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STEM education in the Global North and Global South: competition, conformity, and convenient collaborations

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Science, technology, engineering, and mathematics (STEM) education is increasingly viewed as a vehicle for global dominance and a panacea to economic downturns, environmental challenges, and food security. However, divergences in STEM education agendas at regional and national levels imply disparities in policy formulation and implementation in the Global North and Global South. This study sought to explore what informs the drivers of STEM education in the two geo-economic blocks with a view to understanding contextual factors that inform practice. A focus on STEM education in the Global North and Global South becomes necessary, given the widespread calls for collaborative work, for example, shared interests in addressing sustainable development goals, and research on the COVID-19 pandemic. A theoretical approach, based on a review of relevant literature, was adopted. Ideology critique informed the analysis and was used to make sense of the salient themes. In the 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 the STEM education enterprise. In the Global South, massification with equity dominates policy formulation and implementation as countries battle to redress past colonial imbalances. The 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 at policy adoption at vocational level. Convenient partnerships are increasingly fashionable as countries in the Global North seek to exploit the geographical advantage of those in the Global South in order to fully utilise the extra-terrestrial space, resources for biomedical science and indigenous natural resources, among others. Collaboration endeavors between the Global North and Global South need to be mutually beneficial. The Global North needs to redistribute the aspects of power it holds in relation to STEM to move towards more equitable policies and practices across these geopolitical realms. We recommend greater vocationalisation of STEM education hinged on STEM integration with the humanities in the Global South and balanced, mutually beneficial STEM collaboration endeavors with the Global North countries.

KEYWORDS

STEM, STEM education, ideology critique, humanistic STEM education, Global South, Global North

Our positionality and our purpose

We are science teacher educators who are collaborating on a science, technology, engineering, and mathematics (STEM) education project. The first author, an African man, is an academic who has studied, worked, and lived in four different Global South countries. The second author is an Indian woman academic who works at a South African higher education institution. We have shared experiences of marginalization based on race, ethnicity and socio-economic status, and currently live in postcolonial societies which are plagued by social, economic and political uncertainty. Within this context our commitment towards a social justice approach in STEM education developed. Although we are critical of cognitive injustice which fuels socio-political and economic injustice, we are aware of our own complacency, complicity and conformity in our work which is located within the corpus of dominant Euro-Western knowledge frameworks. This awareness has served as a transcendental moment in our professional lives and has contributed to our agency to explore the what, why and how of STEM education in the Global South and Global North.

The Global South and the Global North are two zones delineated by the Brandt line based on political and socioeconomic development (Solarz, 2012; Barta, 2020; Lees, 2021). The Global South refers to developing countries in Africa, eastern Europe, Latin America and Asia (including China despite its unique economic growth status). Most of the Global South nations are characterized by a colonial past and an anti-colonial identity, comparatively little industrialization, and foreign exploitation of natural resources. The Global North consists mainly of economically developed countries in Europe, North America, and Australia with extensive industrialization, technological advancement, and free market economies for generation and accumulation of wealth. This zoning of the world apparently emboldens the colonial legacy. In STEM education, the Global South and Global North divide negates the universality of STEM knowledge.

The key question which we seek to answer is: What informs the drivers of STEM education in the Global South and Global North? The purpose is to make visible the different drivers of STEM education in these geo-political blocks, based on different historical, cultural, socio-economic and political contexts, and to critique the ideology which sustains the political and economic imperatives in which STEM education drivers are embedded. The unmasking of ideological forces in STEM education will be significant to research theorists and teacher educators in the field of STEM education. We adopt the theoretical lens of ideology critique, the discussion of which we privilege at the outset in this systematic review, in order to make our philosophical position clear.

Theoretical perspectives

Ideology critique "focuses on exploring whether particular ideas (which represent certain groups' ideology) are influenced by visible or invisible power or other factors leading to a specific way of thinking that influences social development" (Fuchs, 2016, p. 4). Underpinning the normalization of perceived truths are particular socio-political and economic agendas (Friesen, 2008). Friesen (2008) adds that through ideology critique, questions emerge about why decisions are made in particular ways, whose interest is served, and how the politics of knowledge influences decisions. Deep introspection into these questions renders parochial interests visible and creates spaces for developing "emancipatory knowledge" (p. 2) and different ways of acting.

Ideology critique, in this study, makes visible the different drivers of the STEM enterprise in the Global South and Global North, and the ideological forces which shape these. Our refusal to limit our vision of STEM education using a monolithic Euro-Western lens is deliberate. It is intended to cast doubt on the normalization of STEM education and STEM research as a panacea for social and other ills, and for the greater good for the human population and natural environment. Instead, it forces the researcher gaze on the neoliberal model of STEM research and STEM education, which are undergirded by the "realities of capitalism, profiteering, racism, and oppression" (Basile and Azevedo, 2022, p. 1085).

Ethical questions about advancing the STEM enterprise include: which needs, whose wants, and at what cost (to people, wildlife and the environment) (Kahn, 2015). When using this critical lens, Apple (2019, pp. 279–280) draws attention to "relational action, and repositioning." Considering that institutions, including those in the education sector, are inextricably linked to inequalities that frame society, acting relationally to address the existing inequalities is underscored. Repositioning involves peering through the lenses of the dispossessed and disenfranchised, then devising action against institutional processes which deepen oppression.

