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Empowering Transformation Through STEAM: Equity, Justice, and Community Innovation

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Preface

The development of STEAM education through Science, Technology Engineering, Arts, and Mathematics must move beyond traditional learning to embrace social inclusion and empowerment. This is a challenging task for society due to technological, environmental and technological challenges. The book, entitled Empowering Change Through STEAM: Equity, Justice, and Community Innovation, builds upon the principles of participatory and culturally based education, in which students can use transformative learning practices to break down systemic inequalities and create opportunities for action.

STEAM education should not be solely informative, as per the principles of this book. Educators must possess the ability to question, co-create, and lead meaningful change within their own communities, in addition to skills. Each chapter contains an essential component to this evolving perspective, integrating theory, practice, and lived experiences from the margins to the mainstream.

Chapter 1: Technology and Digital Literacy
In this chapter, we explore how technology can serve as an effective balance when used with intention and equity. Digital literacy is a protected right that includes programs that empower underprivileged groups with tools, training and platforms to access economic opportunities as well as civic engagement and creative expression. By examining case studies, it showcases how communities are reclaiming digital spaces to construct their own futures.

In STEAM: Teaching for Liberation, Chapter 2 explores Critical Pedagogy. The chapter explores the fundamental role of critical pedagogy in STEAM education. By drawing on Paulo Freire and other scholars in recent years, this chapter outlines how educators can prioritize dialogue, cultural relevance, and critical thinking to counter oppressive systems. It explores a structure of free education, where students are partners in producing knowledge and actively participate in shaping their world./

The third chapter discusses the challenges of STEAM participation and addressing systemic inequalities. Many still struggle to access STEAM education due to economic hardship, racial discrimination, gender bias, and geographic isolation. This chapter addresses the structural factors that contribute to inequality in STEAM pathways and highlights these systemic barriers. Additionally, it demonstrates measures and policy adjustments designed to enhance access and representation.

In Chapter 4, STEM Education and Environmental Justice is the main topic of discussion. The chapter focuses on the integration of science and environmental justice in STEAM education. The research investigates how climate change, pollution, and resource extraction disproportionately impact underprivileged groups and how education can empower these communities to advocate for sustainable development. Additionally, Youth-led projects and place-based learning that link ecological awareness with activism and innovation are highlighted through real-life examples.

Chapter 5 highlights the role of STEAM in community-driven initiatives, highlighting how participants can make significant contributions. In the last chapter, the book focuses on examples of education created by communities rather than for individuals. Through the application of participatory action research and co-design principles, this chapter presents case studies in which communities are instrumental in developing STEAM programs using Indigenous knowledge, local needs, and cultural resilience. The significance of shared ownership and iterative learning lies in the enhancement of collective agency and long-term capacity.

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Chapter 1: Technological Empowerment and Digital Literacy

1 Introduction

Rather than being the ultimate solution, technology has become crucial in providing essential services in the 21st century. As digital tools become more prevalent in modern societies, the need to access, understand, and use them has become a crucial aspect of personal development as well as civic engagement and advancement (Chamunorwa. et al, 2022). Technology has two dimensions in the education of STEAM.? Firstly, it serves as both content and conduit, and secondly, students must master this knowledge, while also altering the learning process, assigning roles to learners, or valuing their knowledge.

In Southern Africa, technology has the potential to break cycles of exclusion for historically disadvantaged and marginalized groups (Chamunorwa et al, 2022). The realization of this potential necessitates intentional strategies that emphasize digital literacy and technological empowerment. Digital literacy encompassed beyond mere device use (Falloon, 2023). It involves critical thinking, ethical consideration, information evaluation, and the ability to produce, rather than simply consume, content. It empowers students to navigate the digital realm with purpose, challenge established narratives, and make meaningful contributions to their communities. Moreover, Technological empowerment involves not only empowering students with tools, but also equipping them with the necessary skills to contribute to local innovation, economic activity, and community problem-solving (Alam, & Mohanty, 2023). In this chapter, we provide an example of how to incorporate technology into STEAM education while keeping it culturally relevant and context-sensitive for students in Southern Africa.

1.1. Technology can facilitate inclusive STEAM education by providing opportunities for students to gain skills and knowledge.

With technology becoming more prevalent, it has the potential to transform not only economies and industries but also the ways in which we teach, learn, and relate to knowledge (Agunowei & Mayombe, 2025). The adoption of technology can transform educational approaches for marginalized communities in Southern Africa's underprivileged settings, by ensuring equity and inclusion. In STEAM education, technology integration is not limited to technical issues but rather serves as a powerful political and cultural tool for empowerment (O'Donoghue, et al. in 2024). This concept should be recognized alongside STEM education.

Post-colonial settings in particular often position students in traditional education systems as passive agents of acquired knowledge from elsewhere. This trend can be reversed by using technology, especially in a STEAM context. By providing learners with digital resources and urging them to code, build, design and innovate, they shift from being content consumers to solution creators.

Low-cost robotics kits and open source tools like Science MakerLab are being used in Zimbabwe to provide affordable STEM and robotic education, both locally and internationally. Through the use of these tools, students can construct weather monitoring systems, solar-powered devices, and even small irrigation controllers using materials they have access to locally. By reinterpreting the technology to address local issues and providing students with the necessary tools, it is not intended as a final solution. This process not only enhances technical skills but also transforms the way learners perceive science and technology. The internalization of identities like "inventor," "engineer," or "designer" starts, and these roles are typically reserved for elites or outsiders. The utilization of technology is a reflection and enables students to see their own abilities, while also opening up fresh opportunities.

Access to devices and connectivity is not the only factor. In order for technology to be empowering, it must also possess critical digital literacy skills that enable individuals to analyze and evaluate digital content with care and create ethically and thoughtfully (Chanda et al, 2024). This is exemplified in STEAM education by emphasizing the significance of algorithms, identifying bias in data sets, and employing technology to enhance local narratives instead of repeating dominant ones. Schools in Malawi have implemented GIS training that involves questioning the identity, labeling, and visibility of maps in their buildings. This allows students to decolonize digital spaces by incorporating local knowledge and perspectives such as traditional land-use patterns or sacred ecological sites. Additionally, they learn technical tools while learning new technologies. Critical engagement is essential in a world where digital divides are not only about access but also over who produces knowledge. Teaching students to question and modify digital content, rather than just watching it, is a crucial factor in developing them into agents of change rather quelling the hunger for change.

In order to be fair, STEAM education must address the historical and systemic barriers to learning. Under-resourced communities often face obstacles such as inadequate infrastructure, insufficient qualified teachers, and outdated curriculum materials. Although technological advancements can address these gaps, they must be done in a comprehensive manner. OERs provide students and teachers in remote areas with access to current, contextually relevant STEAM content. Educators can access interactive simulations, multilingual explanations and culturally relevant case studies on platforms such as Siyavula (South Africa), Kolibri (global) or digital libraries supported by localNGOs.

Additionally, mobile devices have gained considerable sway in African settings, with smartphones being frequently more easily accessible than computers (Aker & Mbiti, 2010). By utilizing mobile learning apps, WhatsApp tutorials and SMS-based quizzes, STEAM content can be easily accessible and personalized for learners to access it wherever they are (Sunzuma et al., 2022). The approach fosters differentiated learning, enabling students with diverse skills and needs to learn content at their own pace. This flexibility is crucial for students who come from marginalized groups, such as those with disabilities, gender, or rural areas, to achieve meaningful inclusion.

STEAM education fosters empowerment through the integration of learning and application in real-life scenarios (Allina, 2017). Through technology, future-oriented, experiential and community-based learning can be facilitated through project implementation (Maspul, 2024). By engaging in this activity, learners can develop innovative solutions to address environmental, health or economic issues in their communities, becoming social entrepreneurs. In Botswana, the "Young Inventors Programme" serves as an example by encouraging high school students to develop technology-based products such as energy-saving cookstoves, water purification devices, and indigenous language apps. These projects are evaluated not only for their academic merit but also for social and cultural significance. Students are able to engage in citizenship by moving beyond abstract knowledge through such programs. They begin to see themselves not as mere future workers in global markets, but as active contributors to local sustainability and resilience.

Embedding the arts and humanities into STEAM allows technology to serve both economic and cultural purposes (Huser, et al. in 2024). African traditions rely on oral storytelling, visual arts, and music as key tools for transmitting knowledge. The use of digital tools can aid in the preservation and reinterpretation of these practices in contemporary formats (Alsaleh, 2024). In Namibia, students have recorded and saved folktales from elders through digital audio tools while in Zimbabwe, they have created apps for teaching mathematics that incorporate local adverbs and metaphors. See examples: The integrations enhance indigenous culture while also fostering engagement and identity consolidation. Instead of replacing traditional knowledge systems, technology can interact with it in a creative manner, leading to emergence of futuristic and deep-rooted innovation (Alsaleh, 2024).

2. Technology Integration in STEAM Education

Technology can transform STEAM education within traditionally low-income contexts by promoting equity, inclusion, and cultural relevance (Castek et al, 2019). By doing so, the learner can be transformed from a non-abstract recipient of abstract knowledge to an active creator, solving agent, and visible force in society. The shift is not solely pedagogical for communities that have been excluded from the mainstream narratives of innovation and progress, but also deeply political and liberating.

Across Southern Africa, technology is frequently used in classrooms where students are taught about their realities, languages, or ancestral knowledge systems (Gumbo, 2017). It is common for this juncture to reinforce feelings of isolation rather than motivation. If digital tools are introduced without considering their purpose, purpose or application, they may become replication tools and reinforce existing power structures and epistemic hierarchies. The use of local realities, cultural knowledge, and collective aspirations can transform these tools into instruments of liberation.

The use of technology in STEAM education should begin with a culturally sensitive approach that considers the lived experiences, values, and challenges of learners. What are the knowledge systems that our communities possess, and why is this important? What issues do our learners aim to address? What kinds of resources, relational, and culture can we utilize to build? Putting technology in the hands of learners rather than exclusion makes them more empowered. Figure 1.1 illustrates the framework for integration technology in STEAM education, which is based on four interrelated domains: digital access and infrastructure, critical digital literacy, cultural relevance, innovation and entrepreneurship, and equity and social justice. These domains work together to make STEAM education a platform for inclusive innovation, meaningful participation and community-rooted development.

2.1. Managing Digital Divide: Achieving Access and Infrastructure.

Addressing the digital divide is crucial in any attempt to incorporate technology into STEAM education, as it prevents millions of students from engaging in meaningful digital learning. (Chanda & Phiri, 2024) This division is not just about the individual who has access to an internet, but also about how one can afford it in Southern Africa through infrastructure and policies. In rural areas, it is common to have no basic electricity, let alone functional computer labs or internet connections. Some regions have students walking kilometres to use the digital tools in their learning centres but when power goes out or bandwidth is restricted, it becomes unusable. The problem may be different in urban informal communities, where households often use multiple smartphones and the cost of data is prohibitively high. In all of these contexts, the digital divide reflects entrenched inequalities among income, geography, gender, and race, which will continue to widen the gap between those with access to education and those without.

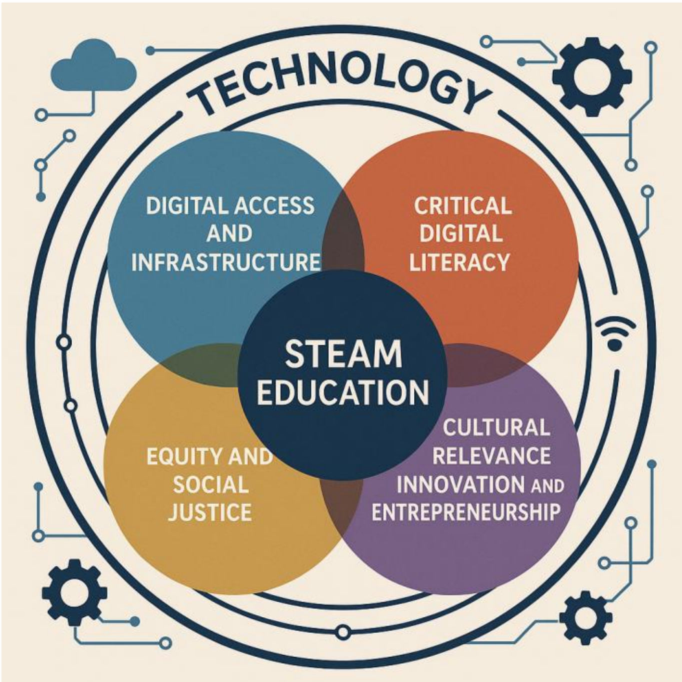

Figure 1.1Technology-Integrated STEAM Equity Framework (TISEF)

Access does not merely involve devices being present. Accurate digital access enables learners to use technology in sustainable, practical, and empowering ways (Chanda et al, 2024). When laptops are donated by teachers in a classroom, the devices become unrefined and only function as decoration. Also, introducing online services that presuppose fast internet in localities where students have limited access to 2G connections can cause more frustration and alienation. The process of redefining access requires consideration of cultural factors, rather than just technical aspects, to determine whether the technology is suitable for its intended audience.

A STEAM framework that is culturally based facilitates the use of technology tools and solutions that are compatible with local communities' infrastructural, economic, and social structures. Another approach to consider is using offline-first platforms such as Kolibri or RACHEL, or other open-source STEAM education apps that allow students access to interactive content outside of the internet. By loading these platforms onto servers or hard drives and distributing them to schools or community centres, data consumption can be greatly reduced while still providing a rich learning experience. These media become more familiar to many students and may even serve as a means of accessing increasingly complex technologies.edu.

The use of solar-powered digital classrooms is another potential solution for off-grid areas. By installing solar energy systems in classrooms or mobile labs, schools can be made resilient to national power cuts and become hub of the Internet. Such educational spaces are permanent in schools or can be moved between communities.edu. Libraries, vocational centres, and youth clubs are examples of community-based digital hubs that offer shared access to devices like computers/webcams or internet and training opportunities for individuals who lack home connectivity. Shared ownership models are being tested in some cases, where kits with tablets, microcontrollers like Arduino, and robotics components are distributed among multiple schools or made available during specific project-based learning modules.

However, even with the appropriate technology, long-term impact requires support structures. The maintenance of equipment, software updates and the use of tools with confidence is essential for both students and teachers. Investing in local digital facilitators, community-based technicians, and continuous teacher development is necessary. Having someone on-site or nearby to help with technical problems, staff training and content customization is also likely to increase the likelihood of effective and sustainable use of the technology in a school. By creating local employment opportunities, these roles decrease the need for external technical assistance that is often only available on an occasional basis or absent in under-resourced areas.

Rather than creating a uniform access level, we need to address the diversity of needs and bridge the digital divide. Whether in urban areas or perhaps in some remote village, the goal should be to build locally inclusive, resilient and inclusive digital ecosystems supporting STEAM learning. Digital access is a foundational element in STEAM education that provides transformative benefits, regardless of its logistical and cultural implications. It must also be contextually relevant to ensure student learning. The transition from technology being a remote, unattainable goal to merely an adaptive tool owned by and shared by its users.

2.2. Beyond Basic Skills: A Guide to Critical Digital Literacy in STEAM Education.

Digital literacy is still a restricted subject in many Southern African classrooms, where basic technological skills like typing on computers, browsing the internet, or uploading and exporting files are taught. Despite the importance of these skills as foundations, they do not fully capture the full potential or transformative value of technology in education, particularly within STEAM. A more holistic, reflective, and creative engagement with technology is required for learners in under-resourced or marginalized settings to achieve the desired level of empowerment through digital literacy (Chamunorwa et al. 2018). This advanced digital literacy approach equips students not only to consume but also to critically evaluate, question and create digital content. It entails comprehending the design, management, and values of digital technologies, as well as their potential use and misuse. In a region where access to digital resources is increasing but inequalities persist, critical digital literacy becomes essential for social participation, economic innovation and cultural preservation.

