration (National Academies Press, 2012).

The last decade has witnessed a new paradigm shift in the conception of STEM which goes beyond the approach of integrating the four pillars of STEM to accommodate a holistic approach that opens the integrated STEM whole to other disciplines including non-scientific areas of learning. This encouraged the integration of health, humanities, social sciences, languages development and the arts, giving rise to a host of variations on the acronym from STEM to STEAM (STEM and the Arts), STEMM (STEM and Medicine), STEAMED (STEM, the Arts, Education and Design), and STREAM (STEAM with Robotics or Readings) among others (Belbase, 2022; Ilhan et al., 2019; Kocabas et al., 2020; Lyons, 2018). Curricula developed based on these new conceptualisations of STEM allowed a more holistic development of students. For instance, the addition of Arts to STEM was brought about to improve on the existing knowledge and skills to meet the needs of the 21st century citizens (Belbase et al., 2022). STEAM is gaining a lot of importance globally as creativity and arts form the basis of the 21st century competences such as logical, reasoning, problem solving as well as inquiry skills (Braund & Reiss, 2019; Correia, 2024). The coding and robotics for STEM (C-STEM) program used coding and robotics to help students develop practical problem-solving skills while tackling real-world issues (Wright, 2024).

The opening of integrated STEM education to other disciplines has not only improved development of students' competencies but has also broadened the focus to address societal issues such as the environment, sustainability, and gender equality. For instance, the Community-STEM Project-Based Learning (C-STEM-PBL) approach, where pre-service mathematics and science teachers are involved in project-based learning, incorporates community assets, voices, and needs into their teaching practices. This approach emphasises community involvement, making STEM education more relevant and impactful within local contexts (Nava & Park, 2021). The Environmental STEM (E-STEM) integrates environmental education with STEM disciplines for environment-centred learning, and collaboration among teachers, professionals, and researchers in STEM activity, designed for more authentic learning experiences (He et al., 2024). E-STEM highlights the importance of sustainability and calls for updated curricula and digital infrastructure to address the evolving demands of education (Jasrai & Kaur, 2024). Likewise, Education for Sustainable Development in STEM (ESD-STEM) combines STEM education with the principles of ESD. In addition, gender-specific STEM education (e.g. STEM for Girls and Women) explores the cultural and societal influences that contribute to the gender gap in STEM fields, particularly in specific contexts such as China and Africa. This approach advocates for cultural change, gender-sensitive pedagogy, and research focusing on intersectionality and classroom dynamics to effectively address disparities and increase female participation (Gao, 2024).

Implementation of STEM education

In alignment with the evolving conceptualisations of STEM education, which have transitioned from a compartmentalised, discipline-specific approach to an interdisciplinary, integrated, and holistic framework, the implementation of STEM education varies from one country to the other (Glaze, 2020). In certain countries, the implementation of STEM education is limited to predominantly enhancing individual STEM disciplines (i.e., science, technology, engineering, and mathematics). For instance, South Korea's approach to STEM education is more siloed, with science, technology, engineering, and mathematics taught as separate subjects. However, there are efforts underway to integrate these subjects more effectively. The government has invested in initiatives that promote project-based learning and teacher training in STEM integration (Ryu et al., 2021). Conversely, other countries have adopted a more integrated approach to STEM education, fostering a cohesive and interdisciplinary learning environment (English, 2016). For instance, Singapore and Finland have a strong emphasis on integrated STEM education, where subjects are taught in a way that emphasises their connections in real-world applications. This approach is evident in their national curriculum framework, which encourages the use of project-based learning and encourages teachers to collaborate across disciplines (Brand, 2021).

Though the current position of STEM education varies in different countries, there is an ever-growing movement towards integrated STEM education and curriculum development. To add to this debate, the perspectives on how discipline integration can be achieved remained complex and varied, especially when considering the difference between multidisciplinary, interdisciplinary, and transdisciplinary approaches (English, 2016). While multidisciplinary approach to STEM education includes core concepts and skills being taught separately in each discipline but housed within a common theme, the interdisciplinary approach includes the introduction of closely linked concepts and skills from two or more disciplines with the aim of deepening understanding and skills. The transdisciplinary approach includes the application of knowledge and skills from two or more disciplines to solve real-world problems and projects with the aim of shaping the total learning experience (Xu et al., 2022).

Conversely, many countries have not successfully implemented the recommendations and concepts of integrated and holistic STEM education for several reasons (Blackley & Howell, 2015; Freeman et al., 2019; Oh, 2023). A case-to-case analysis revealed that the countries which are better ranked in STEM education are those that have developed strategic national STEM policy frameworks. These policy frameworks provide a space for centrally driven and funded programmes, including curriculum reform at all levels and new teaching standards (Gonzalez & Kuenzi, 2012; Yan et al., 2024)). These countries have also formulated a comprehensive set of strategies to achieve their STEM goals. They aligned their STEM standards, assessments and requirements with workforce expectations, enhanced student achievements in STEM disciplines and strengthened the internal capacity of educational institutions to improve the teaching and learning of STEM subjects to uplift the quality of the STEM teaching workforce. Additionally, they identified and scaled best practices in STEM education to better prepare students for STEM-related occupations. They also initiated actions to broaden the participation of underrepresented groups, such as girls, in STEM studies and careers. Another priority was to engage students across all educational levels in cross-disciplinary projects (Blackley & Howell, 2015; Freeman et al., 2019; Oh, 2023; Thiry et al., 2023).

STEM education in the Global North and South

Mudaly and Chirikure (2023) and Wolff et al. (2022) revealed that the success of STEM education is much higher in high income and developed countries as compared to the low income developing and underdeveloped countries, giving rise to speculations that STEM education is favoring the North countries as compared to the South countries. They explained that the lack of appropriate STEM education in these countries can be attributed to several factors. Despite the evolution in the conceptualisation of STEM education, the focus is still on specialised or discrete STEM disciplines rather than embracing an integrated approach. Additionally, emphasis is still on solving problems correctly rather than creatively, limiting the development of critical thinking and 21st century skills. Moreover, the education systems in these countries are still prioritising tests, grades, college admission, degrees, and factual competencies, rather than fostering a deeper understanding and application of STEM concepts.