The influence of the culture of neoliberalism on STEM education is significant, given the imperatives to work transnationally, across cultures, assuming a position of working for the greater good. It is crucial to acknowledge that [STEM] fields comprise "high status knowledge" (Apple, 2019, p. 277) but there is need to question the practice of STEM. Who does STEM education serve? Is [STEM] education steered towards human flourishing or is it intended to serve the economically elite (Weinstein et al., 2016)? Millar (2020) questions who decides what the barometer of valid knowledge in STEM disciplines is, and how, for whom, and for which context the knowledge produced is recontextualized. Other scholars are skeptical about the subtexts of "ideological and valuative visions" (Apple, 2018, p. 686). Further questions can be asked in relation to assessment. Whose knowledge is being assessed in international tests, and for whose benefit? What do scores on these international tests represent in terms of power relations and the knowledge economy? What are the effects of policies which influence the what and why of STEM education, and the beneficiaries of the STEM enterprise? The questions, which are disquieting to Apple and Millar, are not new. Indeed, these have been raised previously, for example, Hountondji, in Kiti (2013, p. 2) asked:

> Where, […], does all the equipment used for research come from? How are research topics selected? On what social needs or other practical requirements are they based, directly or indirectly? Where on earth are these needs felt? Who in reality are the intended beneficiaries of this research? Where will the findings end up?

These are important considerations which, through ideology critique, can reveal the complexity of the drivers of STEM education which are neither neutral nor value-free. We locate ourselves within this theoretical positioning.

Conceptualizing STEM

The emergence of STEM (science, technology, engineering, and mathematics) education in the 1990s is credited to the USA's National Science Foundation who first conceptualized it as SMET. In essence, STEM (education) is a social construct (Akerson et al., 2018) touted as a panacea for economic and global challenges. However, the ambiguity in the meaning and significance of STEM has persisted since it was first conceptualized (Sanders, 2009; Bybee, 2013; Aguilera and Ortiz-Revilla, 2021). Skepticism surrounding the impact of STEM education is highlighted by Akerson et al. (2018) who questioned whether calling what we do STEM changes what we are doing and calling what we teach STEM changes the content and how it is mediated. The integration of two or more STEM domains has gained traction over the years (Becker and Park, 2011; Bybee, 2013; Blackley and Howell, 2015; Millar, 2020). Some advocates for an integrated STEM approach define it as a "seamless amalgamation of content and concepts from multiple STEM disciplines" (Nadelson and Seifert, 2017, p. 221). However, this utopian view of integration obviates the diversity of school contexts in the Global South and Global North thus rendering it untenable. Herein lies our rationale for focussing on STEM education in these two geo-economic blocks. The negative impact of the industrial practice of STEM has precipitated advocacy for a humanistic approach, which includes the arts, to STEM education. This has given birth to STEAM premised on the notion that socio-scientific and moral considerations (Zeidler, 2014; Kahn, 2015; Zeidler, 2016) can provide a holistic STEM education for the 21st Century citizenry.

Contention over the nature of STEM persists, and some scholars assert that STEM has no real nature (Akerson et al., 2018). Differences between science and engineering in terms of goals, processes and products, for example, make the integration questionable. Some common characteristics of these disciplines such as the scientific method(s), empirical evidence, the role of observation and scientific theories to understand natural phenomena, can connect them conceptually (Akerson et al., 2018). Cross cutting concepts which link STEM disciplines include creative design (which can be based on scientific discovery) and the cultural embeddedness of STEM as socially constructed by humans who attempt to interpret phenomena in the natural and material worlds (Akerson et al., 2018). Other scholars posit that the integration of STEM disciplines is based on instrumental interdisciplinarity and conceptual interdisciplinarity (Millar, 2020). The commodification of STEM disciplines towards meeting economic needs, buttressed by governments, is an example of instrumental interdisciplinarity. Conceptual interdisciplinarity is philosophically aligned, can be demonstrated by understanding the interconnectedness of STEM disciplines, and is viewed as being well suited in a world where "problems are complex and intertwined" (Millar, 2020, p. 935).

Zeidler (2016) recommends an interdisciplinary approach to STEM, which connects science to the humanities, and underscores skills for success in STEM, which are similar to 21st Century skills. These include the capacity for being reflexive when acting in the social and natural world, responsible decision making informed by ethical and moral imperatives, being a conscious practitioner (Green, 1999), and demonstrating agency in taking responsibility for one's own learning. The humanistic approach to [STEM] education involves raising critical consciousness.

The notion of addressing and being respectful of [societal and individual] differences is crucial especially when one considers that Eurocentric norms and perspectives dominate education globally (Twelker, 2015). Twelker (2015, p. 7) reminds us that "The way people think of the world is developed in Europe and, through colonialism, transferred to the rest of the world." The global order is premised on the superiority of Euro-western values and views [*ibid*]. This has implications for teaching STEM subjects for 21st Century citizenship, and conceptualisation in different settings of what is a sustainable world, and what skills are needed to work towards this.

STEM education initiatives are often criticized as vehicles for industrial democratization and corporate aggrandizement (Bencze et al., 2018). Neoliberalism refers to an agenda of socioeconomic transformation premised on an unregulated free market economy. It is characterized by optimizing profits as a legitimate incentive for successful competition and prioritization of corporate and individual wealth accumulation (Kotz, 2002; Harvey, 2007; Connell, 2010, 2013) and permeates the economies of the Global South and Global North.

Reframing the STEM discourse

Weinstein et al. (2016) and Zeidler (2016) provide a critique of STEM education which reveals that in our haste to leverage the affordances of innovation borne of STEM disciplines, we miss the signs which point to a neoliberal, deficit model of STEM education. Weinstein et al. (2016) contend that through the advancement of intellectual property rights and the maintenance of the market as a purveyor of truth, the "quantity and quality of scientific research" (p. 202) has been diminished because the record of unexpected results which stimulates further scientific endeavors is reduced.