Learning to critically analyze and use digital information with objectivity, including misinformation, biased content or exploitative platforms, is achieved through critical digital literacy (Chanda et al, 2024). This helps them to grasp the invisible workings of digital world, algorithmic content generation, data collection and processing, platform-based thinking/action. Students should be aware that a search engine is not unbiased and represents only commercial interests and concealed biases. For example, in STEAM education, the focus shifts from passive learning to active solutions and critical digital literacy. Educators are empowered to produce digital artifacts, such as apps and videos, interactive experiences, and games that address real-world issues in their surroundings. Through it, they assume the position of creators and moderators, rather than just users or consumers.

The most effective way to incorporate critical engagement into STEAM subjects is through interdisciplinary, context-sensitive projects. Students in a life sciences classroom may analyze publicly available data on local health trends, such as malaria incidence or sanitation challenges, and create infographics, blogs, or short educational videos to promote awareness. In addition to teaching biological and technological concepts, this also trains communication skills and social responsibility.. As part of a technology course, learners could develop mobile apps that document indigenous plants and their applications or promote recycling efforts using symbols and language that resonate with them. By means of these activities, they employ coding and design thinking skills to validate identity and tackle concrete issues. Students were able to monitor rainfall patterns and climate variability in mathematics by using spreadsheet software or indigenous knowledge systems, as well as comparing scientific predictions with traditional seasonal markers. It enhances analytical abilities while also recognizing ancestral knowledge and promotes epistemological diversity.

Beyond skill development, these activities are also exercises in moral reasoning, civic duty and critical thinking. The question should be asked to students: What is the purpose of this device? Which individuals' voices are heard or ignored? What are some issues that my community needs to address using technology? These types of questions are not only used for economic participation but also serve as a foundation for justice, agency, and cultural resilience in STEAM education. Learning to thrive in the digital world, while being aware of the past, languages and future aspirations is crucial for cultivating critical thinking skills.

2.3. Cultural Relevance in the Technology Model: Importing Indigenous Knowledge and Identity

The uncritical importation of Western norms, content, and languages has become a common feature in African educational contexts with limited resources or access to rural areas. The process has resulted in the disconnection of pedagogical boundaries and the exclusion of Indigenous Knowledge Systems (IKS), community values, and local languages (Gumbo, 2017: Mutsvangwa, 2023). Digitization efforts have frequently resulted in cultural erasure rather than cultural inclusion. STEAM education, in contrast, should resist the tendency to emphasize technology integration and instead center its curriculum on cultural aspects. Technology should not be a barrier between learners' past knowledge and their future aspirations. It must also serve as reconnection. The aim is to create and deliver STEAM education that acknowledges, validates and draws from and respects the rich cultural heritage and lived experiences of learners in Southern Africa (Adesina et al, 2023).

Indigenous knowledge systems provide for the deep contextualised and experiential understandings of science, environment, engineering, health and aesthetics (Mutsvangwa, 2023). Southern African communities have for generations relied on intricate agricultural calendars that were influenced by celestial and seasonal patterns, followed by sustainable architecture through bio mimicry principles, and ecological stewardship based on communal ethics. It is not necessary to discard pre-scientific ideas, but rather valid epistemological frameworks that can influence contemporary innovation. The incorporation of these in the STEAM classroom fosters a mindset of self-assessment and community building, rather than just accepting ideas from outside. Cultural relevance is not a supplement, but rather the context within which content takes place (Adesina et al, 2023). It transforms abstract STEM concepts into practical, local situations and links technological education to identity, purpose or pride (Mutsvangwa, 2020).

To incorporate culturally sensitive approaches into STEAM classrooms, it is imperative to rethink both the teaching and learning processes through changes in terms of pedagogy. Foreign analogies and corporate logic need not be the only factors used in coding. In lieu of this, learners can create algorithms or interfaces that are based on local storytelling traditions, proverbs, or metaphors with deep moral and practical knowledge. Similarly, traditional games, musical instruments and crafts can be engaging ways to introduce concepts such as geometry, acoustics or both physical and digital, as well as design thinking. The same applies in the classroom. The accessibility of abstract content through these activities is enhanced by the inherent creativity already present in student cultures.

An effective way to incorporate community knowledge holders, such as elders, artisans and healers, farmers, or masons (not scientists), as co-educators in STEAM instruction is suggested. They bridge generational divides, validate local traditions, and reframe education as a communal endeavor, not confined to individual experiences. As an illustration, a combination of herbalist teaching and biology tutoring can aid in understanding medicinal plants, photo chemistry methods, and sustainable harvesting practices while maintaining cultural integrity. In the same way, a skilled builder can instruct students on structural engineering principles using indigenous techniques and locally produced materials, which will reinforce their commitment to environmental awareness and heritage conservation.

Through the integration of place-based and project-Based learning, digital work can be made more relevant culturally. Students could use GIS to map ancestral lands, create apps that preserve and share oral histories, or develop prototypes for solar cookers that can cook in the local environment. Additionally, there are other opportunities. Rather than teaching technical skills, such initiatives integrate learning into a social and historical context that empowers students to innovate with cultural strength. ".

The importance of cultural relevance cannot be equated with its ability to represent one's own culture (Mutsvangwa, 2023). Learning individuals view technology as a means of self-improvement when it aligns with their cultural background, rather than being enforced by external influences. In a time where global innovation often fails to acknowledge or prioritize local knowledge, STEAM education that is culturally grounded provides realism by asserting identity, creating sense of self-worth, and sparking creativity.

2.4. Innovation and entrepreneurship

STEAM education requires innovation beyond theoretical considerations to foster the development of practical, sustainable and community-based approaches. To achieve this in Southern Africa, it is essential to train students with the necessary tools, mindsets, and support systems to move from school projects to practical actions that address pressing social and economic problems. A STEAM education program should acknowledge that innovation is not solely about technological inventions but also encompassed local creativity, adaptation and the strategic use of knowledge to enhance daily life. Educators must be prepared not only to think critically, but also to take bold action by identifying challenges within their communities, such as water shortages and food insecurity, unreliable energy sources, or unemployment. An entrepreneurial mindset is the starting point for this transformation. The program aims to promote student observation, creative thinking, implementation of ideas through both digital and physical tools, and networking with peers and mentors from various age groups and academic disciplines. Learning to pitch ideas, seek support and refine them for practical use transforms students from passive learners of knowledge to active change makers with a sense of ownership and agency.

The informal economy and tech-savvy youth in many parts of Southern Africa are already experiencing a spirit of innovation that creatively uses digital tools to support survival and self-expression (Aderoju, et al. (2018), 2025). Social media is being used by young people to sell handmade crafts, while agro-tech apps are being created to assist smallholder farmers, educational YouTube channels for academic subjects or indigenous languages, and mobile phone repair or digital design services. These cases are not isolated, but rather point to a larger potential for tech-based social innovation. By providing structures, mentorship, and resources that convert informal hustle into structured opportunity, STEAM education must institutionalize this energy to meet the challenge. In schools, libraries or community centres, learners can access tools such as 3D printers, microcontrollers and other electronics, robotic kits, and multimedia software in an innovation hub or maker spaces. This is a common practice. The spaces must be based on local significance, relevant to the community and culturally sensitive, so that students are contributing to solving relevant problems.

The outcomes of this method are diverse. In the field of agriculture, students have various options such as designing cost-effective irrigation systems, utilizing open-source tools like Arduino to develop weather monitoring sensors, or developing mobile apps that offer planting guidance in local languages. Medical students may create mobile applications that detect diseases or aim to raise awareness about hygiene and nutrition, depending on their language and cultural backgrounds in healthcare. Students in the energy field can experiment with solar-powered lighting, biomass stoves that use bio energy sources, and wind-driven water pumps, all of which are innovations that directly benefit non traditional communities. In the cultural domain, students can digitize spoken history; create music or animation that honors native legends, or design keyboards and text-to-speech equipment. The objective is not to produce technology exclusively for personal gain but to foster innovation as a shared activity that incorporates creativity, technical proficiency, and social responsibility. By emphasizing entrepreneurship in STEAM education, we can produce future generations of learners who are not only job-ready but also skilled in creating and developing innovative solutions for their communities.

2.5. Equity and Social Justice.

Equity and social justice are integral to any meaningful technology-based approach to STEAM education. The absence of this base could lead to innovation that replicates the inequalities they aim to eliminate. To address the challenges posed by colonialism in Southern Africa and the economic dispossession it represents, education is not limited to the transfer of content or skills; it must become a tool for redress, recognition, and collective renewal. We must address not just the digital divide, but also fundamental systemic differences that impact who has access to quality education, whose knowledge is valued, and their role in shaping the future.

The goal of STEAM education is not to provide uniform resources or content, but rather to meet learners' individual needs and recognize their diverse histories, identities, and capacities. Justice-oriented education recognizes that certain communities have been intentionally excluded from science, technology, and the economy due to dispossession and ongoing structural challenges, rather than a lack of ability or interest. It is imperative that equity is a factual expression, not an intangible phrase present through STEAM education design and funding. It should be reflected in the technologies we support, the languages we use in online communication, and the goals we set in our educational environments.

This vision can only be realized through multi-level endeavors. At the policy level, national governments must integrate digital equity into their strategies for education, while also ensuring that infrastructure investments and budgets are allocated appropriately to support rural, low-income, and underserved communities. Not just hardware deployment; we also need sustained investment in connectivity, teacher assistance and community infrastructure to enable meaningful use of technology. Eurocentric content and the integration of African knowledge systems, indigenous technologies, or local problem-solving strategies into STEAM subjects are necessary at the curricular level. Through this method, pupils become familiar with the curriculum and acknowledge their heritage as a source of innovation rather than relic.

Teacher training should include instruction in not only how to use digital tools but also how the work and critical engagement of power, identity, and culture in digital environments (Gumbo, 2017). The task requires comprehending how algorithms, data, and platforms can reinforce bias and how culturally responsive pedagogy can counteract it. Finally, community participation is essential. Learning should be shared among parents, elders, artists, entrepreneurs, and other local stakeholders, rather than being passive beneficiaries. Their knowledge and experiences will be instrumental in determining the relevant content and outcomes in STEAM education.

In STEAM education, equity is not just about gaining access; it also involves acknowledging and redistributing representation and attention. It's about envisioning a future where people have access to not only instruments but also the capacity to modify the systems in their surroundings. Justice is necessary for genuine innovation to occur, leading to the replication of existing hierarchies. STEAM education can be a catalyst for transformation by creating societal and economic equity, while also elevating local economies.

Conclusions

In this chapter, we have examined how technology can bring about significant change when it is integrated into an equitable, culturally relevant and purpose-oriented educational system. In a time when digital tools are revolutionizing economies, communication, and knowledge production, Southern African learners, particularly those in under-resourced and historically marginalized communities, must not be left behind. More importantly, they shouldn't be seen as just adopters of imported technologies; rather than creators, problem solvers and agents of change. Technological empowerment requires more than just technology and devices; it also involves critical digital literacy, culturally relevant content, and opportunities for learners to apply their knowledge in ways that uplift their communities and reflect their realities.

The developed model centers on STEAM education, which is not limited to job placement but rather serves as a means of liberation, innovation, and socio-economic advancement. A fundamental basis for all these fields is equity and social justice, which prevents technological advancement from jeopardizing cultural identity, community participation, or educational inclusivity. Digital literacy, as per the chapter, should encompass more than just using devices and platforms; it should also include essential abilities such as asking and answering questions about digital assets. Education gains greater significance and effectiveness by integrating technology with the actual experiences and desires of learners. Regardless of the approach taken, whether it is through robotics to tackle local agriculture challenges, mobile applications written in indigenous languages, or solar-powered devices made from recycled materials, the aim remains unchanged: to convert passive participation into active innovation that is driven by justice.

In addition, techno-empowerment must be accompanied by institutional change through policy reform, inclusive curricula, teacher professional development, and community co-creation of educational agendas. These are the systemic efforts that lead to long-term outcomes. Schools become a platform for the integration of local and digital knowledge, and students can incorporate their own cultural practices into their education, making education not only empowering but also revolutionary.

Finally, the road is now open to both intentionality and imagination. The digital divides that persist must be addressed with intentionality and imagination in creating STEAM education that not only prepares students for the future but also enables them to influence it. When technology is integrated into STEAM education with care and justice it becomes a catalyst for emancipation not only from poverty or underdevelopment, but from epistemic erasure and historical exclusion. In the hands of empowered learners and communities, it can spark new ways of thinking, building, and thriving.

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Chapter 2: Critical Pedagogy in STEAM: Teaching for Liberation

1 Introduction

The 2030 Agenda by the African Union promotes inclusive growth and sustainable education programs that encourage a skills revolution in innovation, science, and technology. However many argue against this approach. To achieve this vision, the African Union's Continental Education Strategy for Africa (CESA) seek to reform Africa' s education and training systems to produce knowledge that can be used for sustainable development through innovation, creativity, skills, and competencies. The African nations are addressing the issue by enhancing access to high-quality education, strengthening their training programs as a whole and improving education management and integration. Also, they're enhancing the teaching of STEM subjects (STEAM) curricula and spreading scientific knowledge while also developing African societies to cultivate science as an integral part.

African nations must prioritize STEAM education as a means of creating skilled human resources to drive transformative, innovation-led, and knowledge-based economic growth. Countries such as Rwanda have already taken notice and implemented significant changes in their education curricula, making STEAM regarded as an essential aspect. Significant improvements in infrastructure have been made as a result of this shift, including well-equipped STEAM laboratories that enhance the practicality of STEM subjects. Rwanda has made significant strides in promoting STEAM education, which is known to promote critical thinking and problem-solving skills.

Consequently, African nations are encouraged to support STEAM education, which empowers students to conduct independent experiments and enhances their critical thinking and problem-solving abilities. The use of STEAM activities can lead to the creation of real-world problems for a wider range of students than is currently done in traditional STEM (Roberts & Schnepp, 2020). With knowledge acquisition increasing more and more complex every year, Africa is adopting STAM education as an educational approach to increase depth; creativity; and employability.

The impact of education on society is significant. Nevertheless, customary education frameworks frequently reinforce existing social structures, leaving underprivileged groups with few opportunities for empowerment. Freire's (1976) critical pedagogy challenges the current status of education as an essential component of liberation. The movement also highlights the importance of learning in educational reform. STEAM education can use critical pedagogy to create inclusive and empowering learning experiences that equip students with the skills, knowledge, and consciousness needed for challenging systemic oppression. According to Perales and Aróstegui (2024) STEAM education is an approach that emphasizes the integrated teaching of scientific, technological, artistic, and other humanistic skills, with integration being seen as a progressive process from interdisciplinarity to transdisciplinary. In the STEAM approach, Dark and Burns (2004) proposed three levels of integration. Multidisciplinary learning involves students gaining knowledge and skills from different fields while referencing one another. Students must apply principles, concepts, and skills from related disciplines in an interdisciplinary manner to succeed in the second. The third type, transdisciplinary, involves students working on real-life problems or projects, integrating knowledge from various disciplines to shape their own learning experiences. This chapter delves into the use of critical pedagogy in STEAM education to empower students from marginalized groups, encouraging them to engage in critical thinking and problem-solving.

1.1. Education and Critical Pedagogy.

An educational approach known as critical pedagogy regards teaching and learning in a political manner. The "banking model" of education, which involves teachers passing on knowledge to passive students, was criticized by Freire in 1970 for being outdated and replaced with a dialogical approach that promotes critical thinking. The approach emphasizes the importance of active participation in learning, which involves asking questions, analyzing ideas, and taking action to alter their social surroundings. By promoting the collaboration between students and teachers in co-construction of knowledge, Paulo Freire's critical pedagogy serves as a theoretical framework for STEAM education. In his critical pedagogy, Freire employs "problem-posing" to encourage students to question assumptions and engage in inquiry-driven learning. This approach is known as Critical PTE. In a STEAM environment, students are encouraged to engage in critical thinking and explore scientific/technical, engineering/artistic and mathematical topics while also developing creativity and analytical thinking. The teacher is not the only one in charge when it comes to implementing dialogic learning strategies. Hooks (1994) argues that the collaborative process ensures that learning is student-centered and dynamic. STEAM education incorporates critical pedagogy, which promotes interdisciplinary problem-solving through inquiry, experimentation, and reflection.