There is increasing debate on the impacts of the STEM education, as conceptualised by the global North, on the countries of the global South. One school of thought believes that the future of any country, independent of being part of the North or South, depends on the STEM education policies to support the required STEM workforce. The success of Rwanda is often cited, where the country has recognised the significance of STEM education and subsequently increased efforts towards reviewing the country's education curriculum and at all levels. However, a second school of thought believes that STEM education, as conceptualised by the North, has a political agenda for the rich and developed countries to maintain their economical supremacy and control over the world. They therefore advocate for a STEM education for the South by the South to legitimately position themselves at the competing edge with the Northern countries.

Frameworks underpinning STEM education

There is a challenge in selecting theoretical and conceptual frameworks for STEM education research because of two main reasons. Firstly, there are no universally accepted set of

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frameworks to guide STEM education research and secondly, the field boasts a rich abundance of diverse theoretical perspectives informing research endeavours (Bybee, 2013). It should also be noted that the alignment of such frameworks is usually positioned within the disciplinary practice of the fields that are inevitably heterogeneous (varies from context to context). However, the Framing Triangle theoretical framework, described by Cohen et al. (2003), Ball and Forzani (2007) and Sujarwanto et al. (2021), was used as a lens to capture STEM conceptions from a policy, cultural and values perspectives.

In addition to the Framing Triangle framework, two other conceptual frameworks which spouse the Framing Triangle framework were used. The first one is the conceptual framework for integrated STEM education, developed by Kelley and Knowles (2016), which pivots around learning theories and pedagogies that require a deep understanding of the complexities surrounding how people learn and teach STEM content. The second one, developed by Ortiz-Revilla et al. (2022), is the theoretical framework for integrated STEM, which focused on the important current momentum along three axes of support namely, epistemological, psychological, and didactical, which consider the integration of disciplines within STEM.

Together, these frameworks offer multi-faceted perspectives, guiding this study. The Framing Triangle framework provided insights into the interactions and dynamics between key elements of educational practice. Kelley and Knowles' framework (2016) emphasised the need for integrated STEM education and Ortiz-Revilla et al. (2022) framework highlighted the importance of epistemological and pedagogical considerations. By drawing on these theoretical perspectives, the study comprehensively and systematically explores the conceptions of STEM education.

Methodology

This study used a desktop research methodology with a three-level analysis framework to uncover the evolution of STEM conceptions over the past decade within the STEM education literature. This three-level analysis aimed to explore the landscape of peer-reviewed papers, referred to as secondary data, in the field of STEM education, as follows:

Level 1: Identification of literature relevant to conceptions of STEM education

A systematic search was conducted to identify papers on STEM education that have been published during the last 10 years (2012-2022) in peer-reviewed academic journals. The criterion of 10 years was used to ensure that recent debates in STEM education are captured. The search engines and databases used were Google Scholar, EBSCO, Emerald, and Web of Science. The search method involved using keywords relevant to STEM education, including "STEM education," "siloed approach", "interdisciplinary education", "cross disciplinary education", and "transdisciplinary education". The search was further refined to include terms such as

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“conceptualisation”, “integration”, "pedagogy", "curriculum", "innovation", and "emerging trends".

Level 2: Analysis for the emergence of common conceptual themes

At this level, papers identified in stage one, were analysed to identify common conceptual themes across the literature. The associated thematic analysis involved iterative coding and categorisation of key ideas, concepts, and findings present in the literature. The iterative process began with the development of an initial set of codes derived from a comprehensive review of the literature and the research questions. The initial codes were then applied to fifty selected articles to identify recurring themes and patterns. As the analysis progressed, the codes were refined and expanded through multiple rounds of coding and recoding, allowing for the emergence of new themes. This iterative approach ensured that the coding framework was both comprehensive and flexible, adapting to the data as new insights were gained (Lim, 2024). The researchers independently coded a subset of the fifty papers and the findings were compared and discussed to resolve discrepancies and to ensure validity of data. This process facilitated the identification of overarching themes and patterns prevalent in the literature. The categorization steps involved grouping the identified themes into broader categories, which were then quantified to determine their prevalence across the dataset, termed thematic loadings. This rigorous process ensured a thorough and nuanced understanding of the major themes that emerged from the analysis (Lim, 2024).

Level 3: Deep Analysis for the emergence of new STEM-related ideas and concepts

In the third level, the narratives given in the papers within the conceptual themes identified in Level 2 were compiled and analysed to produce syntheses that were then critically analysed to identify the emergence of new STEM-related ideas and concepts. This involved deep analysis to identify nuanced perspectives and novel insights related to the themes identified in the second stage. To ensure thorough exploration, we used the method of theoretical saturation, whereby data analysis continued until no new insights or ideas emerged from the literature (Strauss & Corbin, 1998). All findings were discussed and validated by the group of researchers to ensure data validity.

This iterative process of data immersion, reflection, and refinement allowed for a comprehensive understanding of the evolving discourse and emergent trends in STEM education.

Findings

During the first level analysis, a corpus of 50 scholarly articles focusing on conceptions of STEM education, published between 2012 and 2022, were identified. In the second level of analysis, the 50 selected articles underwent systematic thematic analysis to identify the key themes or dimensions that represent the conceptions of STEM that emerged from the findings of the researchers. The analysis revealed that the key themes/dimensions that represent the central focus of the STEM conceptions were (i) STEM focus on science and mathematics, (ii) knowledge-in-use and language in-use, (iii) interdisciplinary and integrated approach, (iv) assessment, (v) teacher education, (vi) economic, societal and community, (vii) policy and (viii) culture. Figure 1 illustrates the loadings of the thematic analysis, representing the percentage of articles focusing on each identified theme. These themes encapsulated the core ideas and perspectives that underpin the conceptualisation of STEM education across the selected articles.