It is undisputed that while the COVID-19 pandemic leaves in its wake unprecedented social and economic devastation, it has also made way for collaborative partnerships among public and private entities, scientists, donors, government departments and other bodies. These partnerships which include contributions from African scientists (Kana et al., 2021) have resulted in the accelerated production of diagnostic testing kits and life-saving SARS-CoV-2 vaccines. The dynamics of collaboration, however, are complex and in the case of the COVID-19 pandemic, two models of collaboration have been identified, namely, "knowledge sharing (sharing of knowledge and technological expertise)" and "materials transfer (transfer of materials, technical infrastructure and intellectual property rights)" (Druedahl et al., 2021, p. 6292). Within these partnerships, materials transfer and not the active sharing of knowledge, has been favored. Several of the knowledge transfer partnerships were characterized by a unidirectional flow of knowledge, for example, from Pfizer to government departments, in a way which severely limited governments' claims to any intellectual property rights of new products which are formed through further research (Druedahl et al., 2021). The call to waive intellectual property rights temporarily, in order to share the work of scientists globally, has been emphasized (del Rio et al., 2021).

The neoliberal model of STEM becomes increasingly visible by the corporatisation of laboratories and universities, where competition rather than collaboration is prized. The COVID-19 pandemic has demonstrated the complicity of STEM in the manifestation of "for-profit medicine and marketised approaches to health" (Sparke and Williams, 2022, p. 16). The deepening of social instability and economic inequality, and the advancement of opportunities for economic exploitation in the wake of the pandemic, have resulted in the proliferation of what Sparke and Williams (2022) refer to as a neoliberal disease.

Curricular priorities for STEM education

The curricular priorities for STEM education include producing a STEM-capable citizenry, a STEM proficient workforce, and future STEM experts (The President's Council of Advisors on Science and Technology, 2010). Achieving these priorities entails improving STEM teaching by recruiting, training, and incentivizing great STEM teachers. Prioritizing the upskilling of teacher educators is crucial. Otherwise the cycle of teacher educators with limited or no engineering backgrounds who teach preservice teachers (who themselves have no engineering backgrounds) remains unbroken. From a social justice perspective, there is need to promote inclusivity in STEM education by emphasizing equity with respect to gender, disability, and minority groups (BrckaLorenz et al., 2021; Klimaitis and Mullen, 2021).

There is acknowledgement that the practice of STEM has led to unintended consequences hence the need for a socio-scientific approach (Committee on Prospering in the Global Economy of the 21st Century, 2007). A socio-scientific issues approach empowers learners to critically reflect on the human dimension in the practice of science (Evagorou and Dillon, 2020). Hence, scholars have argued cogently for moral and socio-scientific considerations in the mediation of STEM curricula (Kahn, 2015; Zeidler, 2016).

This gives impetus to the advocacy for STEM curricula which go beyond integrating at least two of science, technology, engineering, and mathematics to include the arts (STEAM). The need for STEM education to produce a workforce and experts who are innovative enough to address global health, environmental, food supply, and other economic issues suggests that the integration of the humanities should be prioritized as a relevant socio-scientific response (Zeidler, 2016). Arguably, the priorities of STEM education are defined by the scientific, academic, educational and/or political contexts and geographical spaces in different countries (Aguilera and Ortiz-Revilla, 2021). Furthermore, political reactionism often influences STEM education policies and priorities (Blackley and Howell, 2015), albeit, in different ways across the globe. To gain an understanding of what drives STEM education in the Global South and Global North from an ideology critique perspective, we undertook a systematic literature review. The details of our methodological choices are outlined in the sections that follow.

Methodology

Our inductive process began with discussions of our professional experiences and our working knowledge of STEM education. We then purposively collected, recorded, and created a repository of documents related to the phenomenon. During a period of 14 months, we used scholarly databases to access a dense pool of literature on STEM education, which was augmented with STEM-related publications which we had gathered prior to this study for our professional work. Our repository comprised mainly articles and book chapters on STEM education which were published in the last 14 years. The aspects of interest in our literature search are shown in Table 1.

Our search terms generated several possible sources of data. These were then screened by excluding duplicates, sources which were not aligned to the research objective or did not yield full texts (Figure 1). The selected sources were analyzed to synthesize the drivers of STEM education in the Global North and Global South.

For each search term, exemplar authors from each zone are included in the Table 2.

The quote from the president of the United States of America was extracted from a press statement found in the repository of The White House Office of the Press Secretary.

The data analysis was informed by the "recursive and iterative" cycle proposed by Yin (2016, p. 187). Compiling the data involved sorting the documents into batches based on their focus areas. We generated five questions which guided our analysis (Table 3). Each researcher individually coded the data. We then collated our codes and subsequently engaged in axial coding (Cohen et al., 2018; Denzin and Lincoln, 2018) by reassembling, refining, and merging where necessary. The data analysis continued until we reached saturation of codes. We conducted constant comparative analysis (Strauss and Corbin, 1990) between our previous ideas and evolving ideas, and

TABLE 1 Elements of the systematic literature review.

Element	Description
Inclusion criteria	*Type of publication* • Journal articles • Books/book chapters • STEM frameworks • Reports • Press statements by politicians • Newspapers opinion pieces/articles *Publication period:* • 2008–2021 *Place of publication*: • Worldwide *Type of study:* • Empirical studies • Theoretical studies
Exclusion criteria	*Type of publication:* • Dissertations • Predatory journals
Literature search	*Main search terms:* • STEM education • drivers of STEM education • STEM policy • Massification of STEM • STEM education in the Global South • STEM education in the Global North
Databases	• ERIC • Google Scholar

between existing literature and our own work in order to increase validity. The interpretation process entailed developing a narrative on the drivers of STEM education in the Global South and Global North based on the emerging themes. In concluding, we drew from the conceptualisation of the study, the theoretical framework and the findings.