Critical pedagogy is defined differently by different definitions, but scholars agree that it centers on creating an approach to learning that is contextualized, culturally relevant, and reflective. Why is this important? A STEAM approach involves blending theoretical concepts with experiential, inquiry-based experiences that acknowledge and respect students' cultural heritages, experiences, and diverse ways of thinking. Through it, students can gain the knowledge and abilities required to dismantle oppressive systems and work towards liberation (Saunders & Wong, 2020). Margonis (1999) maintains that Freire's ontological perspective is inherently relational, highlighting the fact that students and teachers are co-constructed through their interactions within the educational system and exist as part of a larger social structure. The emphasis of critical pedagogy shifts from teacher-led or student-centred teaches to one that emphasizes dialogical relationships as the foundation of practice, rather than individualism.

STEAM can be utilized as a tool for critical pedagogical purposes in several studies (Chung & Li, 2021; Fletcher & Hernandez-Gantes, 2020; Kiyani et al, 2020). According to the studies, STEAM contributes to increasing students' critical thinking skills, particularly in regards of issues that are relevant to their communities. STEAM, as argued by Kiyani et al. (2020), not only fosters creativity and innovation but also motivates students to tackle challenges that are contextually relevant and culturally sensitive beyond the scope of STEM education. STEAM approaches, rooted in critical pedagogy, center learning on topics that reflect students' experiences, strengthening connections between schools and their communities and ensuring students are recognized as social beings whose identities extend beyond the classroom. Additionally,

2. STEAM Critical Pedagogy Framework.

The integration of STEAM and critical pedagogy into the education approach is achieved through the use of the STAM Critical Pedagogical Framework, which integrates STEM into this curricular model by promoting creativity, critical thinking, problem-solving skills, and student engagement in real-world issues (Dahal, 2022). By engaging in interdisciplinary collaboration, reflection, and action, the STEAM critical pedagogy promotes an educational environment where students are active participants in making significant contributions to the world through their knowledge and skills.

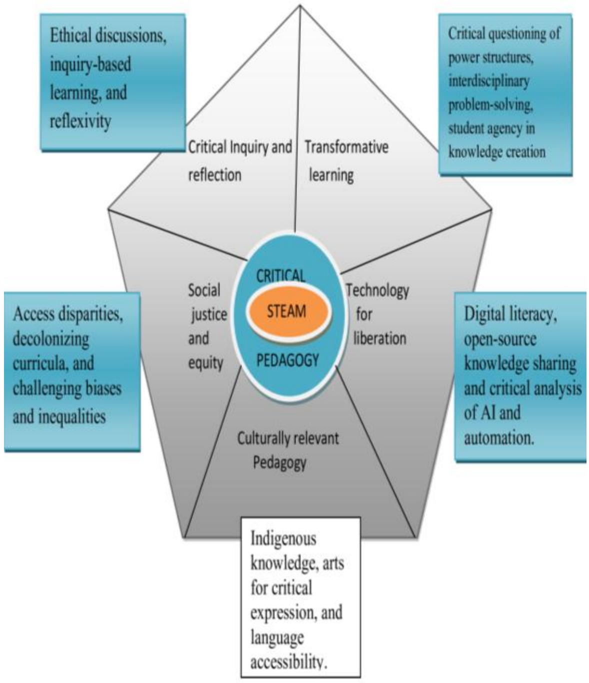

Fig 2.1 STEAM Critical Pedagogy Framework

Figure 2.1 demonstrates that STEAM Critical Pedagogy is the cornerstone of this structure, serving as an essential component. The framework's central position indicates that its fundamental purpose is to unite the concepts of critical pedagogy with those of the other branches of Science, Technology Engineering and Mathematics (STEAM) to create an active intersection that drives the educational experience. The central placement of STEAM Critical Pedagogy highlights the integration of various fields for better understanding of their respective areas of study. The central concept is accompanied by Science, Technology, Engineering, Arts, and Mathematics as core components in all fields. This combination promotes an integrated learning experience, where each subject contributes to the other within itself, creating an environment that encourages creative problem-solving and critical thinking. By means of this diagram, it is evident that education within this framework remains a comprehensive and interdependent process, not just based on subject matter. The central component of the diagram incorporates critical pedagogy, which serves as the guideline for the educational process. The diagram highlights the importance of critical pedagogy in education within this framework, with the aim of encouraging students to engage with and challenge societal structures while also fostering intellectual and creative development.

2.1. Social Justice and Equity.

Figure 1 illustrates the significance of social justice and equity in STEAM critical pedagogy. It is essential to provide education that is accessible, inclusive and relevant to all students, particularly those from marginalized or underrepresented groups (Upadhyay, et al, 2020). In this framework, social justice and equity are crucial strategies to address these disparities, decolonize curricula, and counteract prejudices against women and systemic inequalities.

Managing STEAM Education Access Disparities

The framework highlights the importance of social justice and equity, with a focus on addressing disparities in STEAM education accessibility. The limited quality of education provided by STEAM education has historically been inaccessible to certain groups in Africa, particularly those with low economic status, marginalized populations, and specific racial or ethnic groups (Upadhyay, et al, 2020), which can result in unequal opportunities for students to develop skills and pursue careers in STEM fields. This concept is shown in figure 1.1, which represents a key aspect of social justice and equity, connected with the STEAM critical pedagogy that emphasizes creating inclusive educational spaces. The framework's goal is to promote equal access and learning opportunities for all students, regardless of their background, by ensuring access to resources, tools, and other resources.

Equality through diversity and the decolonization of curricula

In the context of social justice and equity, curricula must be decolonized to allow for diversity in perspectives. The Eurocentric approach has been adopted by many traditional educational systems, which aim to present knowledge and cultural values in a unique, Westernized manner. This could result in students feeling disconnected to non-Western cultures and reinforce unequal representations of knowledge systems. At the educational level, STEAM-based curricula that promotes democracy and critical thinking as well as the development of human beings are an alternative solution for our society today and future (Perales & Aróstegui, 2021), making them more accessible to all.

According to the diagram, curricula used in STEAM subjects are being decolonized by incorporating a range of cultural perspectives, worldviews, and epistemologies. Through the inclusion of native knowledge, local solutions to problems, and examples that relate to their cultural backgrounds, the framework ensures that students' experiences & histories are integrated into our curriculum. It enhances the educational relevance of education for students and also fosters a more inclusive and all-encompassing approach to learning. The framework seeks to break free from narratives dominated by the West and allow multiple knowledge systems to exist, while also encouraging cultural diversity and making education more equitable for all learners from an African perspective.

Challenging Biases and Systemic Inequalities

Essentially, social justice and equity seeks to combat prejudices and systemic inequalities within STEAM educational settings. The range of biases can be diverse and includes both racial prejudice and gender stereotypes, as well as assumptions about students' intellectual aptitude based on their socioeconomic status or ethnicity (Sun & Saleh, 2024). Differing perspectives can affect students' treatment, access to resources and future prospects in the field of STEAM (Nyaaba et al. 2024). Figure 1 highlights the importance of creating a learning environment that challenges discriminatory practices and fosters critical thinking, which is a hallmark of STEAM critical pedagogy. This approach seeks to educate students on how to recognize and confront biases within themselves and the wider educational system. The framework fosters critical analysis of the influence of stereotypes and biased practices on academic achievement, and it empowers students to promote systemic reform. Additionally, For instance, it may necessitate the establishment of open communication spaces, addressing minor infractions, and maintaining culturally appropriate teaching approaches. This is to create equal educational environments for all students, regardless of race, gender or background (Fields & Kafai, 2023).

2.2. Transformative Learning.

Cultural self-knowing, relational knowing and critical knowing (Taylor 2016), visionary and ethical knowing and knowledge in action are interdependent ways of knowing that are grounded on transformative learning. Figure 2.1 highlights the crucial concept of STEAM critical pedagogy, which is transformative Learning. The main objective of this component is to modify the way students interact with knowledge and the world, not only in terms of textbook topics but also through the cultivation of critical thinking, social awareness, and capacity for influencing change. Transformative Learning includes critical thinking, interdisciplinary problem-solving, and student agency.

Encouraging Critical Questioning of Power Structures in STEAM Fields

Transformative learning seeks to encourage students to question and challenge the power structures that shape the STEAM fields. Traditional educational institutions often rely on established norms and experts to exercise control. STEAM may involve examining the authority of those who define "knowledge," how individuals are permitted to participate in high-priority fields like technology and engineering, and the impact of gender, race, or socioeconomic status on access to these fields. Figure 2.1 illustrates the critical questioning of power structures that students need to address in order to gain knowledge about the social, political, and historical factors involved in knowledge production. STEAM students are encouraged to question how these power structures can either support or challenge inequality. Students who develop a critical awareness will be more inclined to inquire about the organization of knowledge and identify individuals who benefit from certain educational practices, leading to democratization and equity in education (Upadhyay et al, 2021).

Interdisciplinary Problem-Solving for Social Issues.

Interdisciplinary problem-solving is emphasized in the STEAM critical pedagogy framework, which promotes transformative learning. By drawing on a diverse range of subjects from Science, Technology, Engineering and Mathematics to tackle complex problems in various ways, STEAM is an interdisciplinary field (Taylor, 2015). In the context of transformative learning, the interdisciplinary STEAM approach goes beyond academic achievement and allows students to engage with various social issues, including climate change, poverty, healthcare inequities, and justice (Dahal 2002). According to the diagram, students can solve problems by combining knowledge from different fields and applying it to social issues. By engaging in projects that reflect both academic rigor and social relevance, students not only develop their technical abilities but also consider the social implications of their work. Students can appreciate the interdependence between disciplines and the significance of collaboration among different fields to tackle issues that impact society, thanks to this approach.

Enhancing Student Agency through Knowledge Creation

Student agency is a fundamental aspect of transformative learning, as it empowers students to participate in their learning and knowledge creation. The STEAM critical pedagogy environment promotes active learning through inquiry, collaboration, and self-directed exploration, while students are encouraged to actively seek information instead of passively receptive to it. Through this process, students can develop critical thinking skills that enable them to analyze, synthesize, and apply knowledge to solve problems or generate new ideas. Student agency in knowledge creation is a significant component of the transformative learning process, as demonstrated in Figure 2.1. This emphasizes the shift from teacher-centered to student-centred approach; a learning mindset that encourages students to take ownership of their education and actively engage in its development. Students become more involved in their education by utilizing project-based learning, inquiry-driven tasks, and reflective practice. Empowerment is essential for students to gain the confidence to make significant contributions to their communities and society.

2.3. Culturally Relevant Pedagogy.

STEAM education's social value and cultural responsiveness are based on the implementation of culture-sensitive pedagogies. It is important to recognize and consider the cultural diversity of students, as outlined in this component. This guarantees that students acknowledge their own identity in the curriculum and are given the chance to learn through a lens that is inclusive of their culture.' Furthermore, incorporating relevant cultural elements into STEAM projects can enhance students' engagement with their communities and foster a meaningful connection between STAM education and local issues (Nyaaba et al, 2024). The succeeding section explicates the particular aspects of culturally relevant pedagogy in the outline, with an emphasis on indigenous knowledge, arts for critical expression, and language accessibility.

Integrating Indigenous Understanding and Cultural Perspectives

The incorporation of indigenous knowledge and cultural perspectives into the STEAM curriculum is a crucial aspect of culturally relevant pedagogy. Native methods of knowing, understanding and interpretation of the world are often excluded or marginalized in traditional educational settings where knowledge is presented from a Western perspective. On the other hand, indigenous knowledge systems are a key asset to STEAM education as they provide valuable insights into sustainability management, environmental science, technology, and holistic thinking. Figure 2.1 illustrates the concept that STEAM subjects should not solely rely on global, Western-based knowledge, but also incorporate local and culturally specific knowledge from their own communities. By emphasizing the use of indigenous practices, community-based wisdom, and local problem-solving strategies in the curriculum, students are more involved in their education because it aligns with their lived experiences (Dahal, 2022). This approach also promotes cultural respect and social inclusion, which helps to bridge the gap between STEAM education and cultural identity.

Critical Expression and Participatory Engagement Through the Arts

The STEAM critical pedagogy places significant emphasis on the arts as part of culturally relevant curricular activities. Artistic expression through visual arts, music, theater or literature is a potent instrument for critical thinking and social commentary. Students engage in arts-based learning to explore ideas, feelings, and perspectives on social issues, challenge established narratives, question individual identities, or participate in discussions about justice (Peppler & Wohlwend, 2018). Figure 2.1 from the perspective of the arts for critical expression and engagement shows how incorporating creative mediums into STEAM subjects can encourage students to question societal norms, express their opinions, and participate in the educational process (Colucci-Gray et al, 2019). Through the arts, students can engage with their culture and experiences through reflection on social issues while also being able to express themselves in a meaningful way. Through this method, students can engage with the STEAM curriculum in a critical manner and express their individual perspectives on the world.

Ensuring Language Accessibility and Contextualized Learning

The aim of transformative learning is to motivate students to question and challenge the power structures that shape the STEAM fields. Traditional schools often rely on experts and established procedures to exercise control. STEAM research may involve exploring the role of individuals in defining "knowledge," how people are allowed to engage in high-priority fields like technology and engineering, and whether gender, race or socioeconomic status plays a role in accessing these fields. The questioning of power structures that students must confront to gain knowledge about the social, political, and historical aspects of knowledge production is portrayed in Figure 1. STEAM students should explore how these power structures can either support or challenge inequality. Why is this so? Students who exhibit critical awareness are more likely to ask about the organization of knowledge and identify individuals who benefit from certain educational practices, leading to democratization and equity in education (Upadhyay et al, 2021).

2.4. Critical Inquiry and Reflection.

The integration of critical inquiry and reflection is a crucial aspect of STEAM education, which fosters active learning, ethical engagement, and self-awareness. Students and educators can learn by engaging in critical inquiry & reflection, questioning established norms as well as asking socially relevant questions of the content (Perignat & Katz-Buonincontro, 2019). The development of reflective learning is closely tied to STEAM practices, enabling students to develop strategic competencies, acquire necessary skills, and cultivate attitudes and emotions that influence their future actions (Bassachs, 2020). Additionally, it fosters an early awareness of oneself, advances self-awareness, and facilitates the identification of connections between different scientific fields. Scholars can enhance their comprehension of societal and community processes by reflecting (Bassachses, 2020).

Participating in moral discourse concerning technology and society

The intersection of technology and society in which we discuss ethical issues is a central theme of critical inquiry and reflection. In an era of swift technological advancements, students must examine the impact of technology on social structures, the environment, and individual rights with critical thinking. It entails deliberating on ethics related to technology, encompassing privacy, data security, artificial intelligence, and the digital divide. The concept of STEAM education provides a means for students to engage in meaningful conversations, inquiry, and critical thinking that can be used as tools. (Guyotte, 2020) Figure 2.1 demonstrates the significance of engaging in a critical discussion on the ethical implications of technology. Teachers facilitate discussions on the ethical implications of emerging technologies to help students approach questions like such as Who benefits from technological advancements?, How does technology contribute to addressing social justice issues? , Can you identify the potential negative impacts of technological advancements?

Students can learn about their role as innovators and consumers of technology by incorporating this reflection. Furthermore, it motivates them to explore how their involvement in STEAM can advance or complicate social conventions, resulting in an ethical and socially responsible approach to STAM applications.