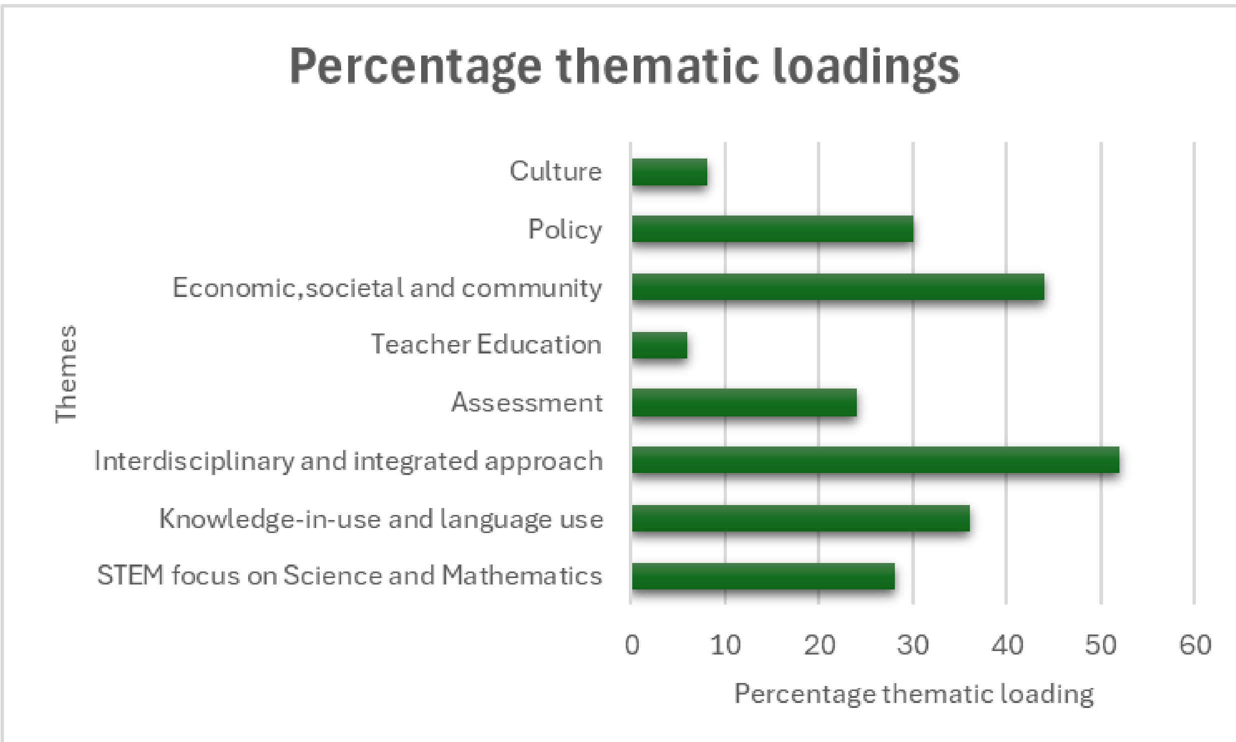

Figure 1. Thematic loadings derived from the thematic analysis

In the third level of analysis, a synthesis was prepared for each identified theme to capture the essential insights derived from a set of identified articles. Table 1 presents the themes/dimensions identified in the second level of analysis. The table also provides the corresponding set of articles that were analysed to prepare the comprehensive synthesis for each identified theme.

Table 1.
Themes and comprehensive syntheses derived from the thematic analysis.

Themes	Selected publications	Synthesis
STEM focus on science and mathematics	• Ahmed (2016) • Breiner, et al. (2012) • Bybee (2010) • Hoachlander and Yanofsky (2011) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Marginson et al. (2013) • Mcdonald et al. (2016) • Mumcu et al. (2022) • Sanders (2009) • Wang et al. (2011) • Widya et al. (2019) • Williams P J (2011) • Xu et al (2022)	Though STEM education focuses on the integration of science, technology, engineering, and mathematics, several studies expounded the role of mathematics and science as the drivers of STEM education. Mathematics and science play important roles in (i) preparing students for future careers in STEM fields, (ii) developing critical thinking skills and problem-solving abilities, (iii) encouraging students to think analytically and to use evidence-based reasoning to support their arguments, (iv) using mathematical skills in real-world contexts, (v) promoting the use of data and statistics to make informed decisions, among others. The role of mathematics and science in STEM education has evolved over time, from initially a supporting role to a fundamental role in STEM education. One reason for this shift is the growing recognition of the importance of mathematical thinking and scientific investigative skills in the modern world, as key skills for the future workforce and to address local and global challenges. Mathematics is not just a collection of formulas and equations, but a way of thinking about the world, where emphasis is on the use on the use of logic, abstraction, and quantitative reasoning to solve problems and make sense of complex phenomena. Mathematics is a foundational discipline that underlies many other fields such as science, engineering and technology, thus remains a key area that supports the interdisciplinary and integrated nature of STEM education. Furthermore, the increasing use of technology in today's world calls for an increased demand for mathematical skills. Many technological innovations, including machine learning algorithms and computer simulations, rely heavily on mathematical models and algorithms. As far as science is concerned, it remains key for understanding natural phenomena and addressing current and future challenges such as climate change, energy crises, food security, and emergence of new epidemics/pandemics among others.
Knowledge-in-use and language in-use	• Ahmed (2016) • Akgündüz et al. (2022) • Archer et al. (2022) • Aydin and Cinkaya (2018) • Costa et al. (2022) • Ismail Z (2018) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Kayumova et al. (2019) • Marginson et al. (2013) • Margot and Kettler (2019)	Knowledge in-use and language in-use are key themes in STEM education. These allow students to apply their knowledge in practical ways, as it promotes a deeper understanding of the subject matter and enhances the relevance of STEM education to real-world problems. Language in-use is also emphasised, where students are encouraged to use language to (i) explain concepts and ideas, (ii) promote clarity and precision in communication and (iii) enhance the ability of students to communicate their ideas effectively. The way that knowledge is used in STEM education has evolved significantly over time, reflecting changes in the way