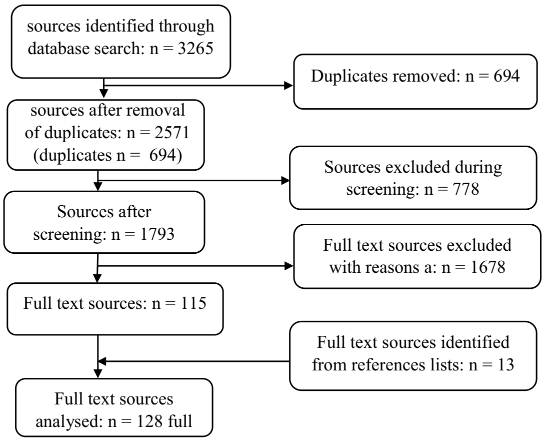

FIGURE 1
Data source identification, screening and sources used.

Drivers of STEM education through a politico-economic prism

The drivers of STEM education in both the Global South and Global North are shaped by past and present political standpoints, economic contexts, and massification agendas. Expectedly, there are points of convergence and divergence in the enactment of STEM education for the 21st Century citizenship.

The politics of STEM policies

Worldwide, there are concerted efforts to leverage the affordances of expertise derived from STEM education to "fix" global challenges, and little time to pause to reflect on the "politically correct chatter advancing STEM initiatives at all costs" (Zeidler, 2016, p. 12). The advancement of STEM and STEM education is historically linked to global military dominance as evidenced by the documented investment in military-biased industries during World

TABLE 2 Search terms and exemplar data sources.

Search terms	Exemplar data sources
STEM education	Blackley and Howell (2015), Bybee (2010), Kelly and Knowles (2016), Lubert (2018), Moore et al. (2014), O'Callaghan (2021), Takeuchi et al. (2020), van Zyl (2015), Zeidler (2016)
Drivers of STEM education	Hoeg and Bencze (2017b), Kerr et al. (2018), Kuenzi (2008), Marginson et al. (2013), Weinstein et al. (2016), Williams (2011), Spaull (2013)
STEM policy	Binkley (2018), Burke and McNeill (2011), Li et al. (2020), Mohr-Schroeder et al. (2015), O'Callaghan (2021), Ouma-Mugabe and Chaminuka (2020), Peck et al. (2018), Ritz and Fan (2015)
Massification in STEM education	Amano et al. (2021), Hoeg and Bencze (2017a), Teitelbaum (2014),
STEM in the Global South	African Union (2015), Fomunyam (2020), Gardner et al. (2018), Gorur and Wu (2015), Horta (2014), Irving (2012), Mbiti (2016), Van der Berg and Hofmeyr (2017)
STEM in the Global North	Bencze et al. (2018), Breiner et al. (2012), Gilbert et al. (2020), Chapin et al. (2016), Christophers (2020, 2021), Frey and Osborne (2013), Sanders (2009), Tobin (2016)

TABLE 3 Components of analysis for drivers of STEM education.

Guiding questions	Codes
What informs STEM policy nationally and/or regionally?	• Global technological dominance • Exploration of extra-terrestrial spaces • Military dominance and competition
How does the state of the economy influence the STEM agenda?	• Neoliberal agenda • Shortage of STEM workforce • Exploitation of natural resources
How does social stratification influence participation in STEM education programs?	• Racial diversity in STEM • Gender in STEM • The colonial legacy
How does curriculum enactment impact on the STEM agenda?	• The iSTEM approach, • Siloism and hierarchal gains
How do international STEM benchmarking assessments influence the STEM agenda?	• Transnational power • Inequality

War II and the Cold War era. Undoubtedly, the availability of financial resources propelled innovation and creativity in a way that benefitted humanity far beyond the two epochs. The continued obsession and pursuit of global dominance through STEM (Ritz and Fan, 2015) is encapsulated in Obama's 2009 speech when officially opening the Educate to Innovate Campaign for Excellence in Science, Technology, Engineering and Math [STEM] Education. The goal was "Reaffirming and strengthening America's role as the world's engine of scientific discovery and technological innovation" (The White House Office of the Press Secretary, 2009), which is important to address the challenges of the 21st century. The goals of Educate to Innovate are to increase racial diversity in STEM fields and careers, and improve STEM teacher quality and federal investment in STEM (Burke and McNeill, 2011; Mohr-Schroeder et al., 2015).

The last 40 years have seen increased, if not tense, socioeconomic competition between the United States and China. The push for a free market global economic climate by the Global North competes with Sino-socialism (Peck et al., 2018) which is also characterized by mechanization and mass production of goods to drive economic growth.

Weak participation by the Global South nations in setting the global science, technology, and innovation agenda (Ouma-Mugabe and Chaminuka, 2020) has dire implications for STEM education. These include the unmitigated exploitation of natural and human resources (Binkley, 2018) leading to irreversible environmental degradation and the loss of jobs for humans due to mechanization and automation of industrial production. Consequently, contrived conformity seems to drive pursuance of the STEM education agenda in the Global South (Ritz and Fan, 2015). Sustainable South–North partnerships are required to address Sustainable Development Goals (SDGs) through STEM education, which are most needed in the Global South, for example, food security (SDG2), health (SDG3), and climate change (SDG13) (Ouma-Mugabe and Chaminuka, 2020).

Extra-terrestrial colonization through STEM

After World War II and the gradual demise of terrestrial colonization, the Global North's desire to explore outer space escalated with a view to demonstrate superior intellectual potency through innovations in STEM. Russia's launch of Sputnick I in 1957 (Lubert, 2018) sparked extra-terrestrial colonization which has seen the landing of space vehicles on other planets. The landing on Mars of the interplanetary spaceship Perseverance on 18 February 2021 and Tianwen-1 on 14 May 2021 is evidence of the unlimited possibilities rendered by the practice of STEM. In the same vein, this has sparked an undeclared race to bring the first specimens of the red planet to earth, thus exemplifying the socioeconomic competitiveness with China (O'Callaghan, 2021). The long-term project to send humans on a one-way ticket to settle on Mars, if accomplished, will be a new height in extra-terrestrial colonization and expression of dominance by the Global North in STEM.