Inquiry-Based and Participatory Learning Methods

Another important aspect of critical inquiry and reflection is the use of methods of inquiry-based and participatory learning. These methods emphasize student-centered learning, enabling learners to engage with real-life problems and develop their own questions and solutions (Bauld, 2022) Rather than being passive recipients of knowledge, students become more involved in the process of inquiry and actively participate as researchers. Students engage in an interdisciplinary approach to inquiry learning, as depicted by the diagram, through collaboration, question-answering, and problem-solving. Students can engage in meaningful learning through project-based learning, collaborative tasks, and community-related research to enhance the relevance and context of their experience. This approach is emphasized by (Bauld, 2022) for academic achievement. Students are encouraged to explore questions, test hypotheses, and reflect on their learning as they develop new knowledge through these methods. It teaches critical thinking, encourages questioning and builds confidence to learn from those they've already learned.

Promoting Reflexivity in Students and Educators

Reflexivity is the fundamental concept that forms at the core of critical inquiry and reflection, which involves critically examining one's own thoughts actions or biase. Students and educators who are involved in reflexivity reflect on their roles in STEAM education, cultural identities, and perceptions of others (Upadhyay, et al. Figure 2.1 illustrates the importance of reflexivity as a process for both students and educators, ensuring that everyone in the learning environment engages in continuous self-examination. Students can use reflexivity to evaluate the impact of their personal experiences, cultural background, and values on decision-making and STEAM learning. Educators must consider how their teaching methods, assumptions, and interactions with students can shape the learning environment for STEAM learners.

By utilizing their reflexivity, learners and instructors can recognize potential biases or preconceptions that may affect their comprehension or teaching of a given subject. This reflection enables both parties to make more ethical choices in their interactions and work, leading to an environment of mutual respect and learning.'

2.5. Technology for Liberation.

Technology for liberation promotes technology as a means of effecting social change, empowering, and engaging with oneself critically. Technology for liberation reveals how digital literacy and technological tools can challenge oppression, promote equity, and support the liberating of marginalized groups (Perales & Aróstegui, 2024). The subsequent section explicates the fundamental elements of Technology for Liberation, such as digital literacy, open-source knowledge sharing, and critical reflection on AI and automation.

Digital Literacy as a means of empowerment

To ensure equal access to digital resources, it is essential that all individuals, particularly those from marginalized or underrepresented groups, have access (Aguayo et al., 2023). Beyond the ability to use technology, digital literacy is also portrayed as an essential skill. The ability to view, interpret and analyze digital media facilitates the empowerment of individuals to navigate the digital world in a responsible manner. Digital literacy is associated with empowerment in STEAM critical pedagogy, particularly among those who are marginalized or underprivileged due to technology (Aguayo, et al. 2023; Chappell & Hetherington, 2024). STEAM education empowers students to create and criticize technology by teaching them how it works, rather than solely relying on digital literacy. Students are able to use technology to tackle social justice issues, develop innovative solutions for their communities, and engage in global discussions.

Open-Source Knowledge Sharing and Accessibility.

Open-source knowledge sharing is essential for providing access to information and learning resources that are accessible to all, regardless of socio-economic status. Figure 1 demonstrates how technology for liberation works by emphasizing the importance of making STEAM educational content and tools accessible to all students, particularly those in rural areas who lack access to traditional STAM learning materials. The framework incorporates open-source platforms and collaborative technologies, including creative commons licenses, online learning communities, and social media repositories. Individuals can freely contribute to and access knowledge, without the need for costly expenditures or restrictive systems. By participating in open-source knowledge sharing, students can collaborate on solutions to problems that are relevant both locally and globally. This allows them to contribute to global knowledge. The use of technology enables students to collaborate, learn, and share solutions and innovations, making STEAM education a shared experience.

Examining AI, Automation and Digital Ethics with Critical Criticism

The impact of artificial intelligence (AI) and automation technologies on the workplace, society, and the environment requires critical thinking skills among students. Digital ethics are highlighted in the diagram as a means of motivating students to explore how these technologies are utilized, who gains from them, and what potential negative consequences might result from their use. Students are encouraged to engage in critical analysis of AI, automation, and digital ethics by asking questions like: Which industries would benefit from automating their jobs more ethically? , What are the ethical, equitable, and inclusive ways in which AI can be utilized? , In what ways does automation impact employment, particularly those in marginalized areas?

Students can gain knowledge about technology and its ethical implications by critically examining them in the STEAM Critical Pedagogy Framework (Dahal, 2022) and their impact on society. Students are educated on the social implications of new technologies, with the challenge of resolving that controls technology, who benefits from it, and who is left out.

To create a transformative educational experience, the STEAM Critical Pedagogy Framework integrates key elements of critical pedagogical thinking with STEM disciplines like Science, Technology, Engineering, Arts, and Mathematics (STEAM). This framework is unique. Through the use of five key components, which are social justice and equity (through transformative learning), culturally relevant pedagogy, critical inquiry and reflection, and technology for liberation, we can create a holistic approach to learning that incorporates empowerment, reflective thinking, and ethical responsibility towards diversity in an inclusive educational framework. STEAM education is intended to be empowering, transformative, equitable and enjoyable for all learners. Through the integration of principles like these into education, the STEAM Critical Pedagogy Framework facilitates the development of a more equitable and democratic society where students are not only equipped for STAM-related activities but also capable of understanding complex world situations. In this framework, education is a means of liberating society and creating 'creative minds' who are responsible citizens.

Conclusions

STEAM education adopts a critical approach to pedagogy that redefines learning as empathetic, engaged and socially constructed. The emphasis on dialogue, reflection, and community relevance in this approach allows learners to engage with their realities critically and actively participate in making changes. The STEAM Critical Pedagogy Framework is designed to blend interdisciplinary learning with equity, justice and cultural relevance while making educational experiences not just intellectually demanding but deeply humane. Through the collaborative process of inquiry and action, students acquire the knowledge, skills, consciousnesses and confidence to rise above repressive systems and imagine fairer, more equal futures.

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Chapter 3: Barriers to STEAM Participation: Addressing Systemic Inequities

1. Introduction

The value structures and ideology of particular groups of people either limit or allow the participation of others in different societal activities. Sumerau and Grollman (2018) regard ideologies as socially constructed sets of ideas, principles, or beliefs that individuals or groups use as frameworks for political, economic, or organizational interpretations. Similarly, value structures relate to collective systems of beliefs and principles that influence how individuals perceive, understand, and engage with the world. There is empirical evidence suggesting that different types of situations, such as those on social justice, sustainability, environmental challenges, and inequalities, may be underpinned in value structures that certain dominant societal groups hold (Harmáčková et al, 2023). Individuals, institutions, or policies might prioritize subsets of values, while in a similar vein, the same subsets of values or ideological stances might favour the participation of some groups of people at the expense of others (Pascual et al., 2023). School learning exists in societies laden with such value systems and dominant ideologies. Values have always been part of the education system. They are reflected variously in the way teachers interact with learners, existing school culture, curriculum content selection, and governance systems (Van Niekerk, 2012).

Achieving equity in education takes cognizance of the nature of learning. Castek et al. (2019) suggest that learning is a social activity shaped by power hierarchies and the interplay between structure and agency, which can actively marginalize potential learners through oppressive factors such as racism and sexism, among others. The social dynamics that dictate status and power in hierarchical differentiation are common in many groups and organizations (Magee & Galinsky, 2008). Some researchers posit that the prevalence of males in STEM careers reflects decision-making processes dominated by men within organizational power structures, alongside a scarcity of supportive social frameworks (Chiang et al., 2024; Hur et al., 2017). The establishment, modification, and reinforcement of gendered ideologies related to social relations contribute to the ongoing creation and perpetuation of inequality over time (Magee & Galinsky, 2008). A relevant example includes elite schools, which have taken various forms since the Victorian era. Notably, the "Victorian English culture" that characterized the early elite schools has persisted for centuries. Similar to their historical counterparts, modern elite schools (i) consistently achieve remarkable success in public examinations, (ii) secure admission to high-ranking universities, and (iii) produce distinguished alumni in government, industry, and other fields (Kenway & Lazarus, 2017). From the perspective of some sociologists, like Karl Marx, these elite schools exemplify societal inequities and the commodification of social relations under capitalism, the obfuscation of commodities, and the expropriation of morality to uphold dominant class ideologies (Kenway & Lazarus, 2017).

The documented impediments to STEM education are largely similar in nature and existence to those of STEAM. STEAM is essentially STEM education that has incorporated the arts and humanities to achieve a broad-based interdisciplinary approach to learning. The arts and humanities often address issues of social and cultural awareness as well as social justice (Cruz et al., 2021). The authors further note that the nature of STEAM education, falling into the designation of multidisciplinary, interdisciplinary, and transdisciplinary indicate a notion of broader inclusion in gender, race, socio-economic class, and viewpoints for marginalized groups. Thus, in the initial analysis of this chapter, the generic barriers to both STEM and STEAM are first considered.

In the U.S., it has been observed that there is unjustifiably an uneven representation among those successful at completing STEM degrees between students of color and their White counterparts (Nikischer et al., 2016; Whittaker & Montgomery, 2012). Citing Campos (2014), Nikischer et al. (2016) observed that African American students comprised a very small proportion (2.5%) of STEM doctoral degree awardees in 2011, and about nine percent of bachelor’s degrees in the same fields were awarded to African American students, while sixty-three percent of these same degrees were awarded to White students. The reasons cited for this situation include systemic racism and segregation, historic barriers and stigmatization, a lack of support and mentorship by institutional staff, lowered expectations for students of colour, implicit biases and stereotypes about Afro-American students' abilities in STEM fields, and a lack of cultural relevance in the materials and resources used in teaching, which often leads to disengagement among African American students (Ndiang’ui & Koklu, 2024).

While STEAM practices are becoming increasingly advanced across Europe (Chappell & Hetherington, 2024), STEAM education in Africa has only recently begun to gain prominence. This presents a significant challenge, as the continent is still grappling with the demands of STEM education. It underscores the difficulties of expecting students to benefit from STEAM initiatives when many teachers and institutions struggle to meet these requirements. The introduction of additional elements in the STEAM framework may further complicate matters for numerous institutions and their staff. According to DeJarnette (2018), eighty percent of educators in government primary schools in South Africa lack the necessary subject matter knowledge and pedagogical competences to effectively teach mathematics. Furthermore, in a state-wide representative sample of Basic Education Level schools, seventy-nine percent of Grade 6 Mathematics teachers did not achieve a score of sixty percent on a Grade 6 mathematics test. Mufanechiya and Makgalwa (2024) suggest that many countries in the Global South are struggling to address the challenges associated with developing STEM education due to inadequate learning infrastructure in institutions, teacher shortages, a lack of essential teaching resources, limited conceptual understanding and practical experience, a shortage of qualified STEM educators, and curriculum inadequacies. There is a direct correlation between the shortage of qualified STEAM professionals and societal inequalities. DeJarnette (2018) claims that most provinces in South Africa suffer inequality, poverty, and a high rate of unemployment as a direct result of obsolete pedagogical practices, skills gap, and skills shortage perpetuated by educational systems. This chapter interrogates the factors causing systemic inequities that hamper student participation in STEAM education. The chapter attempts to answer three basic questions as follows:

1. What theoretical frameworks guide the provision of STEAM education?
2. What are the existing barriers to STEAM education development in southern Africa?
3. How can institutions address the systemic inequities existing in STEAM education development?

2. Theoretical considerations

The STEAM education development that this chapter attempts to articulate is situated at the intersection of several theoretical frameworks. Kim et al. (2012) proposed a STEAM model for STEAM that outlines key concepts and major competences, as well as three elements of STEAM convergence. The three elements of STEAM convergence: contexts, convergence methods, and convergence units, relate to the individual, community, and global contexts; multidisciplinary, interdisciplinary, and transdisciplinary approaches; and the concepts of inquiry and resolution of everyday problems/phenomena, respectively. In their study establishing the theoretical framework that explains and justifies the integration of the arts into science education, Chu et al. (2019) utilized social constructivism. Social constructivism posits that the construction of knowledge is collective consensus process undertaken socially and that learning is a cognitive process occurring in situated contexts, highlighting the learners' prior experiences (Chu et al., 2019).

This chapter employs a social justice framework to explore barriers and address systemic inequities within STEAM education. Social justice is defined as a theoretical framework that guides the implementation of policy guidelines and practices aimed at promoting diversity and equity (Rodriguez & Morrison, 2019). The use of such frameworks assists in three distinct ways. Firstly, it aids the understanding of the oppressive dynamics between those in power and the historically marginalised groups within and beyond the school environment. Secondly, it creates an awareness of cultural imperialism and its manifestations within STEAM education curricula. Finally, it provides frameworks for developing mutual respect and collaboration in a democratized process of knowledge co-construction. Justice in science education is anchored in concepts of equity and equality that focus on issues related to the distribution of both power and resources, access, opportunity, and the broadening of participation in the various sectors of society and the economy (Kayumova et al., 2019). To achieve justice and social equity, programs aim to inspire children from traditionally underrepresented communities to engage with science, providing them with opportunities to pursue scientific careers, helping them recognize the connection between science and the broader world, and highlighting the transformative potential of scientific knowledge and practices (Kayumova et al., 2019).

Equity refers to implementing fair and just policies and practices to ensure that those disadvantaged have access and opportunities for success, as do the advantaged groups (Rodriguez & Morrison, 2019). It involves recognizing and addressing existing imbalances and disparities among social groups by strategically deploying resources to mitigate these inequalities. Therefore, creating an effective framework for school participation centered on equity and inclusion requires some disruptive pedagogies to ensure that historically excluded groups that are underrepresented in STEAM education are brought to the fore (Castek et al., 2019).

The theory of epistemic (in)justice serves as a framework to explore the obstacles hindering STEAM education and to highlight strategies aimed at addressing these injustices. This concept of epistemic (in)justice was first introduced by Miranda Fricker, a British philosopher, in 1999. Fricker proposed that the term epistemic injustice could capture the injustices associated with knowledge, defined as "...the systematic distortion or misrepresentation of one's meanings or contributions; undervaluation of one's status or standing in communicative practices; unfair distinctions in authority; and unwarranted distrust" (Fricker, 2007, p. 27). In the context of STEAM education, epistemic injustice arises when individuals are treated unjustly or excluded from the process of knowledge creation and sharing based on their social identities, including gender, race, geo-spatial location, socioeconomic status, which leads to the neglect or disregard of their voices and viewpoints (Omodan, 2023). Fricker referred to this unjust treatment as 'epistemic wrongs,' reflecting the moral violations that arise in knowledge production, utilization, or circulation that result in epistemic injustices when the knowledge held by individuals from disadvantaged groups is systematically demeaned as less credible, and when their interpretive resources are not acknowledged (Bhakuni & Abimbola, 2021). Consequently, these epistemic wrongs manifest when the role of marginalized groups as knowers is undervalued, their interpretative tools for understanding the world are overlooked, or when they are unable to engage with knowledge that has been generated without their involvement (Bhakuni & Abimbola, 2021). Fricker (2007) identified testimonial injustice and hermeneutical (interpretive) injustice as the two types of epistemic injustices.

2.1 Testimonial and hermeneutical injustice

Testimonial injustice happens when an individual suffers from a credibility deficit in the role of a knower. This phenomenon can also arise when a listener diminishes a speaker's statements based on prejudicial biases, resulting in actions that deter, devalue, or contort the speaker’s submissions (Bhakuni & Abimbola, 2021). The speaker faces an unjust disadvantage when their message or communication is disregarded due to biases related to sexuality, tone of voice, gender, religion, social background, accent, ethnicity, or race (Byskov, 2020). As Byskov (2020, p. 2) further articulates:

> Testimonial injustices wrong someone in their capacity as a speaker or knower because the increased or decreased credibility accorded to their testimony is based not on any relevant concerns, but on prejudices that have nothing to do with whether the speaker or knower should be granted credibility. This in turn gives an unfair advantage in communicating their knowledge to those who are not subject to these prejudices.