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Themes	Selected publications	Synthesis
	• Mumcu et al. (2022) • Murphy et al. (2019) • Ortiz-Revilla et al. (2022) • Reynante et al. (2020) • Weyer and Erba (2022) • Widya et al. (2019) • Williams P J (2011)	educators conceptualise the integration of science, technology, engineering, and mathematics. Initially, STEM education was focused on developing specific knowledge and a set of discrete skills within each discipline, without focusing on how this knowledge and skills could be integrated to solve real-world problems. Thus, knowledge in STEM education was often fragmented, discipline-specific, and disconnected from real-world applications. However, with the advent of integrated STEM education and the need to integrate different fields to address complex problems, a shift in the way knowledge is used in STEM education was noted. The focus has shifted towards cross-cutting concepts that cut across multiple disciplines. Knowledge in STEM education has also evolved with the advances in technology and the increasing availability of data. The language used in STEM education has evolved significantly over time. Initially, language in STEM education was primarily focused on teaching language skills discretely within its discipline, with little attention paid to how these skills could be integrated to solve real-world problems. Language in STEM education was only limited to mastering the jargon and conventions of the field. However, with the evolution of STEM education from a discrete disciplinary approach to an interdisciplinary and integrated approach, the role of language in STEM education has changed. In fact, the language used in STEM education has become more accessible and inclusive over time, with educators recognising the importance of engaging all students in language. This has led to a greater emphasis on the use of language (i) to explain complex concepts, (ii) to use analogies and metaphors to make STEM concepts more accessible and understandable, and (iii) for development communication skills that prepares students for the world of work. As STEM fields become more interdisciplinary and collaborative, the ability to communicate effectively across different fields and with different stakeholders becomes increasingly important.
Interdisciplinary and integrated approach	• Ahmed (2016) • Akgündüz et al. (2022) • Brown et al. (2017) • Costa et al (2022) • Irwanto et al. (2020) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Kocabas et al. (2016) • Kocabas et al. (2020) • Laboy-Rush (2011) • Lesseig and Slavit (2019) • Li et al (2020) • Marginson et al. (2013) • Margot and Kettler (2019) • Mcdonald et al. (2016)	The interdisciplinary and integrated approach in STEM education involves integrating concepts, skills, and knowledge across different disciplines to address complex problems. These require educators to move beyond the traditional boundaries of individual disciplines and to focus on the connections and relationships between different fields. The evolution of the interdisciplinary and integrated approaches in STEM education has been driven by several factors, including technological advancements, globalisation, and changing societal needs. Moreover, the interdisciplinary and integrated approaches in STEM education have also been shaped by changes in the way that STEM fields themselves are evolving. As fields such as biotechnology, nanotechnology, AI and materials science continue to develop, they are increasingly reliant on knowledge and skills from multiple disciplines. This has led to a greater emphasis on

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Themes	Selected publications	Synthesis
	• Milner-Bolotin M (2018) • Mumcu et al. (2022) • Murphy et al. (2019) • Ntemngwa and Oliver (2018) • Ortiz-Revilla et al. (2022) • Roehrig G et al. (2022) • Sanders (2009) • Stains et al. (2018) • Stohlmann (2018) • Sujarwanto et al. (2022) • Xu et al. (2022)	interdisciplinary approaches in STEM education to prepare students for these emerging fields and future careers.
Assessment	• Ahmed (2016) • Freeman B (2014) • Holincheck and Galanti (2022) • Kalolo (2016) • Kayan-Fadlelmula et al (2022) • Kocabas et al. (2020) • Li et al. (2020) • Marginson et al. (2013) • Margot and Kettler (2019) • Sujarwanto et al (2022) • Widya et al (2019) • Williams P J (2018)	Teachers identify challenges in assessment tools, planning time, and STEM knowledge. Lack of standardised classroom assessments to gauge understanding of diverse concepts are insufficient, and concerns arise about individual assessment with group projects. The debate is also centered around effective formative assessment strategies in STEM education, which take into consideration assessment of competencies including the 21st century skills, such as digital and problem solving, but also wellbeing. Studies have also shown that STEM education coupled with effective assessment of STEM competencies also addresses low scores in international assessments like TIMMS and PISA and students' low interest in science. For instance, Korea introduced STEAM education coupled with assessment of STEM competencies to enhance learning quality, focusing on convergent thinking, creativity, and character development. America's rankings in PISA and TIMSS are lower than some developed countries, with Mathematics' and science teaching quality stagnant, while ranking is being improved for other countries which include those who has adopted STEM education. In fact, STEM research funding has influenced non-western countries' adoption, such as Saudi Arabia, Malaysia, Korea and Thailand. Effective professional development programmes for STEM teaching and assessment are essential to enhance teachers' attitudes towards science and meet professional requirements.
Teacher education	• Dare and Ring-Whalen (2021) • Li et al. (2020) • Marginson et al. (2013)	Teacher education is essential to build capacities of educators and pupils to promote STEM education. There is a strong focus of STEM education practices which are research-based such as inquiry-based learning. Rather than simply teaching students a set of facts or procedures, STEM educators are now focused on developing students' ability to ask questions, investigate problems, and develop evidence-based solutions. This has also led to a greater emphasis on the use of scientific inquiry, engineering design, and other problem-solving approaches in STEM education. STEM education is informed by professional roles and contexts as it creates the necessary space for stakeholders such as teachers, students among others to raise questions about the coherence of STEM and how it makes sense in different ways.