In the Global South, economic challenges imply that space exploration is largely limited to land-based activities. Astronomy and Space Science [A & SS] research involves certain key players in Africa, including South Africa, Morocco, Algeria, and Egypt. However, since 2010, the African Union has increased the involvement of more African countries in A & SS. For example, in Kenya there is funding by the UK Astronomy Technology Center for an optical observatory. Kenya also works with the Japan Aerospace Exploration Agency and has developed CubeSat, a miniature satellite for space research (Pović et al., 2018). South African students who worked in partnership with a French institute, launched a CubeSat named TshepisoSat in 2013 (van Zyl, 2015). The potential for using these miniature satellites to meet challenges in the Global South context, such as responding to disasters, advancing tele-medicine and for environmental management are being explored (van Zyl, 2015).

The economy as a STEM driver

While the advocacy for STEM education seems noble, it is undergirded by neoliberalism premised on developing and exploiting immaterial labor (Hoeg and Bencze, 2017b). The focus on STEM education rises during economic downturns (Kuenzi, 2008; Williams, 2011), environmental catastrophes, and pandemics. Predictably, governments believe STEM is key in addressing declining productivity, environmental degradation, and producing medical remedies to save humanity. To this end the Global North has resorted to adopting a STEM crisis management approach (Marginson et al., 2013). The current heightened investment in STEM and STEM education is in response to visible and perceived adverse effects of global warming. This has led to the proliferation of electric and other green fuel powered vehicles across the globe.

The COVID-19 pandemic paralyzed economies across the world but medical innovations and inventions brought hope for a gradual return to the old order and economic revival with a range of COVID-19 vaccines and remedies introduced on the market. The development and use of STEM skills related to combating current and future viral diseases is unprecedented. However, this has exposed the economic chasm between and within the Global North and Global South with the former leveraging their industrial capacity and financial muscle to produce what they consume. Despite the economic disparities, South African scientists, who are well positioned to contribute to knowledge sharing, use the Network for Genomic Surveillance together with the National Health Laboratory Service to grow viruses in laboratories, study antibodies in response to vaccines, and detect new COVID-19 variants (Tegally et al., 2021). These reflect notable milestones in STEM-related research in Global South nations (including the first detection of the Omicron variant in South Africa and Botswana) (Andrews et al., 2022).

A skills shortage approach permeates the global economic divide, albeit at different levels. In mitigation, STEM education has benefitted from increased funding by governments and promotion by politicians (Blackley and Howell, 2015). Federal government funding in the United States led to the establishment of the National Science Foundation. In Europe, the European Union STEM Coalition spearheads a common STEM agenda and equitable distribution of the necessary resources. In Australia, the Prime Minister's Science, Engineering, and Innovation Council [PSEIC] spearheads the STEM agenda at all levels (Marginson et al., 2013). The Canadian government has a number of STEM initiatives intended to boost participation at different levels. For example, the Let us Talk Science initiative champions the STEM agenda at primary and high school level with significant financial injections by government and the private sector. While all these initiatives and associated investments have good intentions on the face of it, there is need to guard against the misinformation exemplified by false claims of an abundance of STEM-related jobs (Hoeg and Bencze, 2017a,b).

The purposes of STEM policies in the Global North include:

> Enacting an economic policy agenda with a focus on lifting the general quality of the supply of human capital as STEM qualifications prepare graduates for a wide range of occupations … (and) enlarging the high-end STEM skilled workforce to engage in research and development, industry innovation, and effective responses to technological change (Gough, 2015, p. 446).

However, critics suggest that this focus, with neoliberal undertones, ultimately leads to an oversupply of a STEM skilled workforce in a shrinking labor market (Teitelbaum, 2014). What emerges is that STEM education is far from being ideologically or politically neutral. It drives the agenda for global competitiveness, dominance in military expertise and resources, space exploration, healthcare, and other socio-political spaces by producing more scientists, technologists, engineers and mathematicians to achieve these goals (Weinstein et al., 2016). STEM education is bound and censored by economic missions of corporates who are propelled by the quest for maximizing profit and seldom value the welfare of people or the planet (*ibid*). While there are visible concerted collective efforts in the United States, United Kingdom, China, South Korea, Japan, Australia, and the European Union to advance the STEM education agenda, in the Global South, particularly Africa, the reliance on western donor funding is conspicuous. This apparent benevolence may be tied to the tendency of transnational corporates seeking to establish new entities in developing countries with a view to minimizing labor costs and optimizing profits. This also nurtures naïve participation by STEM enthusiasts who may be oblivious to the neoliberal agenda in the Global South.

Knowledge to respond locally and globally in responsible ways is useful if education policy advances "knowledge as enactment, embodied, and transcendent" (Tobin, 2016, p. 29). Despite multiple efforts to reform STEM education, the content and pedagogy has remained almost the same, possibly due to political forces which mould STEM education policy based on neoliberal models. STEM education goals towards "sustainability, harmony and restoration" (Tobin, 2016, p. 30) for all of humanity, other living things and a complex web of interactions, should be promoted instead of producing scientists, engineers, mathematicians and technologists, as a technical fix to global challenges (Weinstein et al., 2016). Of all citizens in the world, only a small minority will be involved in STEM-related careers. Therefore, it is crucial to educate all citizens to change their lifestyles, for example, by consuming less, albeit a threat to the capitalist, neoliberal agenda which drives education policy in many societies. Herein lies a clash in the politically-driven ambitions for STEM education, and those that are crafted towards responsible living. This politically-driven force, which is usually not acknowledged and is viewed as a "lurking variable" (Joiner, 1981, p. 227) could be contributing to the resistance to transformation in STEM content and pedagogy, despite numerous reform efforts.