Unlike testimonial injustice, hermeneutical or interpretive injustice pertains to circumstances in which individuals are unable to express or comprehend their disadvantaged status due to a deficiency in their linguistic capabilities, which is a result of that same status (Dubgen, 2016). People or communities find it challenging to understand and communicate their experiences of the world because of a lack of recognized collective interpretive tools (Bhakuni & Abimbola, 2021). Elzinga (2018) states that hermeneutical injustice arises when the interpretive tools accessible to people belonging to particular societies are insufficient due to the systemic marginalization of individuals within the same social group from processes of sense-making, or when individuals from epistemically oppressed groups cannot convey their experiences to others due to the deliberate hermeneutical ignorance exhibited by those in possession of epistemic power. Both types of injustices function as obstacles to the successful implementation of STEAM education.

The identification and evaluation of claims of epistemic injustice manifest in five conditions set out by Byskov (2020), as shown in Table 1 below.

Table 1.

The five conditions for identifying and evaluating epistemic injustice (Source: Byskov, 2020)

CONDITION	**DESCRIPTION**	**ASPECT OF (IN)JUSTICE**
STANDING AT A DISADVANTAGE POSITION	If one is unjustifiably discriminated against as a knower, and suffers epistemic and socioeconomic disadvantages as a result of the discrimination	Unfair outcome
THE PREJUDICE POSITION	Holding prejudiced opinions or judging a knower's sentiments unfairly in ways that create disadvantages or inequities for the speaker	Unfair judgment about epistemic capacity
THE STAKEHOLDER CONDITION	A condition where one is affected negatively as a stakeholder by decisions they were not part of	Unfair denial of stakeholder rights
THE EPISTEMIC POSITION	Individuals possess knowledge that is relevant to some decision that they were excluded from, and in the process, get disadvantaged	Unfair denial of knowledge
THE SOCIAL JUSTICE STANCE	For someone to be unjustifiably discriminated against as a knower, they must at the same time also suffer from other social injustices	Unfair existing Vulnerability

The table outlines various conditions that contribute to the identification of injustices, specifically within the context of STEAM education. It emphasizes several key elements: disadvantaged circumstances, prejudiced experiences, stakeholder involvement, epistemic factors, and social justice considerations. An example of an epistemic condition arises in circumstances of unfair denial of knowledge. This happens when educators fail to acknowledge the prior knowledge that learners bring to the classroom. For instance, teachers might overlook indigenous knowledge systems and the leaners' diverse worldviews, which can lead to misunderstandings or misconceptions among students. Additionally, research by Ndofirepi & Gwaravanda (2019) highlights how this exclusion serves to diminish the educational experience of learners, particularly those from marginalized backgrounds. Implying that the learners' educational experiences in science learning are limited to concepts that are foreign to them because their world views, replete with experiences from their indigenous backgrounds, are disregarded. The exclusion extends to situations where the creativity competence requisite for innovation and critical thinking is neglected in the teaching of STEM disciplines, as noted by Chu et al. (2019). This exclusion not only undervalues artistic and creative contributions but also stifles the holistic development of students, suggesting that a more integrative approach is essential for cultivating well-rounded learners in STEAM fields.

3. Existing barriers to STEAM education development

This section delves into the barriers that impede the advancement of STEAM education, further examining the systemic issues that perpetuate these injustices and exploring potential pathways for fostering a more inclusive educational environment.

Numerous barriers can impede the effective development of STEAM education, as its implementation occurs within a variety of contexts, each presenting unique challenges, inclusive of socio-economic conditions, cultural differences, and access to resources. The existing digital divide between nations in the Global North and those in the Global South exemplifies these challenges. In contexts where educational practices rely on technology-driven activities, such as conducting online experiments, utilizing interactive digital books, engaging in gamification, participating in simulations, and producing videos, schools in less technologically advanced settings (like those in the nations of the Global South) may struggle to provide these essential resources and tools (Nadelson & Seifert, 2017). Successful teaching of integrated STEAM education requires educators to understand how diverse contexts can enhance the learning of multiple STEM disciplines and concepts.

Literature identifies the infrastructure (internet access, laboratories, classrooms), economic divide (the developed versus the underdeveloped nations), school culture (nature of organisations), and the academic (teachers' competences, learners' abilities, nature of curricular) contexts as some of the determinant factors in the successful implementation of STEAM programmes. Teachers are resistant to expanding their understanding of interdisciplinary approaches are less likely to actively support and foster effective STEAM teaching (Perales & Aróstegui, 2024). Consequently, educational systems must self-retrospect to assess what is relevant for their context. They must also provide ongoing professional development opportunities that equip teachers with both the content knowledge and pedagogical content knowledge necessary for interdisciplinary STEAM instruction. This investment in teacher training is essential to ensure that educators are prepared and motivated to offer high-quality STEAM experiences for their students (Perales & Aróstegui, 2024).

3.1 Practitioners' lack of capacity

STEAM teachers need special sets of skills for the successful implementation of programmes. Kim and Kim (2016) claim that mandatory STEAM teaching competences include intellectual ability in subjects, critical thinking ability, ability to engage the community, and personal emotional ability. These skills mean a STEAM practitioner should be able to understand and use convergent knowledge, have abilities to scaffold learners to innovate, problem-solve, think critically, make decisions, communicate, collaborate, and engage in social relationships as well as cultivate virtues of self-introspection, self-awareness, empathy, and civil awareness among the learners. These competencies also entail acumen in pedagogical content knowledge (PCK) for STEAM teaching and information technology literacy. Nadelson and Seifert (2017 p. 221) contend that the curriculum and instruction in the age of ICT targets "…new domains of expertise such as evaluating and applying seemingly disparate information, accommodating the accelerated emergence of new knowledge and sophisticated technologies, preparing for transdisciplinary careers, and merging traditional disciplines to better meet the needs of citizens in the 21st century". Therefore, a lack of ability to adapt to the new set of skills for STEAM education hampers the effective enactment of STEAM.

Since the teacher plays a vital role in executing a STEAM education program, their Pedagogical Content Knowledge (PCK) is a crucial element. PCK represents a facet of teachers' professional expertise that pertains to their ability to identify the most effective teaching strategies for specific subjects. This concept lies at the crossroads of content knowledge and pedagogical understanding, encapsulating not only a teacher's familiarity with the material but also how they apply this knowledge in their teaching practice (Martins & Baptista, 2024). Given that the quality of educators is critical for the success of STEAM education programmes, Martins and Baptista (2024) believed it was important to create opportunities for teachers to enhance their Pedagogical Content Knowledge (PCK) for integrated STEAM. The authors (Martins & Baptista, 2024, p. 164) envision that STEAM-PCK must include the following aspects:

(i) Understanding what students already know;
(ii) Awareness of the topics that are challenging to teach;
(iii) Insight into the curricular significance of the topic and/or concepts involved in each STEAM area;
(iv) Familiarity with various forms of representations;
(v) Knowledge of interactive teaching approaches, cooperative, and student-centered teaching methods; and
(vi) Understanding how to integrate subjects through a transdisciplinary approach.

Martins and Baptista's (2024) framing of an integrated STEAM education PCK is not merely tentative; it highlights essential requirements that are often lacking among teachers, hindering the effective enactment of this approach (DeJarnette, 2018). These requirements demand that practitioners possess a strong foundation in both subject matter knowledge and pedagogy. Research clearly shows that insufficient PCK presents a significant barrier to effective teaching of STEM subjects (Anney & Hume, 2014).

The success of these STEAM education programmes hinges on the ability of teachers to exemplify creativity and foster its development in their students. Creativity, which entails the generation of novel ideas and finding new solutions to problems, is a fundamental component that defines the essence of STEAM, as it engages students in scientific inquiry processes and integrates innovation into the teaching process (Niu & Cheng, 2022). Leroy and Romero (2021) assert that teachers' competencies, including their awareness of creative mindsets and their ability to engage automatically in creative activities, are vital for effective STEAM instruction. Creativity itself is characterized by the capacity to generate ideas or products through various cognitive processes, such as imaginative, divergent, and convergent thinking. This skill can be nurtured both individually and collaboratively, with groups harnessing individual creative potential to brainstorm and devise innovative solutions to challenges.

Research has indicated a link between creativity and the learning preferences of girls. The integration of the artistic and humanistic aspects represented by the 'A' in STEAM plays a significant role in cultivating girls' interests in technology, thereby addressing the gender imbalance within scientific and digital fields (Card & Payne, 2020). Several initiatives in Africa exemplify the use of STEAM education as a means for women and girls' empowerment. For instance, the Women Entrepreneurs for Africa program established community libraries to enhance the STEAM education of women and girls (Belbase et al., 2019). Additionally, Inspire Africa launched a STEAM initiative in South African schools, specifically targeting girls and integrating drone technology with the sciences, mathematics, and the arts disciplines (Kruger, 2019).

3.2 Inadequate resources for STEAM education

Empirical evidence has established that the distribution of resources in a society favours some groups less than others. For instance, ethnic bias and nepotism has defined the leadership in many African countries as different ethnic groups are treated unequally, particularly in the areas of national resource allocation and political representation (Ilorah, 2009). This has led to a "resource divide" between the rich versus the poor, political elite versus the governed, countries of the Global North versus those of the Global South, the dominant ethnic groups versus minority ethnic tribes, men versus women, and schools in the urban centres versus schools in remote rural areas. Mestry (2014) reports that despite government efforts to redress the inequities in resource distribution that were caused by the Apartheid system in South Africa, some rural schools and some urban working-class communities suffer the legacy of crowded classrooms, dilapidated infrastructure, teacher shortages, and the absence of learning resources. Okunlola and Hendricks (2023) observed a similar pattern where rural secondary schools experienced teacher shortage and textbooks, in critical subjects such as science and mathematics, compared to urban schools in sub-Saharan African countries. STEAM education is not spared by these power relations imbalances relating to the equitable distribution of resources.

The instruction of STEAM disciplines necessitates materials like paints, brushes, musical and cultural instruments, computers, internet access, and laboratory tools, among others. In a paper that presents a theoretical framework explaining and supporting the blend of arts and socio-cultural interactions into science education and learning, Chu et al. (2017) utilized technologies such as video and tele-conferencing, audio threads, and virtual boards to establish a digital environment for collaborative learning and to promote joint knowledge creation between students in Australia and Korea. Success in such initiatives is challenging without adequate resources. Numerous studies (Moluayonge & Park, 2017; Sephania et al., 2017) have demonstrated the detrimental effects of insufficient resources on the effective implementation of STEAM programs. The successful teaching and learning of STEAM subjects can be affected by the availability science learning resources, chemicals, and materials, laboratory staff, conditions within the lab, comprehensive textbooks, and digital resources like computers and the Internet (Moluayonge & Park, 2017).

Therefore, resources and tools (see Figure 1) that facilitate the conceptualization of disciplinary knowledge in STEAM education must be accessible for the successful implementation of this initiative. An inadequate or unjust distribution of these resources can lead to what Fricker (2013) refers to as distributive epistemic injustice. This concept is characterized by the inequitable allocation of epistemic goods, including education, educational resources, and information (Fricker, 2013). Despite it being a broad area of study, this chapter specifically examines the resources and tools that enhance the conceptualization of disciplinary knowledge in STEAM education. The research in this field explores various epistemic tools, from students' representational gestures to innovative technologies that aid students in investigating phenomena, as well as strategies for making thought processes transparent and accessible to all (Stroupe et al., 2019). Stroupe et al. (2019) contends that these tools—including artifacts and technology—are utilized in classroom routines, STEM practices to foster productive student engagement, discourse, their collaborative sense-making, and to support them in articulating their thought processes.

Figure 1. A hybrid laboratory with a Smart Board showing simulated experiments (Photo courtesy of Rukara Model School, Rwanda)

On one hand, studies have shown that having resources and tools for STEAM education enhances student access to knowledge, while on the other hand a lack of these resources hinders the effective execution of STEAM programmes. In a research effort focusing on the obstacles and approaches for fostering equity in STEAM education activities in Chinese kindergartens, Sun and Saleh (2024) identified multiple challenges to implementing equitable STEAM activities, such as limited resources, differing degrees of parental involvement, and the necessity for continuous professional development for educators. Their research highlighted how the availability of resources affects the overall quality of STEAM education. Similarly, Belbase et al. (2022) observed other obstacles in STEAM pedagogy as insufficient funding and resources, inadequate books and facilities, limited access to technological tools, and large class sizes. For example, a study assessing teachers' competencies in STEAM education by Buthelezi et al. (2024) revealed that while many teachers were dedicated to fostering reflective and critical thinking among their learners, a lack of STEAM equipment and infrastructure remained the chief barrier to effective implementation.

Accordingly, in African nations, issues such as inadequate electricity in schools, insufficient training for teachers, and a lack of computers in classrooms obstruct the successful rollout of STEAM education initiatives.

3.4 Unfair denial of stakeholder rights

Using Fricker's (2013) analogy, a learner belonging to a minority language group that is excluded from societal sense-making processes and the generation of social meaning is thereby put at an unfair disadvantage when it comes to sense-making in particular STEAM disciplines that are taught in a foreign language other than their mother tongue and are traditionally regarded as a preserve for a few. Most of the countries in sub-Saharan Africa have a history of colonization. The majority of the countries were colonized by Britain, Germany, France, or Belgium. In the post-colonial period, the education systems in these countries remained largely westernized, with either English or French as the official languages of instruction. That implies the textbooks, the instruction, labels for apparatus, and all disciplinary and Information Technology (IT) communications remained in foreign languages (Babaci-Wilhite et al., 2019). Despite the current debate to decolonize educational institutions (De Lissovoy, 2010; Desai & Sanya, 2016; Ndofirepi & Gwaravada, 2019), none of the countries has adopted a language policy that recognizes and prioritizes the use of indigenous languages as a medium of instruction, less for infant classes (Hays, 2009; Kago & Cissé, 2022). Ndofirepi and Gwaravada (2019) argue that decolonization, which entails reclaiming intellectual and cultural spaces, is a conscious epistemic process that places indigenous African knowledge systems at the fore while utilizing other canons of thought for a broader and dialogical system of knowledge.

The learner's right to the use of their mother tongue, a cultural and interpretive resource for sense-making, is denied upon entry into the Physics laboratory, where the epistemic discourse is replete with Western dominance. According to Babaci-Wilhite et al. (2019, p. vii). A child speaks the language of her culture at home. They know a lot about their bodies, the names of the different parts, and their connections. They already know about food, chewing, digestion, and the separation of nutrients and waste, the nutrients absorbed in the body, and the waste expelled. When in school, they encounter English or any language of education that is not their mother tongue, they suddenly hear terms like anatomy, physiology, and the digestive system, and suddenly, what was an integral part of their experience sounds splendidly mental and strange. The citation by Babaci-Wilhite et al. (2019) demonstrates the importance of acknowledging the learners' prior knowledge, power, and language experiences as sources of empowerment during the learning process, as well as the cultural essence of disciplinary knowledge and school practice.

The cultural characteristics of disciplinary knowledge in Western science curricula often place significant weight on the individual white male professor as a role model, while neglecting the inherent social, political, and cultural dimensions of the science curriculum (Chappell & Hetherington, 2024). Therefore, at the heart of every science classroom is a complex interplay of tools and language that students utilize to formulate arguments and compete for acknowledgment during the discussions linked to knowledge construction (Settlage & Southerland, 2019). Ignoring these tools represents a violation, which, in the context of this chapter, acts as a barrier to the effective development of STEAM education, as the use of more familiar languages rather than foreign languages has consistently been shown to enhance understanding of scientific concepts (Kago & Cissé, 2021).