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Themes	Selected publications	Synthesis
		Researchers reported that planning for and implementing STEM education requires a professional dialogue among stakeholders to create a collective sensemaking and thus this dialogue among stakeholders from different contexts and professional roles is critical where issues related to STEM teaching and learning, curriculum planning and opportunities for students in terms of further learning and employability would be discussed. The trend in STEM literature strongly put forward that STEM education distinguishes itself from the single subject-based teaching and learning. In countries such as US, Canada, Australia, Taiwan and some countries in Asia, there are most collaborations among authors in STEM education research, the trend is now geared towards establishing collaborations across countries. A triadic functioning model of a theoretical framework to integrate STEM education has been proposed. This model comprises three axes, namely epistemology, didactic and psychological. The epistemological axis lays emphasis on teaching -learning process as a continuous problem solving. The psychological axis provides the learners with diverse opportunities or contexts to provide them with opportunities to manage a set of operational invariants, to develop, and to verify schemes. The didactic axis lays importance in representations and obstacles as a form of knowledge, which traditionally does not happen in single subject teaching and learning. This triadic model will help to move towards a humanistic educational contextualisation to integrate STEM education. Three key factors need to be considered when attempting to integrate STEM in teaching and learning at schools. Lack of engagement of students in early years of compulsory schooling (9 years), second implementing effective pedagogical practices to increase student interest and motivation and to develop 21st century competencies and thirdly the role of the teacher is critical in positively affecting students' attitudes and motivation.
Economic, societal and community	• Akgündüz et al. (2022) • Archer et al. (2022) • Aydin and Cinkaya (2018) • Freeman B (2014) • Gonzalez and Kuenzi (2012) • Ismail Z (2018) • Kalolo (2016) • Kayan-Fadlelmula et al. (2022) • Kayumova et al. (2019) • Kocabas et al. (2020) • Lesseig and Slavit (2019) • Margot & Kettler (2019) • Mcdonald et al. (2016) • Murphy et al. (2019) • Ortiz-Revilla et al (2022)	Social and economic rationales are key to initiate and sustain STEM education in schools. Coordination and integration of STEM activities will provide a manpower to deal with the contemporary and emerging nature of business and industry. Researchers have introduced a framework referred as informal STEM learning (ISL) settings which according to him can provide an entry point for young people who have not previously been engaged in STEM learning at schools. This framework drawing on STEM capital and sociological conceptual lens aims to capture equitable youth outcomes by foregrounding issues of complexity, power and injustice. Five equitable outcome areas were identified, namely, STEM learning, skills, knowledge; STEM attitudes and interests; STEM path-making and progression; STEM identity and identity work and finally critical STEM agency. The first two spouse the STEM capital whereas the last three align with the sociological lens.

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Themes	Selected publications	Synthesis
	• Ortiz-Revilla et al. (2019) • Sujarwanto et al. (2022) • Tang and Williams (2019) • Weyer and Erba (2022) • Widya et al (2019) • Williams P J (2011) • Xu et al. (2022)	The differences among the disciplines which constitute the STEM umbrella posits the distinction between STEM literacy and STEM literacies. STEM literacy refers to (STEM for all) all students—whether or not they pursue careers in science, will be consumers of news and information on STEM issues that will directly affect their lives. STEM literacies, drawing on UNESCO "plurality of literacy" (2004), emphasises the varying linguistic, cognitive and epistemic dimensions of the disciplines which is more appropriate in capturing the wide range of skills and emphasis related to specialised professions (Tang and Williams, 2019). This "plurality of literacy" recognises that there are "many practices of literacy embedded in different cultural processes, personal circumstance and collective structures". Therefore, this distinction of STEM literacies from the singular STEM literacy is key to interpreting, critiquing, and creating the different kind of cognitive and metacognitive processes used across the disciplines and in multiple communities and educational contexts.Practices from a single subject area may provide a framework to integrate the various STEM-related subjects though this can be influenced by the content knowledge. Each discipline has its own distinct epistemologies. While these epistemological frameworks inform the types of practices, they also orient practitioners toward different ways of thinking and understanding. (Brandon et al 2020).
Policy	• Ahmed (2016) • Akgündüz et al. (2022) • Archer et al. (2022) • Freeman B (2014) • Holincheck and Galanti (2022) • Kalolo (2016) • Kayumova et al. (2019) • Li et al. (2020) • Murphy et al. (2019) • Ortiz-Revilla et al. (2022) • Reynante et al. (2020) • Sujarwanto et al. (2022) • Weyer and Erba (2022) • Williams P J (2011) • Xu et al (2022)	STEM education in some North countries have not been able to prepare students to become workforce needed to maintain their competitive edge in the globalised world, due to lack of appropriate STEM policy. Three key comparisons among countries on STEM education success based on their legislative and policy framework supported with organisations and structures to coordinate the implementation. These are STEM literacy (in breadth), STEM excellence (in depth) and STEM inequity (redressing systemic inequities).
Culture	• Marginson et al (2013) • Kayumova et al (2019) • Otiz-Revilla et al (2022) • Kayan-Fadlelmula et al (2022)	Culture plays a significant role in shaping and influencing STEM education and participation across different contexts. Different cultural factors such as social interaction, educational practices, gender norms and indigenous perspectives, impact the effectiveness and accessibility of STEM education and career pathways. There is a need to integrate cultural insights and adapt teaching methods to align with the cultural contexts of students and educators, fostering more equitable and effective STEM learning environments.

In the third level of analysis, the themes and their corresponding syntheses were subjected to further scrutiny and qualitative analysis. These led to the emergence of novel and nuanced ideas, perspectives, and concepts pertinent to the STEM conceptions discourse. The emergent themes identified were as follows:

Theme 1: Compartmentalised multidisciplinary against integrated approaches

One of the most pertinent discourses around STEM conceptions remains one's positionality concerning the compartmentalised versus integrated approaches to STEM education (Sanders, 2009). In fact, STEM education has evolved significantly over time leading to two ideological stances. The first stance focuses on developing specific knowledge and skills within each STEM discipline, that is science, technology, engineering and mathematics, without focusing on how this knowledge and skills could be integrated to develop concepts and to solve real-world problems (Bybee, 2010; Hoachlander & Yanofsky, 2011). Thus, knowledge and skills remained was fragmented, discipline-specific, and disconnected from real-world applications. The second ideological stance, commonly referred as integrated STEM (iSTEM), is aligned to interdisciplinary learning where different fields are brought together to address complex problems. Several articles have showcased the use of the iSTEM approach by educators, where greater emphasis is laid on cross-cutting concepts, that is concepts that cut across multiple disciplines (Kocabas et al., 2016; Li et al., 2020; Stohlman et al., 2014). However, analysis of the scholarship revealed that though most recent publications showcase increasing enthusiasm for iSTEM, compartmentalised multidisciplinary STEM education remains the persistent approach of learning in most educational settings around the world. We argue the choice for compartmentalised or iSTEM approach may depend on contexts from policies, capacity of teachers across all STEM related disciplines, and curriculum development perspectives.