The STEM massification agenda

Increasing enrolment and participation in STEM education (Marginson et al., 2013) is a shared goal in the Global South and Global North. In the Global North there is significant appreciation of the nature of the jobs and skills demand for the future. It is envisaged that technology [which integrates a number of STEM domains] will permeate everyday life and work spaces hence STEM literacy will be imperative at all levels of life. To this end, the involvement of the community in school organized STEM projects is gaining traction (Gilbert et al., 2020). However, massification in STEM education might not be such an attractive proposition as it is gradually creating a STEM precariat (Frey and Osborne, 2013; Teitelbaum, 2014). Declining enrolments in STEM, coupled with a critical skills shortage, has led to poaching of young brilliant minds from the Global South by offering educational funding as a precursor to granting long term employment and permanent residence. Poaching the best and brightest STEM personnel from the Global South is a direct promotion of rentier capitalism by large corporates from the United States, United Kingdom, and European Union (Christophers, 2020, 2021). Human capital development in the North is partly as a result of human capital drain in the South.

In most Global South countries indigenous people were denied opportunities to study STEM subjects through systemic exclusion during the colonial era. The massification agenda in these countries is driven by a political will to redress educational imbalances which characterized their colonial past (Lewin, 1995) and a general desire to build economies based on STEM (Horta, 2014; African Union, 2015; Gardner et al., 2018; Fomunyam, 2020). Therefore, issues of quality, access, and relevance are crucial in massifying STEM education across diverse groups in Africa (Fomunyam, 2020). STEM education is naively regarded as a remedy to economic challenges and as a result of this notion, there is a move to generate more technologically astute, skills-intensive graduates, particularly in Africa and South America (Bencze et al., 2018). This can be perceived as promoting deceitful development and exploitation of a Global South STEM workforce for the enrichment of Global North capitalists while further impoverishing the affected countries and their people.

A highly visible example related to the STEM workforce is the COVID-19 pandemic, which has witnessed privileging of intellectual property rights of pharmaceutical giants over people's lives and "educational values such as collective well-being, social justice, or democratic education…" (Weinstein et al., 2016, p. 208). Vaccine politics dictated that South Africa will fill and pack vaccines, and not manufacture them in spite of having the infrastructure and human resources to do so, because for-profit intellectual property rights were valued above human lives. For countries in the Global South then, increasing the enrolment of graduates in STEM fields is to oversee filling and packing of vaccines, which are manufactured by STEM graduates in the Global North countries, the latter who reap vast profits in this process. In this example, the complicity of STEM in deepening social injustices, is reified.

The successful integration, in STEM fields, of large numbers of students from the Global South and some racial groups in the Global North is hampered by language and cultural barriers (National Academies of Sciences Engineering and Medicine, 2016; Kerr et al., 2018; Amano et al., 2021). These barriers are imbued with patriarchal views about women being poorly suited to STEM fields, and a lack of qualified or effective STEM teachers. This has implications for the custodians of STEM education in the Global South, who need to address the "inadequacy of a competent domestic STEM workforce…" (Fomunyam, 2020, p. 253).

The "small matter" of the curriculum in STEM education

A brief review of the history of STEM education shed light on what informs the policies which drive its curricula. Historically, the "monolithic, discrete silos occupied by the ancestors of the STEM quadrivium disciplines [arithmetic, music, astronomy, geometry] were disconnected from the disciplines in the trivium [grammar, rhetoric and logic]" (Zeidler, 2016, p. 17). Geometry, arithmetic and astronomy became the superordinate hard sciences, which evolved into STEM disciplines, while other disciplines were classified into the subaltern humanities. This historical separation of STEM from the humanities has contributed to a deficit model of STEM (Zeidler, 2016).

The curriculum in STEM education has undergone multiple reform efforts during the past decade and a half. However, in advocating best pedagogical practices, the intricacies of the social matrix within which people's lives are embedded are not adequately understood. Zeidler (2016) asserts that at best, reform efforts have resulted in inauthentic attempts at connecting science to students' lives. Zeidler contends that the mastering of all STEM topics is not essential, and that if the understanding of science is viewed strictly within the boundaries of STEM, then this reflects a myopic perspective which is "intellectually and developmentally restrictive" (Zeidler, 2016, p. 12). What is more important is to frame a topic in STEM within a personally meaningful context, which considers the prevailing socio-cultural and political milieu. Zeidler points out that the STEM movement adopts a parochial focus on the nature of science, which encompasses data generation, observation, analysis and so on. Notably, this excludes creative critical decision-making and action, thereby creating a deficit framework for STEM education for the 21st century. This "positivist orthodoxy" (Zeidler, 2016, p. 13) constructs science as separate from human affairs, and absolves the STEM enterprise from responsibility for the consequences of *doing science*.

STEM education in the Global South is characterized by a resilient silo approach (Williams, 2011; Blackley and Howell, 2015) where the teaching and learning of STEM domains are compartmentalized possibly due to an acute focus on increasing enrolment figures and static teacher training programs. Teacher training institutions in these countries produce science and mathematics teachers who lack the knowhow to integrate STEM (Bybee, 2010) leading to a persistence of a silo instructional approach (Moore et al., 2014) which does not promote situated learning (Kelly and Knowles, 2016) resulting in learner disinterest and disengagement in STEM fields. Siloed disciplines can be traced to the colonial matrix of knowledge and power, and restricts transcending epistemological boundaries (Takeuchi et al., 2020).