4. Possibilities for addressing the systemic inequities existing in STEAM education development

Addressing the systemic inequities existing in STEAM education development is not easy due to the divergence of opinions on what the term stands for. Scholars and science educators alike do not agree on a common definition, let alone the strategies for implementing the approach. Some critics of STEAM argue that the integration of the "Arts" in STEM education has only served to dilute the strength of the other disciplinary areas. Citing the work of other scholars, Belbase et al. (2017) identified the following as the criticism levelled against the approach:

- Incorporating the arts and humanities with STEM in education may reduce the time allocated for deeper engagement in mathematics, and the other science, disciplines.
- Comprehensive integration has disrupted the strength of the core subjects and weakened the stable structure of schools due to a lack of resources.
- The integration is seen as unnecessary since it leads to greater misconception of the individual disciplines within STEAM rather than improving efficiency and effectiveness.
- The complexity of implementation poses challenges for teachers who may lack a proper understanding of the nuances and goals of the initiative.
- Integrated teaching requires a variety of pedagogical methods, which could detract from the learning of other subjects.
- Teachers feel unprepared to instruct, design materials, and collaborate on an interdisciplinary STEAM curriculum.

In the final aspect, educators often struggle to collaborate because they carry a perceived hierarchy regarding the subjects they teach, which leads them to undervalue the contributions of other subjects (viewed as having lower status) to interdisciplinary instruction. For example, a Physics instructor might see Art or Entrepreneurship Studies as less valuable and therefore resist working with teachers of those subjects. Belbase et al. (2017) argue that educational departments in schools and universities are structured with a silo mentality, where knowledge is rigidly categorized by discipline, creating traditional institutional frameworks that hinder collaboration among staff members. To challenge this mindset and other related issues, transformative STEAM methods are necessary, which this section will explore.

4.1 The socio-transformative approach

The socio-transformative approach is when the STEAM educator works with the public to identify and resolve social justice issues (Rodriguez & Morrison, 2019). Rodriguez and Morrison (2019) further note that critical aspects of this approach are diversity, equity, and social justice, which should link to tangible transformative action. The goal of social justice education is to ensure that all groups can actively participate in a society that is structured to fulfill their needs (Hackman, 2005). Central to Hackman's (2005) perspective on this teaching approach is the establishment of communities of practice where STEAM educators collaborate in research with peers, students, community members, industry professionals, and affiliated organizations. By engaging with communities, vital social justice elements such as mastery of content, critical analysis, practical skills, self-examination, and an understanding of multicultural dynamics are incorporated (Hackman, 2005). Furthermore, teaching and learning science with a focus on social justice not only fosters critical scientific literacy but also addresses the socio-political landscape of STEAM education, which often prioritizes economic advancement to the detriment of disadvantaged and marginalized populations (Barton & Upadhyay, 2010). Thus, as previously mentioned, social justice education is inherently connected to tangible transformative actions.

Transformative action invokes Jack Mezirow's concept of transformative learning. Mezirow conjectured that individuals hold certain world views that are usually based on a set of paradigmatic assumptions derived from their lived experiences, inclusive of traditions, norms, language, or education (Christie et al., 2015). According to Taylor and Taylor (2018), in transformative learning, students use their intellectual, social, emotional, and spiritual development methods to reflect critically and learn to re-conceptualize and modify the relationship between their outer and inner worlds. Taylor and Taylor (2018, p. 4) present five transformative ways of knowing and learning that support effective STEAM programmes, as follows:

- Cultural self-awareness entails recognizing how our culturally embedded identities are formed, particularly through the foundational beliefs, values, ideals, emotional expressions, and spiritual views that shape our cultural identities.
- Relational understanding focuses on fostering empathic and compassionate connections with our authentic selves, our local communities, those from different cultures, and the natural environment.
- Critical awareness involves understanding how and why political, institutional, and economic powers have historically moulded our social realities by establishing class structures and how this often unseen power impacts our life

experiences, our interactions with others, and our relationship with the natural world.

- Visionary and ethical awareness incorporates creative, inspiring, and dialogical processes of idealizing, envisioning, romanticizing, reflecting on, and collaboratively negotiating a shared vision of a better future.
- Actionable knowledge includes the intentional development of our abilities to contribute to a better world, making a commitment to effect change, and engaging in actions locally while considering the global context.

These five dimensions enfold the 21st Century learning skills that champion the moral obligation for STEM educators to draw on Arts and Humanities education approaches to develop students' multidisciplinary abilities for participating as key epistemic agents in critical discourses on development in education, decision-making, and sustainable practices (Taylor & Taylor, 2018).

4.2 Transformative STEAM pedagogy

No consensus exists regarding the definition of pedagogy within the expansive field of transformative STEAM education. Various STEAM education projects have successfully employed diverse approaches. Chappell and Hetherington (2024) provide an overview of these approaches and the development processes informed by mixed-methods research. In their study conducted within a STEAM education initiative, the authors aimed to enhance students' ocean literacy through the integration of creative pedagogies and digital technologies. The project was structured to ensure that the content on ocean literacy was sequential and grounded in a defined set of principles. The approach used in the study facilitated the crossing of disciplinary boundaries, empowering students to leverage knowledge, ideas, and processes from diverse disciplines to formulate and address their inquiries. Moreover, digital technologies were utilized to support design-based inquiry and data-driven analytics learning in ocean literacy, while teaching and learning incorporated eight features of creative pedagogies, as illustrated in Table 2 below.

Table 2.

The eight creative pedagogies features and their description (Source: Chappell & Hetherington, 2024).

CREATIVE PEDAGOGY FEATURE(S)	DESCRIPTION
DIALOGUE	Pedagogically asking questions in a way that leads to new insights
TRANSDISCIPLINARITY	Address disciplinary knowledge from various angles. The relationship between disciplines serving the question or problem at hand
INDIVIDUAL, COLLABORATIVE, AND COMMUNAL ACTIVITIES FOR CHANGE	Ensuring individual accountability in the context of collaboration within communally driven exploratory and experimental learning, often with an emphasis on activism
BALANCE AND NAVIGATION	Maintain work, control and freedom balance in the course of teaching. The consciousness of the existence of structural, and power imbalances, whilst acknowledging educational tensions of assessment, marketisation, and time
EMPOWERMENT AND AGENCY	Empowerment and ownership of the learning through socially engaged practices, to ask their questions and make their own mistakes
RISK, IMMERSION, AND PLAY	Creating risk-taking environments, pedagogy of care, and encouraging immersion in problems, and playful approaches
POSSIBILITIES	Premise all engagements in the maxim, “There is richness in diversity” to allow for multiple possibilities, both in terms of thinking and spaces
ETHICS AND TRUSTEESHIP	Pedagogy is premised on the ethics of care. Considering the ethical implications and impacts on those around them of their creativity, and taking responsibility for holding the values

Notable examples of STEAM initiatives, such as the Global Science Opera, are discussed in Perales & Aróstegui (2024). Every year, Scientix, a science education network in Europe, organizes the Global Science Opera, which serves as a STEAM project focused on producing a science-themed opera. Schools from various countries collaborate to create two-and-a-half-minute scenes featuring libretto, music, set design, costumes, and distinct melodies, all coordinated in pairs. Competitions are conducted on designated days using video conferencing and other online platforms. Additionally, participating schools engage in metacognitive activities related to the chosen theme, which may include trips to scientific institutions or museums, video calls among students, and inquiries or design thinking projects centered around the same subject.

Bevan et al. (2019) assembled a model on collective and individual STEM and arts-based research projects that resulted in the iteration of hybrid epistemic practices shown in Table 3 below.

Table 3.

Epistemic practices in STEAM (Source: Bevan et al., 2019)

	STEM practices	Conjectured STEAM practices	Arts practices
Exploring	Hypothesising, Asking Questions, and Identifying Problems, and engaging in the process of scientific inquiry. Utilise design thinking, mathematical and computational thinking	Define parameters of identified problems Exploring feasibility Defining the problem space	Deeper engagement Utilising aesthetic and creative reasoning. Deconstructing component elements and their respective meanings
Meaning-making	Design and generate Models Data synthesis and analysis. Data interpretation Constructing explanations/ designing solutions	Producing tentative Representations Conducting principled Engage in meaning-making design cycles Finding relevance	Integrate artistic principles to augment Meaning Designing interrelations within and across multiple sign systems Combining Artistic design skills with engineering design.
Critiquing	Arguing from evidence/peer Review Evaluating and communicating findings	Historical actuality of events; hacking the ideas of others Cultivating dissent Holding commitments to standards of the field Information dissemination and sharing	Critiquing science from an Artistic perspective. Negotiating what constitutes a “good” project Given a particular artistic goal, evaluating how successfully this the goal has been met

Table 3 presents a continuum for evidence-based argumentation that bridges STEM subjects with the Arts. As the practices of the Arts are increasingly integrated, deeper engagement emerges, enhancing the learning experiences in both fields. For example, in STEM, the practice of arguing from evidence is further enriched by incorporating elements of critical historicity and the concept of "hacking," where individuals crack into long-established structures and systems of knowledge, and build upon one another's ideas in collaborative discussions. Mejias et al. (2020) point out that these hacking activities, referred to as critiquing in Table 3, embody dynamic interactions, such as leveraging Twitter hashtags to galvanize social movements or choreographing dances to express and position identities and lived experiences within the realm of science. This integration transforms the analytical process, as final ideas are evaluated and contextualized according to specific artistic objectives. Mejias et al. (2020), reflecting on the work of Bevan et al. (2019), highlight that STEAM programs frequently prioritize two hybrid epistemic practices—evidence-based argumentation and critique— as optimal strategies for merging STEM and the Arts effectively.

4.3 Disrupting the language barrier

Previously in this chapter, the issue of language has been identified as a barrier to effective STEAM education when it is foreign to the learners' cultural context. It has been contended that employing foreign languages in the teaching and learning of STEAM subjects undermines learners' rights to their own identities and cultural heritage. Babaci-Wilhite (2019) argues that education conducted in foreign languages and encompassing foreign concepts does not fully represent its respective society's values and knowledge to succeeding generations. Instruction is more effective when rooted in local languages and cultural contexts, including the Arts. Several African nations inclusive of Angola, Botswana, the Democratic Republic of Congo, Malawi, South Africa, Zambia, and Zimbabwe, face this challenge. As former colonies of European countries, they have adopted the colonizers' language as the Language of Instruction (LoI). This chapter advocates for the implementation of language policies that permit the use of local, Indigenous languages as the LoI in STEAM education programs. Babaci-Wilhite (2019 p. 8) say:

> This practice of a method of education that is based on contextualization, that is, using the local LoI, leads to a rethinking of all aspects of education, both formal and informal education in and out of school. Education must therefore acknowledge culture through the Arts. This includes the non-material aspects of life such as language, social, and historical identity.

In the context of STEAM, research has shown that using indigenous languages that are native to the learners' cultures, as opposed to foreign languages, has consistently shown a more nuanced understanding of scientific concepts. Kago and Cisse (2022) argue for the use of African indigenous languages (AILs) in the teaching and learning of the sciences to increase trust. The authors believe that if African countries re-visited initiatives that were made in the Lagos Declaration and Call to Action on Science Communication and the Public Learning and Understanding of Science (PLUS) to engage science in AILs, then conceptualisation, confidence, and ultimately integrity in STEAM education across the diverse audiences on the African continent will increase.

Kago and Cisse (2022) advocate for identifying commonalities among AILs to establish a primary language for translating STEAM textbooks and modeling this approach on the Open Access platform AfricArxiv. As noted by Wild (2021), the Pan-African Open Access platform has initiated the “Decolonize Science” project in partnership with the Natural Language Processing (NLP) research organization, aiming to translate original research papers into six distinct African languages: Amharic, Hausa, isiZulu, Luganda, Northern Sotho, and Yoruba. NLP is among the organizations working to create matched lists of words and sentences that enable computers to connect and correlate meanings across multiple languages (Kago & Cisse, 2022). The authors suggest adopting AILs to enhance science engagement, which would require political and institutional support from governments and other sectors of the economy to provide the necessary resources and incentives for scientists and linguists. This collaboration would help in developing terminology that can be integrated into NLP translation algorithms, subsequently equipping science communicators and journalists with the vocabulary needed to create educational content in AILs (Kago & Cisse, 2022).

5. Conclusion

In this chapter, we decisively address the challenges hindering the effective implementation of STEAM education programs. Numerous barriers—such as deeply entrenched prejudices related to gender, race, ethnicity, and religion, inadequate resources, and the insufficient capacity of practitioners—undoubtedly obstruct learning in STEAM initiatives. We employ Miranda Fricker’s epistemic injustice theory, rooted in a social justice framework, to (i) dissect the oppressive dynamics between those in power and marginalized groups both within and beyond school environments, (ii) illuminate the phenomenon of cultural imperialism and its manifestations within STEAM curricula, and (iii) advocate for the nurturing of mutual respect and collaboration through a democratized process of knowledge co-construction.

We identify key injustices stemming from disadvantaged and prejudiced conditions, including unfair outcomes, biased judgments regarding epistemic capacity, denial of stakeholder rights, suppression of knowledge, and existing vulnerabilities. These epistemic wrongs are prevalent in numerous STEAM education systems, particularly in countries across Southern Africa. We assert that disrupting these harmful practices demands a socio-transformative approach that encompasses cultural self-realization, rational knowing, critical knowing, visionary and ethical knowing, and practical knowing. Rational knowing is crucial for students in STEAM classes to understand the historical rationale for class structures and how transformative pedagogies associated with STEAM education can be used to disrupt these structures. This often invisible power profoundly influences our life experiences, our relationships with others, and our connection with the natural world. The five dimensions outlined are essential for cultivating the 21st-century learning skills that empower STEM educators to integrate Arts and Humanities methods, thereby enhancing students' transdisciplinary abilities.

This integration is vital for students to emerge as key epistemic agents in sustainable development debates, decision-making processes, and practical applications.

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Chapter 4: Building bridges: STEAM education, Environmental justice, and Critical pedagogies of place

1. Introduction

STEAM education and environmental justice are epistemic areas that have emerged in the last two decades. In South Korea, STEAM education was established in schools to integrate both the liberal and creative arts, the humanities, and language study into the teaching of STEM in 2009 (Chu et al., 2019). To achieve this, the Korean National Science Education Curriculum was revised. The STEAM education framework, designed to be adaptable for all levels, types, and styles of teaching, comprises 'Creative Design' and 'Emotional Learning' as important aspects that foster a deeper understanding of the content, processes, and characteristics of STEM disciplines (Yakman & Lee, 2012). Additionally, Yakman and Lee (2012) contend that the Korean framework focuses on the affective aspect of science, technology, and mathematics education through 4CSTEAM, standing for Caring, Creativity, Communication, and Convergence.

In the United States, interdisciplinary STEM education, which gained prominence in the 1990s, evolved into STEAM with the subsequent inclusion of the Arts (Gavari-Starkie et al., 2022). Recent initiatives, such as the Next Generation Science Standards and the Common Core State Standards for Mathematics, have placed emphasis on an integrated STEM approach (Belbase et al., 2022). This push for effective integration in STEM education has further contributed to the development of STEAM (Razi & Zhou, 2022). Within the STEAM framework, the Arts component has been intentionally incorporated into integrated STEM education to foster creativity and innovation (Razi & Zhou, 2022). Since then, Gavari-Starkie et al. (2022) note that government policies, including the Educate to Innovate program and the Science, Technology, Engineering, and Mathematics for Sustainable Development Education (STEM4SD Education) initiative, were introduced to enhance the value of students' curricula and to connect school science with sustainability education and the local community.

The popularity of STEAM education has significantly grown over the past ten years in various regions of Africa. In numerous African nations, initiatives related to STEAM education have emerged as a means of promoting empowerment and equity, with a particular focus on women and girls (Belbase et al., 2022). Additionally, in several African countries, STEAM is regarded as a catalyst for economic development. Like other developing nations in Africa, Ghana's Ministry of Education (MOE) recognized the crucial importance of STEAM in facilitating the country's economic and sociopolitical advancement, leading to the launch of STEM centers and high schools across the nation in 2018 (Nyaaba et al., 2024).