Theme 2: Dominance of disciplines

The second pertinent debate around STEM education is the dominance of disciplines within STEM education. While the latter is designed as an integrated approach where science, technology, engineering, and mathematics are brought together as a cohesive entity to solve real-world problems, the findings exhibited a discernible emphasis and even a dominance on mathematics and science.

The dominance of disciplines is supported by Kristensen et al. (2024) and Shahali and Halim (2023), who explained that there is a prevalent trend in STEM curricula and instructional practices, where mathematics or science often occupies a central position due to its foundational importance and applicability across various STEM disciplines (Tang & Williams, 2019). Numerous studies highlighted the pivotal role of mathematics and sciences in fostering critical thinking, problem-solving skills, and quantitative reasoning essential for success in STEM fields.

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In fact, the role of mathematics and sciences within the framework of STEM education has undergone a notable transformation over time, transitioning from a supporting role to assuming a foundational position (Mcdonald et al., 2016). This shift can be attributed to the growing importance of mathematical thinking and scientific investigative skills in contemporary society, its role as a requisite skill for the future workforce and its foundational role in other disciplines such as technology, and engineering (Boaler, 2016; Hiebert & Wearne, 1996). This shift underscores the dynamic interplay between mathematics or science and STEM education, reflecting the evolving landscape of contemporary education. Additionally with an increasing demand for engineering, the design component of the STEM umbrella make take a leading role in the STEM education agenda.

Theme 3: Extending the core disciplines in STEM

The analysis showed extension of the core disciplines within the realm of STEM education. The extension implies a broadening of the traditional boundaries that delineate the core domains of STEM, to incorporate additional disciplines into the STEM equation. It underscores a shift towards a more integrated and holistic approach to STEM education, aimed at fostering innovation, creativity, and adaptability in addressing complex societal challenges (Breiner et al., 2022; Bybee, 2010; Revilla et al., 2022) One example of extension is the integration of language in-use in STEM education leading to the development of STEM variant STREAM, with the additional R standing for reading/writing (Hoachlander & Yanofsky, 2011). In fact, at its conception, language in STEM education was only limited to mastering the jargon and conventions of the field. However, the role of language in STEM education has changed to become more accessible and inclusive over time, with educators recognising the importance of engaging all students in language (Archer et al., 2022; Murphy et al., 2019). This has led to a greater emphasis on the use of language to explain complex concepts, to use analogies and metaphors to make STEM concepts more accessible and understandable, and to develop communication skills that prepare students for the world of work. As STEM fields become more interdisciplinary and collaborative, the ability to communicate effectively across different fields and with different stakeholders became increasingly important (Kayumova et al., 2022, Murphy et al., 2019). This extension of STEM towards non-scientific disciplines, such as language and arts, might help to promote academic writing and creativity respectively.

Theme 4: Policies and practices for STEM education

Existing policy documents make references to promoting STEM education at different levels in view of providing the required workforce for the present generation and beyond. However, the findings revealed that these are fragmented policies, which do not reflect a systemic or holistic policy for STEM education. Consequently, these existing policies are not sufficient to equip the present and future generations with the necessary STEM competencies needed to create a workforce that will maintain a competitive edge in a globalised world (Kocabas et al., 2020). Today's leading debates include the need to re-orient STEM policies and practices towards achieving the workforce for STEM competencies. These policies and practices should look at the breadth of coverage of STEM in the education policies and practices, referred to as STEM literacy or STEM excellence (STEM in depth) as well as addressing inequities in terms of accessing quality STEM education (STEM inequity). STEM policy making and formulation might become a more dynamic process to incorporate changes and updates in the said policies.

Theme 5: Variations in the implementation of iSTEM education

In addition to the discourse of one's positionality between compartmentalised versus integrated approaches to STEM education, another pertinent discourse that emerged from the findings is the variation in the implementation of iSTEM education. One notable variation identified was the differing approaches to the implementation of iSTEM at the classroom level, in relation to students' engagement, pedagogical practices used, and the role of teachers (McDonald, 2016).

Another variation was the theoretical framework(s) used to guide the implementation of iSTEM education. An example of a functioning framework for the implementation of iSTEM education in teaching and learning is the triadic model proposed by Ortiz-Revilla et al (2022). This framework comprises three axes, namely epistemology, didactic and psychological. The epistemological axis emphasises the teaching-learning process as continuous problem-solving. The psychological axis emphasises on the learners with diverse opportunities or contexts to provide them with opportunities to manage a set of operational invariants. The didactic axis lays importance in representations and obstacles as a form of knowledge, which traditionally does not happen in single subject teaching and learning. This triadic model provides a humanistic educational contextualisation to integrate STEM education. Another example of framework commonly used was the Informal STEM learning (ISL) framework proposed by Archer (2022). It provides an entry point for young people who have not previously been engaged in STEM learning at schools. Drawing on STEM capital and a sociological conceptual lens, this framework aims to capture equitable youth outcomes by foregrounding issues of complexity, power and injustice and thus consolidate the democratic nature of STEM education and education at large.

Theme 6: Epistemological considerations for STEM education

Another interesting discourse in STEM education is the difference in epistemological considerations underpinning the distinction between STEM literacy and STEM literacies. STEM literacy, that is STEM for all, refers to all students regardless of whether they pursue careers in science, as they will engage with information on STEM issues that directly impact their lives.

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STEM literacies, which refers to the plurality of literacy (UNESCO, 2004), states that the varying linguistic, cognitive and epistemic dimensions of the disciplines are more appropriate in capturing the wide range of skills related to specialised professions (Tang & Williams, 2019). This plurality of literacy recognises many practices of literacy embedded in different cultural processes, personal circumstances and collective structures. Therefore, this distinction of STEM literacies from the singular STEM literacy is key to interpreting, critiquing, and creating the different cognitive and metacognitive processes used across the disciplines and in multiple communities and educational contexts.

The findings also revealed that practices from a single subject area may provide a framework to integrate the various STEM-related subjects though this can be influenced by the content knowledge. Each discipline has its own distinct epistemologies. While these epistemological frameworks inform the types of practices, they also orient practitioners toward different ways of thinking and understanding (Brandon et al., 2020). The interesting point here is that it provides more than one entry to engage in the STEM education processes.