In the Global North, there is a shift towards producing specialized STEM teachers by training engineering graduates (Burke and McNeill, 2011; Chapin et al., 2016). In addition, their adoption of embedded (Breiner et al., 2012) and integrated approaches (Sanders, 2009) to STEM education, where engineering design is the fulcrum for content integration (Moore et al., 2014), enhances the quality of teaching and learning. An integrated STEM (iSTEM) approach is perceived as ideal for developing the skills required for the 21st century. Again, one needs to ask: For whom is the quality of teaching and learning enhanced and to what end? In the US and many other neoliberal economies, education policies promote "individualism, consumerism, capitalism, and an unambiguous higher value for human life over other life forms, living things over non-living things…" (Tobin, 2016, p. 28). A curriculum which moves towards a "contextualized humanistic sociocultural model of personal scientific epistemological development" (Zeidler, 2016, p. 19), which uses STEM disciplines as well as disciplines from the humanities can yield the benefit of meaningful, relevant education for all people.

International benchmarking and standardized assessment in STEM

International benchmarking assessments such as TIMSS and PISA promote competitiveness and fuel the desire to dominate in STEM education often leading to knee-jerk policy frameworks (Gorur and Wu, 2015). The competitiveness at national and international levels tragically means that STEM education and examination are rarely practiced as mutually inclusive (Blackley and Howell, 2015). The desire to outperform other nations might mean that quantity supplants quality regarding the development of skills required in the 21st Century. Consequently, international benchmarking tests have influenced STEM policies and practice in participating countries (Schmidt and Wang, 2002).

The reason why countries in the Global South, such as South Africa, underperform, as is evidenced by international assessment results in STEM subjects, is worthy of deeper inquiry. Key explanations include the continued destructive effects of colonial policy on the education of the majority of people which deprived them of intellectual, economic and linguistic capital, and perpetuated underperformance in international tests. In addition, teachers' weak subject content knowledge, for example in mathematics (Spaull, 2013), low teacher motivation and low teacher accountability despite comparatively high remuneration (Mbiti, 2016), high teacher absenteeism (Irving, 2012), resistance from teacher unions to monitoring and policy reforms (Van der Berg and Hofmeyr, 2017) deepens learner disadvantage in all subjects, including STEM disciplines. Low socioeconomic status of learners confines them to dysfunctional schools in poor communities, and policy which considers what informs this reproduction of socio-economic hierarchy, is also required to address this. Learner underperformance in STEM subjects, then, is embedded in the entangled and complex historical, socio-political and economic challenges, among others. The performances of the learners from different countries might also be explained in terms of the (narrow) focus of the benchmarking tests which excludes the application of knowledge and understanding from the humanities and social sciences.

Discussion

A plethora of policies and other documents related to STEM education have been distributed by figures in authority for several decades. Globally, developments and innovations in STEM fields are and have been a priority because these are believed to provide a panacea for challenges encountered by government and society in general.

The economic and military dominance of countries in the Global North is linked to their sharp focus on developing problem-solving, collaboration, teamwork, and innovation (Committee on STEM Education, 2018). Their governments' investment in STEM education through financial support and promotion by politicians has shaped policies in ways which have solidified the superiority of powers in the North (Li et al., 2020). Unfortunately, the huge human and capital investments in STEM education and fields tend to benefit those high up the socioeconomic ladder while increasingly marginalizing those at the bottom end.

Countries in the Global South are perceived as consumers of STEM products, with the most recent example being the COVID-19 global pandemic. The Global South is positioned as a passive recipient of scientific knowledge from the Global North which is accepted as being at the center of knowledge production. Even the intellectual division of labor maintains the knowledge-power hierarchy, because Southern scientists generate data while scientists in the North develop theoretical and methodological paradigms, thereby entrenching dominance of the Global North (Collyer, 2018). Knowledge produced in the North is presumed to be universal, and worthy of publication while Southern scholars are viewed as sub-contractors, whose knowledge is only applicable to local contexts in which it was produced (*ibid*). An example of devaluing knowledge from the South which was termed cultural imperialism, is when Northern scientists refused to accept the science which lead to the detection of the Omicron SARS-CoV-2 variant because it was first uncovered in South Africa (Mariwany and Ware, 2022). In the end, there is a (sub)conscious nurturing of collaborations of convenience characterized by extraverted scientific activities (Hountondji, 2009) where research foci are indirectly stipulated by the North, which is the center of knowledge production. Globalization benefits developed nations and creates a brain drain from less developed settings. From 1989 to 2003, 7 % of the South African professional workforce emigrated to the United States, United Kingdom, Canada, Australia, or New Zealand and for every one professional who immigrated into South Africa, eight left the country (Clifford, 2019).

The appropriation of geographic advantage makes countries such as South Africa suitable for Astronomy and Space Science research. This sets the agenda for convenient collaborations and the use of local STEM expertise thereby minimizing the labor wage bill. In addition, research foci are directly and indirectly imposed by the Global North and compliance is ensured by local knowledge institutions. Epistemologies and methodologies produced in the Global North are prized in the Global South, thereby inadvertently legitimizing a knowledge producer–knowledge consumer relationship which nurtures the peripheralization of the latter. Higher education leadership in the Global South bring to life Hountondji's extraversion of intellectual life, by punishing academics who publish in African journals whose metrics are not favorable. Policy critics such as Apple (2019) ask who develops benchmarks for these metrics and on whose idea of scholarly excellence is this based. Socialization into coercion and conformity in higher education institutions prevents leadership in global knowledge production. Therefore, it is unsurprising that countries in the South lag behind those in the North, in STEM fields in particular.

A way forward

We do not offer concluding remarks in this article. Instead, we provide our thoughts on how we can leverage the affordances of STEM fields to address challenges and work towards the greater good for humanity and the planet in general. We need to engage in an intellectual turn, in which researchers from the South who partner with colleagues from the North change relations of knowledge and power. To this end, Jansen (2017) suggests that the lead researchers or senior collaborators be from a country in the South, such as an African country. An example of such a collaboration where researchers from the South lead research projects involving collaboration with partners from the North, includes research on AIDS, by Quarraisha Abdool Karim and Salim Karim who work in leading capacities collaboratively with other research institutions internationally (Jansen, 2017). The emergence of such accomplished scholars in STEM biased fields of global importance may lead to the adoption of a STEM approach which is inclusive of the Global South perspective. Such an approach could incorporate indigenous STEM knowledge for sustainable development.