Environmental justice has evolved from a singular concern for trees and wildlife into a significant social movement that highlights the environmental inequalities faced by marginalized communities. These systemic disparities, often perpetuated by a political class hierarchy, have historically impacted numerous societies around the world. A notable example is the Land Apportionment Act of 1930 in Southern Rhodesia (now Zimbabwe), which granted White settlers exclusive rights to fertile land while relegating Indigenous African populations to less productive areas known as Tribal Trust Lands (TTL). According to Moyana (1975), this Act established the principle of possessory segregation between black and white populations, ultimately leading to unequal agricultural production. It confined the African population to a state of serfdom and hindered the country's economic development by denying the majority of Indigenous people access to productive farmland.

In the United States, the concept of environmental justice emerged in the mid-1980s amidst the fight for racial equality. Groups such as the African American communities, Black scholars, and the progressive United Church of Christ became conscious of the environmental disparities that Black communities faced (Beretta, 2012; Ryder, 2017). While it was not officially termed as such, activism for environmental justice has served as a foundational perspective in the political landscape of communities of color for over a century (Beretta, 2012). The often cited example of environmental racism that sparked this movement was North Carolina's decision to dispose of soil contaminated with polychlorinated biphenyl in Warren County, a residential area believed to be home to the state's highest percentage of African Americans (Mohai et al., 2009). This activism and discourse have centered around issues of social justice and equity.

Social justice stands as a critical theme in this book, asserting its strong connection to STEAM education and environmental justice. Many public programs across various countries boast of their commitment to social justice as a foundational principle guiding their initiatives. Despite this widespread endorsement, the term "social justice" is frequently misunderstood and lacks a singular, universally accepted definition. This ambiguity arises from unresolved questions surrounding its boundaries, the content that constitutes it, the philosophical underpinnings linking it to distinct disciplines, and the disciplinary and ideological roots from which it emerges (Levin, 2019). While there is some common ground in understanding the concept of social justice, Hytten and Bettez (2011) highlight the rich tapestry of interpretations put forth by philosophers, practitioners in the field (including educators and social workers), ethnographers, theorists, and liberal politicians. This diversity of thought underscores the need for a more precise and coherent understanding of social justice in these contexts.

The philosophical aspect of social justice largely depends on providing extensive criteria, principles, and frameworks for considering justice, connecting it to the fair distribution of resources and rewards, recognition of multiculturalism and diversity, equal opportunities for all groups, and how success outcomes are equitably shared within populations (Hytten & Bettez, 2011). In earlier research, Bettez (2008) identifies practices, and attributes of activist social justice education, which include creating connections between the mind and body, promoting discussions immersed in critical thinking, confronting issues of power, privilege, and oppression directly, showing a care for both learners and the environment, maintaining hope for social justice progress, leaning towards a care-based pedagogy, and cultivating critical communities. Therefore, the varied interpretations and demands of the social justice concept necessitate a close examination of its objectives regarding both STEAM education and Environmental justice.

Environmental justice is fundamentally a matter of social justice. Beltran et al. (2016) argue that research and academic study concerning environmental justice primarily concentrate on its roots as a social movement that emerged from the struggles within the civil rights and environmental movements. Using the U.S. as an illustration, the authors aver that routine environmental threats weigh down on the health and well-being of groups with common traits, especially marginalized groups and those living in poverty. In a similar case, the Juruna, Kayapo, and Arana tribes in Brazil are resisting the destruction of their ancestral land caused by the building of the Belo Monte Dam, along the Xingu River in the Amazon (Bennert, 2014).

In recent decades, scholars (e.g., Alali et al., 2023; Kyle & Belciak, 2024; Ibrahim et al., 2022) have observed that the discourse of teaching and learning in STEM fields has evolved due to various contemporary trends such as climate change, global sustainability goals, and the demand for social justice. Science education, serving as a platform for cultivating scientific literacy, has undergone significant changes to incorporate technology-enhanced multi-modal teaching methods and transformative shifts rooted in historical social justice concerns (Ibrahim et al., 2022). For example, Ibrahim et al. (2022) highlight that global challenges like adverse health effects and environmental destruction from artisanal mining of Coltan in the Congo, the Black Lives Matter movement, which exposed racial disparities, and the Fridays for Future campaign, which raised awareness about climate issues may be interconnected with science and technology. The urgent matters requiring attention encompass environmental challenges, climate change, biodiversity, healthcare, nutrition, poverty eradication, empowerment, gender identities, and racial discrimination (Kyle &

Belciak, 2024; Upadhyay et al., 2021). To ensure that ongoing discussions about social transformation, immigration, human migration, politics, communication, power, and equity enhance the learning experiences of students, many educational institutions have incorporated arts or language arts into STEM, thereby creating STEAM (Upadhyay et al., 2021).

Using this framing, schools and higher education institutions aiming to design curricular framed in the goals of social justice have heightened awareness of the global challenges humanity faces among their student populace by finding creative ways to connect the school with the outside world. However, research in the two fields of STEAM education and Environmental justice has run on parallel and rarely overlapping paths, growing in knowledge stature separately. There exists a thin body of literature that attempts to integrate and establish interconnections between the two disciplines. This chapter advocates for STEAM education approaches that incorporate Environmental justice issues. It provides guidelines on the most effective ways for integrating environmental justice into recent modifications of STEAM education. The following sections of the chapter are organized to guide the reader through a synthesis of literature on (i) Critical pedagogy and Place-based education, (ii) Intersecting STEAM education and Environmental justice (EJ) through the lens of Critical pedagogies of place, and (iii) Navigating EJ through STEAM education.

2. Critical pedagogy and Place-based education

Critical pedagogy and place-based education are profound theoretical frameworks deeply embedded in the quest for social justice. Critical pedagogy is widely acknowledged as an indispensable tool for examining and understanding the intricate dynamics of power, diversity, inclusion, privilege, oppression, and empowerment in the field of social justice education (Loutzenheiser, 2010; Mason et al., 2019). In addition, this pedagogy is inherently linked to the pursuit of social justice, operating as an emancipatory instrument committed to challenging and dismantling entrenched social and economic inequalities (Gist, 2014). By fostering critical awareness and encouraging active participation, these frameworks cultivate environments where learners can confront injustices and advocate for equitable change.

2.1 Critical pedagogy

Critical pedagogy has its roots in the work of critical-oriented philosophers like Antonio Gramsci, Henri Giroux, Ivan Illich, and Paulo Freire, who drew influence from Marxism and the critical theory (Aybar & Bingol, 2023). The term critical theory was initially introduced in 1937 by the Frankfurt Institute of Social Research (Roach & Patrick, 2009). Although the critical theory of the Frankfurt School has faced criticism for its lack of coherence and structure, it argues that modern economic and social systems reinforce inequality and oppression (Giroux, 2003). These philosophers aimed to create a new understanding of education that moves away from traditional views, particularly the dominance of whites over blacks and the structured class hierarchies of the nation-state (Aybar & Bingol, 2023). This interpretation aimed to challenge prevailing common beliefs, questioning the hegemonic nature of knowledge and societal structures. As a result, critical pedagogy developed from this ideology, seeking to change the oppressive power dynamics that contribute to the oppression of individuals (Aliakibari & Faraji, 2011).

As a pedagogical approach, it seeks transformative paths to education that contrast transactional and traditional methods (Mason et al., 2019). According to Kahn (2021, p. 7);

> Critical pedagogy is first and foremost an ongoing political project that axiomatically believes human history advances through contesting and emancipating sets of asymmetrical and inequitable power relations. For this reason, critical pedagogy serves to champion (especially for those most objectified or denigrated through these relations of power) the need to learn how to better reflect upon and understand the nature of the social system, which includes not only considerations of its structures and designs, but also its ideological underpinnings and the everyday behaviors that can serve uncritically to reproduce the same.

In STEAM classrooms, critique and radical utopianism are essential virtues that play a significant role in pedagogical processes. Knowledge is constructed and deconstructed, educational discourse is framed around the interests of emancipation, and learning is extensively done through revisionist practices focused on value ethics and the politic body (Sarroub & Quadros, 2015). According to Carr (2011), critical pedagogy challenges the relationships between education and politics, as well as the sociopolitical dynamics and educational practices that contribute to the ongoing reproduction of power hierarchies and privilege in everyday life. This approach aims to ensure a dignified future for historically marginalized, exploited, or otherwise subjugated groups of people and beings (Carr, 2011).

2.2 Place-based education

Science education frequently adheres to Western-centric frameworks that seldom acknowledge the variety of cultures and geographical differences. For example, in many African high school Chemistry classes, metal elements such as mercury, gold, copper, niobium, and tantalum are identified using the periodic table without considering their local presence (Ajaps & Mbah, 2022; Demssie et al., 2020). Topics like gold panning and artisanal mining, which lead to environmental harm and are common in these regions, are often overlooked in these lessons. With the influence of theophysics intersecting religious and physical cosmology, Western philosophy has established space as universal, absolute, and limitless, while relegating place to being particular, confined, local, and bounded (Escobar, 2001). Additionally, Johnson (2012) points out that by disconnecting our histories, narratives, and sciences from specific locations, Western science has cultivated a sense of superiority that seeks to rise above other knowledge systems, especially those that remain closely tied to their contexts. Place-based education emerged in response to this critique of Western science.

The place-based education movement has recently gained traction, aiming to link school learning with specific local environments. According to Puad et al. (2024), place-based education has grown into a dynamic pedagogy for both Environmental Education (EE) and Education for Sustainable Development (ESD), fostering meaningful connections between humans and places. This approach is characterized as a context-rich, transdisciplinary teaching and learning method that emphasizes the intrinsic relationship to place—defined as any locality imbued with personal significance and attachments through direct or vicarious experiences (Semken, 2017).

By leveraging the local community and environment, educators can introduce concepts within a transdisciplinary STEAM framework, prioritizing real-world, hands-on experiential learning (Semken, 2017). The importance of this methodology lies in its capacity to connect knowledge gained and epiphany to the unique ecological, and socio-cultural contexts of a specific location, thereby helping students forge stronger ties to their community and fostering an increased commitment to active civic engagement (Semken, 2017; Üztemur & Dere, 2023). Consequently, local Indigenous practices and cultural elements are recognized as essential components of STEAM education programs. Our cultural experiences, together with our ecological relationships within and between places, are rooted in the ‘place’ and the ‘geography’ of our daily lives (Gruenewald, 2003a; Johnson, 2012). The emphasis on communities linked by geography and their environments (places), rather than on abstract textbook concepts removed from their contexts, is particularly effective when a learning program tackles a spatially concentrated issue; when the place serves as a high-performance platform for delivery of service; and when the outcomes of such a program can benefit other communities (Jacobson, 2016).

2.3 Critical pedagogies of place

Critical pedagogies of place exist at the crossroads of critical pedagogy theory and place-based education. The philosophers of critical pedagogy focus on issues of social justice, whereas scholars in ecological place-based education advocate for recognizing “places/ecology” as an essential aspect of teaching. The blending of the principles from both pedagogies has resulted in the emergence of critical pedagogies of place. Gruenewald (2003b, p. 8) advocates for this blending by stating:

> Critical approaches to educational research, such as critical ethnography, discourse analysis, and other deconstructive approaches, are needed, yet these methodologies must provide a theoretical rationale to connect schools with the social and ecological dimensions of places.

In other words, the fact that places are defined through a collective rootedness that shapes a people's ideology, existing social hierarchies, and experiences means interrogation of social justice issues cannot be carried out in isolation (Perumal, 2015). Perumal (2015) argues that critical pedagogies focused on place highlight how societal power imbalances influence the definition and construction of place, as well as how they shape individuals' positions within spatial contexts due to the presence of power and domination being embedded in physical spaces. Consequently, while examining societal power dynamics, critical pedagogy should take advantage of the opportunities to investigate ecological connections within and among places that place-based pedagogy presents.

Re-inhabiting and decolonization represent two key dimensions of critical pedagogies of place. The first concept emphasizes the use of education as a means to cultivate cultural knowledge that safeguards both communities and ecological systems (Gruenewald, 2003b). Gruenewald (2003b) contends that this approach involves perspectives and social actions aimed at fostering productive community relationships and supporting the ecological health of specific locations. In the context of STEAM education, the environment serves not only as a resource but also as a laboratory that shapes learners' understanding and guides their actions. By engaging with place-based resources, students can actively work towards establishing sustainable practices and conditions that promote fulfilling lives and relationships (Dimick, 2016).

The second concept combines critical consciousness with the disruption of settler colonial structures and mindsets. Critical consciousness empowers the oppressed and marginalized to engage in transformative action, altering their realities through the examination and critical reflection of societal structures and power dynamics (Dimick, 2016). Therefore, a critical pedagogy of place, as outlined by these two concepts, can support Indigenous and marginalized individuals in understanding their environment, thus equipping them with the tools to foster the social change necessary for sustainability (Ajaps & Mbah, 2022).

3. Intersecting STEAM education and EJ using the lens of Critical Pedagogies of place (CPP)

Before the advent of STEAM education, societal structures for interactions in science domains have been facilitated by frameworks like Socio Scientific Issues (SSI), Science, Technology, and Society (STS), and Science, Technology, Society and Environment (STSE). For example, STSE aims to illuminate how the STEM disciplines have both contributed to and highlighted the challenges in society, such as greenhouse gas emissions from vehicles and industrial activities. These integrated approaches that simulate STEAM education have underscored the significance of the humanistic aspects of learning and encouraged comprehensive scientific practices that are socially aware and environmentally situated (Elden et al., 2023). This is the STEAM education focus. The rationale for this focus is that STEAM education can unite diverse groups towards a shared understanding and empower individuals to confidently advocate for behavioral change through peer-led initiatives instead of relying on top-down governmental strategies (McDonald et al., 2022). Although science and technology are frequently perceived as solutions to global environmental issues, transforming human behavior from a user-centered perspective necessitates holistic, humanistic, and democratic design approaches incorporated into STEAM education (McDonald et al., 2022). This section makes a case for integrating Environmental Justice (EJ) principles into STEAM education and illustrates how critical pedagogies of place can be employed to create synergies between STEAM education and EJ.

Research on environmental justice has significantly expanded to encompass both critical and spatial dimensions, including analyses of rural and social factors, ecological aspects, and prevailing systemic inequities. The social dimension of this research has concentrated on justice issues faced by Indigenous communities, the elderly, ethnic minorities, marginalized groups, individuals with disabilities, and those affected by income disparities. In contrast, the environmental dimension addresses a range of issues, including types of pollution, transportation, drinking water quality, urban decay, wildlife reserves, green spaces, climate change, land reform, oil extraction, genomics, and biodiversity, among others (Walker, 2012). These dimensions are incorporated into school curricula across various subjects, either under the humanities, arts, or sciences, including Music, Art, Human and Social Biology, Geography, Ocean Sciences, Physics, Chemistry, Mathematics, and more. Thus, the advancement of environmental justice across these spatial dimensions presents a unique opportunity within STEAM education to foster a more nuanced and interconnected understanding of environmental commodities, such as natural resources extraction, climate change, sustainability, health and well-being, electronic and material waste disposal, and the distribution infrastructure for such commodities (Ryder, 2017).

Table 1 below illustrates the conjunctive goals of STEAM education, environmental justice, and critical pedagogies of place that collectively form the foundation for convergence. In this chapter, the term "conjunctive goal" is employed to define the interconnected relationship among the objectives pursued by STEAM education, environmental justice, and critical pedagogies of place.

Table 1.