Theme 7: STEM for employability

The global emphasis on STEM education extends beyond innovation to the cultivation of a highly skilled workforce primed for the demands of modern industries. There are ongoing efforts throughout the world to enhance educational standards, with a particular focus on fostering problem-solving abilities, creativity, and critical thinking which are all essential attributes in today's innovation driven economy (Xu et al., 2022; Weyer & Erba, 2022). The success of these endeavours also relies on significant investments in the professional development to attain the relevant STEM employability competencies. Besides, there is an international call for more students to pursue STEM programmes at the tertiary level, which can help them transit into STEM-related research careers (Freeman, 2015). This necessitates programmes that ensure STEM literacy at the secondary level so that a solid foundation is developed for future educational pursuits and career opportunities in STEM.

Entrepreneurship and the corporate sector have pivotal roles in the employment landscape, driving both economic growth and innovation. This role will have to be extended to support the education sector hence address the existing mismatch between the corporate employability requirements and the supply from the education sector. Programme/ curriculum development committees could consider having representatives from the corporate/industry sector.

Theme 8: Realigning Assessment in STEM Education

Assessment in STEM education is crucial for determining the preparedness of students and the workforce to meet the demands of a rapidly evolving global landscape. In current

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education, there is a dominance of summative assessment, both at international and national levels, which focuses mainly on the cognitive aspects of learning. By its nature, STEM education encompasses a set of competencies which are marginalised when it comes to assessment of learning. We, therefore, argue that to ensure a proper equation between an elaborated STEM and assessment, the assessment practices should be foregrounded in the evaluation of STEM competencies from early years to higher education (Kocabas et al., 2016; Widya et al., 2019). Thus, an assessment framework for STEM competencies would help to foreground this proper equation.

STEM Education Conceptions Framework

Figure 2 shows the 'STEM education conceptions framework' that has been developed from conceptions that emerged from the systematic analysis of the scholarship on conceptions of STEM education.

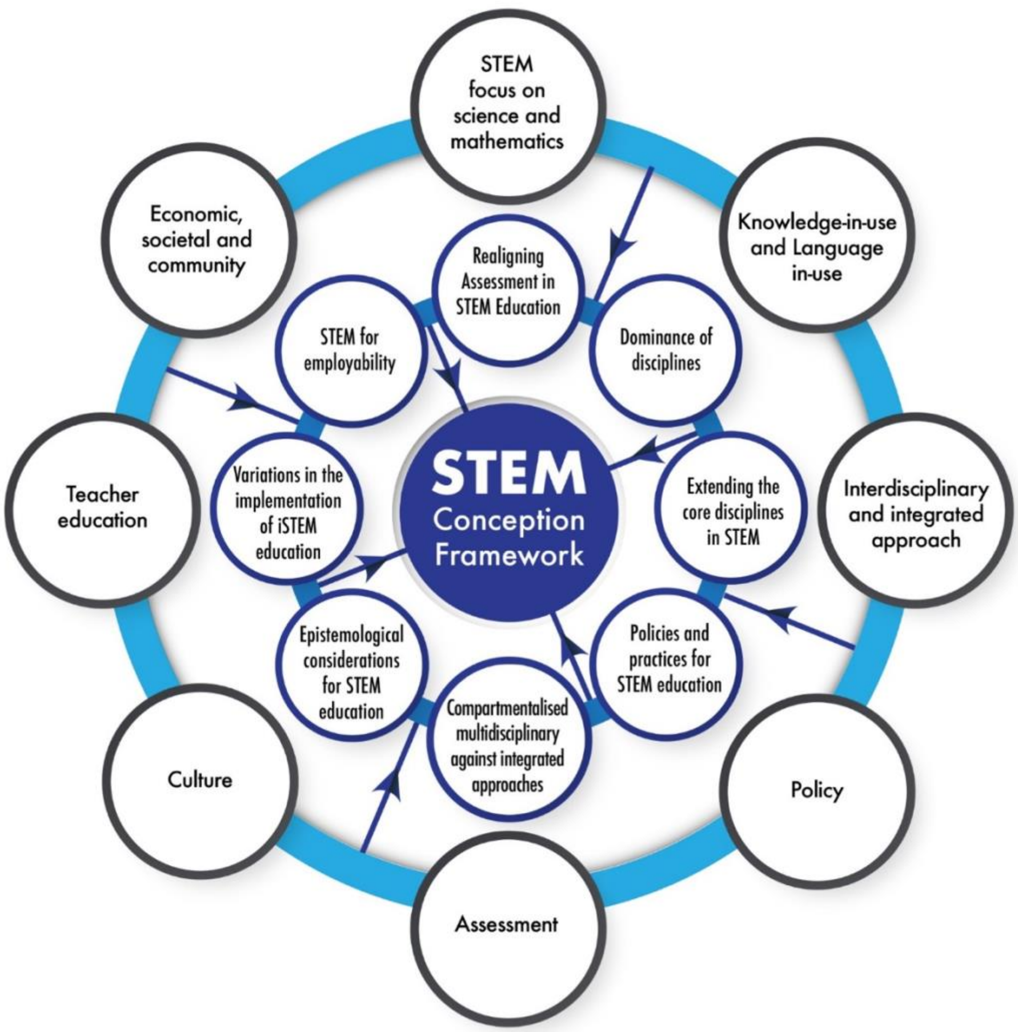

Figure 2. STEM Education Conceptions Framework (SECF)

Discussion

STEM education has assumed significant importance related to debates on educational reform efforts (Holmlund et al., 2018) in the Global North and South. STEM education in both Global North and South has become a figure of rhetoric in education driven by the dynamic duo - global economy and workforce needs (Ahmed, 2016). The arguments thereof are reasonable as appropriate STEM education has a crucial role in enhancing economic fortunes through a highly educated labor force, and thus increasing the national competitiveness (McDonald, 2016).