The work of theorists from the Global South, who are "research productive and intellectually imaginative" (Mudaly, 2018, p. 49) and embark on an "autonomous, self-reliant process of knowledge production [that] meets both intellectual and material needs of societies in the contexts, needs to be made more visible. For example, Le Grange (2014, p. 1288) calls for the "deterritorialisation" of disciplines. It is imperative to consider the deterritorialisation of S, T, E, and M as well as its reterritorialisation as a field which is underpinned by "relational accountability" [curriculum is accountable to other humans and the wider environment] (Le Grange, 2016, p. 9). The "relational accountability" posited by Le Grange is echoed by Zeidler (2016) who calls for STEM students to be given the opportunity to reflect critically on the social context within which knowledge is generated. Weinstein et al. (2016) add that students should be made aware that "science certainly has had devastating effects on environments, developing countries and Indigenous peoples. Science has deep and broad consequences and these can privilege some and marginalize others in their everyday lives" (p. 208).

The deterritorialisation and reterritorialisation can evolve into an integration of STEM subjects with other disciplines, including sociology, psychology, the creative arts and philosophy, in order to make more authentic connections with students' everyday life experiences (Zeidler, 2016). We can also apply insights from Brenda Liebowitz to STEM subjects, by heeding her caution about "separating knowledge from doing, learning from experience, and cognition from emotion" (Jansen, 2017, p. 5). This will go a long way in working towards the 21st Century learning discourse which includes "Learning to know, learning to do, learning to be and learning to live together" (Lee, 2017, p. 25).

Political commitment to STEM fields, with appropriate financing, is required by countries in the South. This should not be motivated by an appetite for competition and intellectual greed, by appropriating intellectual capital and raw materials from poorer countries. The use of STEM disciplines to advance socioeconomic and environmental conditions locally and globally, should be a motivating factor. In the North and South, students of STEM should be encouraged to examine neoliberal agendas which direct STEM policy-making. The

TABLE 4 A humanistic conception of STEM Education.

Dimension	Positive approach	Negative approach
Massification in STEM	• Equity with respect to: - Redressing historical and colonial injustices - Gender - Minority groups - The differently abled	• Neoliberal agenda
STEM Curriculum Design	• iSTEM – within STEM domains • Integration with the humanities (STEAM) • Specialized stem teachers • A curriculum accountable to the people – a curriculum which prioritizes the good of the people	• Siloism • Elitism • Gatekeeping • Boundedness
STEM Policy	• Inclusive – catering for human and non-human elements of the universe • Going beyond policy frameworks to visible implementation	• Reactionary – e.g. prompted by disasters; global dominance • Exclusionary – negating non-human elements of the universe
The economic dimension	• Inclusive – better life/world for all of humanity • Promoting a "green" economy	• Neoliberal agenda (corporate/self-aggrandizement) • Environmental degradation as a peripheral issue
The political dimension	• Positive competition to solve global challenges (health, hunger, drought, poverty, etc) • Intersectional solutions to global issues – reasonable expectations for contributions by different countries and regions rather than not a one size fits all	• (Military) Global dominance • Contrived collaborations • Collaborations of convenience

privileging of for-profit driven solutions to global challenges should be viewed through a critical lens. For example, the use of solar power is advocated in the green economy. Students of STEM should examine how silicone is obtained for use in solar panels, and the environmental costs associated with this, as well as the corporations which benefit financially from providing this renewable energy source (Weinstein et al., 2016). Instead, "pockets of resistance to the neoliberal model of science" (Weinstein et al., 2016, p. 209) should be galvanized to address the real problem, which is excess consumption. This pedagogical moment in STEM education can be seized to raise consciousness about how consumption feeds capitalism, increases the gross domestic product, and makes wealthy nations wealthier, at the expense of degrading the environment (Weinstein et al., 2016).

A key factor in the design of STEM policies should be the advancement of the greater good of all human beings, and the natural and spiritual environments. This involves a departure from the dualist [Western] conceptualisation of being human, towards a pluralistic one. Twenty-first century skills, including intercultural understanding and competence, open-mindedness when making decisions, and eschewing stereotypes, can be developed.

Power differences which permeate education render it a site of struggle. Whose knowledge is privileged, who does this knowledge benefit, what is valuable knowledge, who are legitimate knowledge holders, and which knowledge is reserved for the elite, are questions which are crucial if we are to become intellectually free. Ignoring these questions will render us perpetually enslaved. In re-learning, re-thinking, and re-imagining STEM education, alternatives for producing scientific and technological knowledge between and within the Global South and Global North are vital. In taking a new intellectual turn, STEM education should first address concrete challenges in the South. The inclusion of innovations from alternative knowledge systems, to address climate change, food insecurity, health, and other sustainable development issues, can provide platforms for creativity and critical thinking, which are vital 21st Century skills. We further recommend greater vocationalisation of STEM education hinged on STEM integration with the humanities in the Global South and balanced, mutually beneficial STEM collaboration endeavors with the Global North.

Finally, we coalesced our arguments to advance a humanistic conception of STEM education (Table 4) underscoring positive and negative approaches.

We argue that a humanistic approach to STEM education can be accomplished when nations across the globe work in common purpose. As such collaboration endeavors between the Global South and Global North need to be mutually beneficial. The Global North needs to redistribute the aspects of power it holds in relation to STEM to move towards more equitable policies and practices across these geopolitical realms.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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