Notwithstanding, as Willians (2011) posits, there is a need to proceed with caution, especially when the focus is on meaningful iSTEM education instead of the traditional compartmentalised STEM education. We therefore argue that the development of STEM policies and their implementations should be preceded by a systematic analysis of the conceptions of STEM education and the issues associated with it. Amid arguments that it is not driven by education rationale per se (Williams, 2011) and countries implement it differently (Roehrig et al., 2022), we need to address the issue of what constitutes STEM (Ortiz-Revilla et al., 2022), and a lack of complete unison concerning its global attributes as an innovation (Holmlund et al., 2018). These issues, particularly the latter, are important as they will map out the way forward on how STEM education is conceptualised from national to global levels and critically analyse how it is currently measured especially when STEM education is still conceptualised differently (Xu et al., 2022).

We acknowledge that considerable research has been done on country specific STEM education (Marginson et al., 2013), key definitions of STEM (Hasanah, 2020; Marginson et al., 2013), STEM variations such as STEAM (Anderson, 2021; Belbase et al., 2021; Weyer & Dell'Erbs, 2022), STEM policies, commitments and practices (Kalolo, 2016), and most importantly on STEM frameworks (Kelly & Knowles, 2016; Ortiz-Revilla et al., 2021). Nevertheless, this study has focused on the most current and pertinent discourses around the global conceptions of STEM education. We believe that our findings and the developed 'STEM Education Conceptions Framework (SECF)' will provide a collective uncharted terrain for research and pave the way for meaning and understanding STEM education in the Global South and North countries, which have contrasting outlooks in terms of developing industrial base, education pathways, teacher characteristics and STEM opportunities.

In fact, the development of a STEM education conception framework thereof is crucial for several reasons. Firstly, it provides a structured and coherent understanding of the complex nature of STEM education, which is an amalgamation of various disciplinary approaches, pedagogical strategies, and educational policies (cf. Kelly & Knowles, 2016; Aguilera et al., 2024). The framework encapsulates these diverse dimensions into a unified model that can guide

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educational stakeholders including educators, school leaders, researchers, and policymakers in understanding and implementing effective and meaningful STEM education practices today. Theorising STEM education in contemporary society (marked by technological and economic developments that call for frameworks for rethinking STEM education praxis [Sujarwato et al., 2021]), George Fomuyan (2020) calls for adapting frameworks for application in the era of the fourth industrial revolution where STEM education practices should mould scholars with 21st-century skills, hence prepared for such era's workplace. After all, 21st-century virtual reality, among others, has already attracted practitioners' interest (Christopoulos et al., 2020). It is worth noting here that "most of the pedagogical models proposed for STEM education…focus imprecisely on the methodological dimension of the STEM approach… [hence a need for] a robust epistemological and pedagogical framework…[essential] for the design of coherent and viable didactic model" (Aguilera et al., 2024, pp. 2). By identifying and describing the current and most pertinent discourses around STEM education, such as the compartmentalised versus integrated approaches, dominance of disciplines, variations in the implementation of iSTEM education, epistemological considerations for STEM education and variations in and the role of policies and practices, the framework facilitates a clearer comprehension of how these elements interact and influence each other. The aspect of interdisciplinarity, does not only pinpoint STEM's influence in the collective solving of practical problems but also points to the associated "…generation of new codes, common understanding, methodological conceptual agreements, and ways of formalizing exchanges…a leap that, when achieved, is irreducible to the participating disciples" (Ortiz-Revilla et al., 2022, pp. 385-386). The SECF therefore makes provision to identify and uncover the complex interconnectedness within a broader perspective of STEM education.

Secondly, SECF is vital for addressing the variations in STEM education practices observed across different contexts or countries. As Marginson et al. (2013) reported that despite varying discipline grouping that fall under the ambit of STEM, mathematics and science remain fundamental to both narrow and broad conceptions, SECF framework provides a systematic structure that may be used to analyse these variations, enabling stakeholders to identify best practices, adapt interventions to specific contexts, and enhance the consistency and quality of STEM education across diverse educational settings.

Thirdly, the inclusion of aspects such as STEM for employability and the impact of economic, societal, and community factors underscores the framework's relevance to broader educational and societal goals. STEM education is not merely about imparting knowledge but also about equipping students with the competencies necessary for successful careers and informed citizenship. By integrating these considerations, the framework ensures that STEM education remains aligned with the evolving demands of the workforce and contributes to societal advancement.

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However, for the successful adoption of the SECF, all actors involved in the promotion of STEM education need to have a sound understanding of iSTEM. This could be hindered by the diverse STEM conceptions which might exist among the actors within a particular country and from countries to countries. Furthermore, the SECF does not explicitly situate innovation and values in transforming practices through STEM education. The Values-based model proposed by Vedrenne-Gutiérrez et al. (2024) identified values and ethics in STEM education which are fundamental in directing science and technology policies and shaping organizational cultures to leverage innovation. This values-based model is implicitly captured across the underlying concepts within the SECF.

Conclusion

This study has come up with eight emerging themes for STEM education by drawing on STEM literature from peer-reviewed papers published over the past decade. Existing literature has revealed several frameworks for STEM education (Ball & Forzani, 2007; Cohen et al., 2003; Kelley & Knowles, 2016; Ortiz-Revilla et al., 2022; Sujarwanto et al., 2021) which was either positioned within the disciplinary practice or provided compartmentalised cultural, policy and values perspectives for STEM education or a lens to capture the complexities of interactions within the various conceptions of STEM education. The 'STEM Education Conceptions Framework, developed from the emerged discourses on STEM education provides a holistic view of conceptions allowing space for a much broader and a wide range of perspectives including epistemological, psycho-pedagogical and at the same time opening for more possibilities of connectedness thereby extending the STEM disciplines. This SECF is also crucial for advancing our understanding and practice of STEM education. The framework offers a valuable tool for educational stakeholders to navigate the complexities of STEM education and engage in meaningful STEM education. Stevenson et al. (2024) highlighted key experiences valued for helping teachers learn and integrate STEM education content. However, they stated that the complexity of STEM education and teacher learning means that different activities lead to different learnings. Our conceptual framework will provide guidance to teachers and teacher educators to include STEM-based learning at schools.

Acknowledgment

SECF developed through analysis of existing literature defined within a time frame of 2012-2022 has opened some broader perspectives, yet it could be further evolved by new emerging research ideas on STEM education research.

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