The conjunctive goals of STEAM education, EJ, and Critical pedagogies of place (Source: Authors' own elaboration)

Study area	*"Conjunctive" goals of each study area*	*Supporting (sample) literature*
STEAM education	-interdisciplinary education -creativity (creative design & innovation) -demystify the study of STEM subjects and increase access (social justice) -social and economic development -sustainability -transformative -integrative -community-based action -active learning -emotional and cultural learning	Belbase et al., 2022; Elden et al., 2023; Upadhyay et al., 2021
Environmental Justice	-illuminating environmental inequities -community-based action -cultural learning -environmental action - global sustainable development - social justice and equity -transformative (change advocacy) -productive community relations	Cisneros et al., 2022; Rodriguez-Silver & Alsina, 2023; Ryder, 2017
Critical pedagogies of place	-critical reflection on inequities - The role of power politics in defining and establishing places -Reform in the policies and practices of education -multidsciplinary connotations of place - environmental materiality - creating cultural knowledge that protects people and place - transformative action that changes the realities of the marginalized	Ajaps & Mbah, 2022; Dimick, 2016; Perumal, 2014

Based on the goals of each study area, Table 1 shows the mutual inclusiveness of the three areas. Goals such as social justice, sustainable development, transformative action, interdisciplinary and multidisciplinarity, and multiculturalism intersect the three study areas. Implying that there is more that binds these areas into synergistic relationships than separates them. For instance, creating cultural knowledge that protects people and places is a goal for both EJ and critical pedagogies of place. In STEAM education provision of similar goals is equally critical. Bang and Medin (2010) posit that the "places" of students and science teacher educators from non-dominant groups are increasingly the target of analyses of STEAM education in the United States. Bang and Medin (2010) further note that these places are defined through the discourse of equity that focuses on (under)representation and the aim of establishing curricular environments that will permit learners from minority groups to perform as well as their peers from privileged classes.

Efforts to integrate Environmental Justice (EJ) with other areas of study have been documented in recent literature. Plank (2024) highlights the shifting landscape of global environmental crises alongside the ongoing disparities related to gender and race in STEM fields, underscoring the need for a critical, intersectional environmentalism that emphasise the interconnectedness of environmental and social justice. The agenda premised in this framework aims to equip youth with essential computational thinking skills and social justice perspectives required to tackle the world's pressing challenges. Ryder (2017) has employed an intersectional framework to connect EJ with disaster vulnerability, ultimately fostering a more comprehensive understanding of environmental harms and disaster risks while promoting just and equitable planning, preparedness, response, and recovery efforts. Ryder argues that this intersection opens up opportunities for discussions about power dynamics and the impacts of historical and spatial contexts. Likewise, Table 1 (above) highlights the overlapping elements of STEAM and EJ that can be leveraged to deepen learners' understanding of their relationship to various places.

A few notable instances were identified in the literature that highlight the connectedness of STEAM education and EJ. For example, while interdisciplinarity is seen as an outcome of STEAM education in Table 1, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) perceives it as a teaching approach aimed at enhancing quality education and achieving sustainable development (Rodriguez-Silver & Alsina, 2023). In 2018, UNESCO referenced the interdisciplinary nature of STEAM education as a means to fulfill Sustainable Development Goals (Rodriguez-Silver & Alsina, 2023). This perspective posits that realizing sustainable development requires specific mindsets and the synthesis of multiple disciplines (STEAM), along with community-focused actions (EJ) to highlight environmental injustices (Critical pedagogies of place) and seek solutions grounded in social justice. In support of this integration, Ballard et al. (2023) argue that crowd-sourced science represents a hypothetical practice of shaping the world that emphasizes dialogic understanding, agency, and liberative action aimed at the welfare of individuals, communities, lands, and ecosystems.

Cisneros et al. (2022) adopt a social justice perspective, specifically through the lens of critical pedagogies of place, to advocate for the generation of pathways for learners from previously disadvantaged groups. They emphasize the importance of these pathways within an ethical framework that values plurality, to challenge the dominant push toward a homogenous global culture. The authors argue that it is not only ethically vital but also essential for fostering innovation within economically viable E-STEAM professions to ensure that students from groups such as girls and others are adequately prepared and qualified. This approach is crucial for promoting diverse representation within these fields. The authors insist on E-STEAM, which they define as the amalgam of environment, science, technology, engineering, arts, and mathematics fields to "…emphasize a "practice turn" that positions learners to engage in the epistemic practices of these disciplines to achieve specific, community-focused, transdisciplinary goals such as engaging in investigations to better understand environmental injustices not as a matter of science alone but also as a sociopolitical matter requiring action" (Cisneros et al., 2022 p. 2).

4. Navigating STEAM education and EJ through CPP

STEAM education is recognized for fostering innovation, creativity, and interdisciplinary teaching; however, existing research indicates that integration approaches vary based on fundamental logical elements that guide their focus. Various frameworks emphasize key aspects such as affirming cultural identity, implementing inclusive pedagogy, enhancing digital literacy and skills, promoting sustainable innovation, and encouraging ongoing reflection and adaptation (Deák & Kumar, 2024). Emphasizing cultural identity affirmation involves acknowledging and valuing the learners' cultural backgrounds, histories, values, and practices, while the sustainable innovation aspect aims to create solutions that are both culturally sensitive and environmentally friendly (Deák & Kumar, 2024).

Following their Continuous Reflection and Adaptation of key logical components, Deak and Kumar (2024) introduce the NOISE analysis. This component of continuous reflection and adaptation ensures that frameworks remain relevant and effective in the face of evolving cultural and technological landscapes. The NOISE model illustrates the transformative potential of STEAM by examining five key aspects, focusing on the Needs, Opportunities, Improvements, and Strengths required to upskill educators for the digital age (Deak & Kumar, 2024). The acronym N-O-I-S-E stands for frameworks that: (i) develop a comprehensive range of digital competences relevant for professional activities, e-learning resources, ssessment, and empowering learners, thereby enhancing learners' digital competencies; (ii) offer ongoing opportunities for the upskilling of educators in ICT training, infrastructure provision, pedagogical adaptations, and the promotion of sustainable innovations; (iii) strive for improvements by recruiting Tech Experts to equip faculty with requisite skills, implementing tech-infused courses, and adopting STEAM-based curricula; (iv) foster a desire for innovative pedagogy in developing digital competencies; and (v) represent robust STEAM pedagogy tailored to specific contexts. Although Deak and Kumar's (2024) model is specifically designed for STEAM initiatives in higher education, other frameworks exist to facilitate integration at lower levels of education. Notably, the seminal works of Andrea Ng, an Early Childhood Education practitioner at Monash University in Australia, provide valuable examples of STEAM education frameworks (see Ng et al., 2022; Ng, 2024).

The Concentric Model for STEAM and Environmental Justice Integration proposed in this chapter bears resemblance to Mpofu and Mutseekwa's (2023) contextualized STEAM education model. The contextualised STEAM education model proposed by Mpofu and Mutseekwa (2023) derived inspiration from Zimbabwe's (a country in Southern Africa) Heritage-based Education 5.0 (HBE 5.0). The guiding philosophy underpinning the HBE 5.0 is heritage-based development, which emphasizes an education system rooted in the country's natural environment endowment and that imparts knowledge suitable for the exploitation of such locally available resources (Ministry of Higher and Tertiary Education, Science and Technology Development [MHTESTD], 2018). Cognisant of the contextualized STEAM education model's link to place-based education, the authors suggest the Concentric Model for STEAM and Environmental Justice Integration, shown in Figure 1 below, to argue for an integration model that builds synergic relationships between STEAM education, Environmental Justice, and CPP.

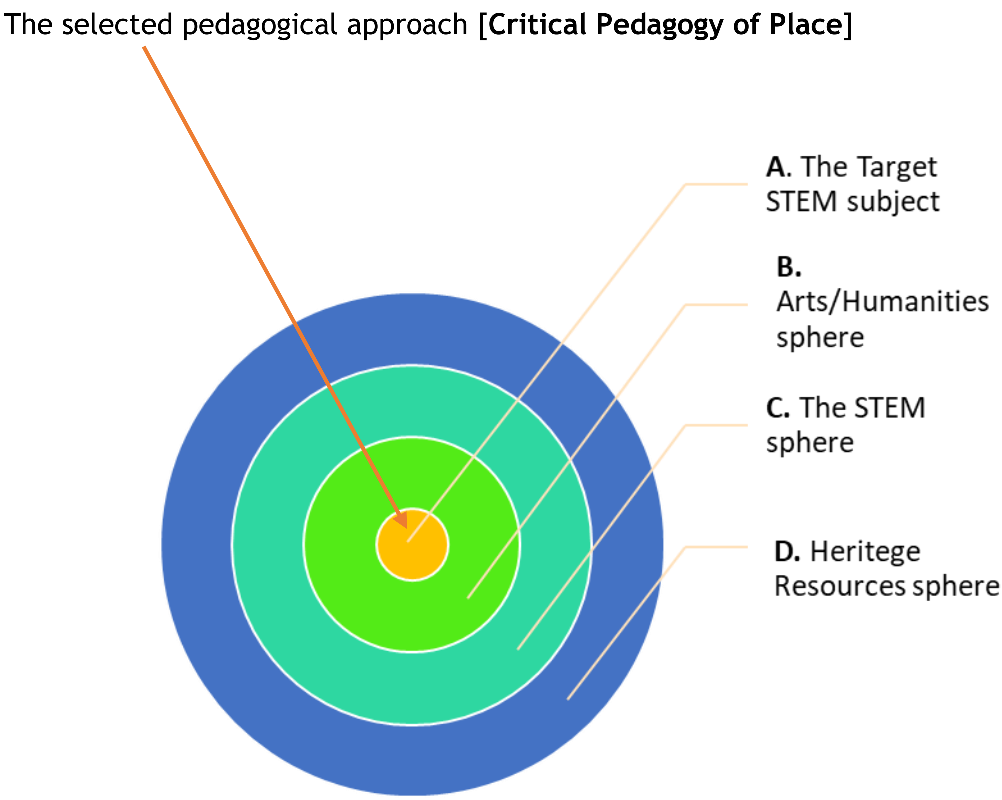

Figure 1. The Concentric Model for STEAM and Environmental Justice Integration (Adapted from Mpofu & Mutseekwa, 2023).

The concentric model for STEAM and Environmental Justice integration shows concentric circles representing spheres influencing each other in diverse STEAM integration possibilities navigated through CPP. Environmental Justice, which does not seem to appear anywhere in the model, manifests as cross-cutting themes that can be integrated in several ways at every sphere. Environmental Justice offers opportunities for critical perspectives to be considered in a wide range of subjects in the school due to its multidisciplinary, intersectional, and cross-cutting nature (Atapattu et al., 2021). Themes integrating the curriculum subjects include gender, race, poverty, cultural learning, sustainability, climate change, transformative learning, and indigeneity (Atapattu et al., 2021; Rodriguez-Silver & Alsina, 2023). Furthermore, some attention to Environmental Justice Education is found in other fields of education such as Social Studies, Religious Education, Art Education, Language Arts, and Environmental Education, which in the current model are mostly represented by the Arts/Humanities sphere (Haliza-DeLay, 2013). The realm of democratic practice, dance, and community theatre practices, the moral discourse on justice, and environmental justice advocacy are aspects embedded in these subjects that present Opportunities for integration (Haliza-DeLay, 2013; Lasker et al., 2017) are highlighted in the context of STEM education. The target STEM subject in the first circle (A) signifies the scheduled topic taught on a specific day, drawn from a range of STEM disciplines such as Environmental Science, Food Sciences, Biology, Geography, Ocean Sciences, Physics, Chemistry, Mathematics, Computer Sciences, and Engineering. This target subject is the focal point for integration with elements from the second and third spheres of influence. Notably, integration with the first sphere of influence—The Arts and Humanities—is essential, as this area defines and operationalizes STEAM education.

There are various avenues for achieving this integration. Citing additional research, Ibrahim et al. (2022) suggest several potential methods to incorporate the "A" in STEAM, including: i) creating diagrams and visuals; ii) illustrating the beauty and aesthetics of science; iii) integrating dance and music into technology and design; and iv) addressing progressive neoliberalism while promoting equity and diversity goals. Thus, The Arts play a crucial role in enhancing STEAM practices by fostering student engagement and the presentation of ideas through music and visual representations (Ng et al., 2022). Moreover, a noteworthy approach at this level is the cross-curricular collaboration between experts in the Arts and STEM subjects. By leveraging their respective backgrounds, these experts can combine both fields through collaborative artistic endeavors. Their classes can engage in discussions about scientific processes, concepts, and research, emphasizing creativity and the application of scientific principles in the resulting artifacts or products of their collaboration (Belardo, 2015; Erduran et al., 2024).

The next integration level extends to the STEM sphere. At this level, the Sciences, Technology, Engineering, and/or Mathematics can be integrated with the Arts + the Target STEM subject. On one hand, EJ can be integrated at this level through cross-cutting themes such as sustainability, health and wellbeing, citizenship education, peace education, vulnerability, argumentation, and design thinking. On the other hand, broad topics associated with STEM subjects such as population education, metallurgy, hydrocarbons, renewable energy, urban settlement, climate change, and pollution become hotbeds for initiating critical discourse on EJ. The Next Generation Science Standards (NGSS) in the United States highlight several cross-cutting concepts suitable for STEAM education, including patterns, cause and effect, scale, proportion, and quantity; system and system models; energy and matter; structure and function; as well as stability and change (Besser et al., 2019). By integrating these cross-cutting concepts with foundational ideas and essential practices, educators can create connections across the disciplines of science, technology, engineering, and mathematics (Besser et al., 2019).

Other integration possibilities in the STEM sphere are highlighted elsewhere in the literature. Yakman & Lee (2012) propose an integrative framework that anchors Mathematics as intersecting the other STEAM subjects. The integration approach thus posits that Science and Technology are interpreted through Engineering and the Arts, all based on Mathematical elements. The approach utilizes design thinking, creativity, and the Engineering design process as tools that can unlock the Science and Technology concepts. Following Kim's (2016) principle of the Wheel model, themes are designed into a topic that is developed and used to study eight subjects-Science, Technology, Engineering, Mathematics, Art, and any other three subjects from the Humanities, and converge them through the process of thesis presentation and discussions, to advance it as a multidisciplinary study. The topic represents the axle, the eight subjects are the spokes of the wheel, and the thesis presentations and critical discussions (based on the CPP approach) on the topic represent the rim (framework) that binds the eight subjects in the multidisciplinary study. Kim's (2016) approach is contrasted with Ng et al.'s (2022) integration approaches that position either Technology, Art, or Engineering as the anchor subject. For instance, in technology-focused STEAM integration, technological tools such as ICT applications, iPads, and even robots are leveraged to navigate (through Project-based learning (PbL), and other inquiry approaches) intersecting concepts in Art, Mathematics, Engineering, and Science (Ng et al., 2022).

The heritage resources sphere (see Figure 1) encompasses elements that influence integration possibilities at every stage. Heritage resources include the natural endowments, culture, language, Indigenous Knowledge systems (IKs), traditions, and artifacts of specific groups. Ndoro (2008) classifies heritage resources into two categories: movable and immovable. Movable heritage encompasses items such as masks, statuettes, textiles, oral traditions, and myths, while immovable heritage refers to structures like monuments, ensembles, sites, cultural landscapes, and various sacred locations, including rivers, mountains, and forests (Ndoro, 2008). Within the context of STEAM education, the heritage sphere underscores the significance of contextualized teaching and learning in the STEAM fields.

Methodologies designed for navigating STEAM integration approaches must acknowledge the value of material heritage sites and their preservation, historical landmarks, cultural artifacts, and the intangible memories embodied in community stories and narratives (Videla et al., 2024). This is essential because the brain, body, and environment collectively function as a complex system of multiscale interactions, which are manifested through the 4Es of cognition—embodied, enacted, embedded, and extended (Aguayo, 2023). In a study focused on preserving cultural traditions, customs, and knowledge and fostering belonging within communities through both digital and non-digital technologies in generative STEAM education, Videla et al. (2024) apply place-based education pedagogy to promote participatory co-design processes with the community. They found that the 4Es cognition framework supports a conceptual understanding of cultural heritage through experiential learning, framed within culturally situated design tools that assume STEAM education is already intertwined with knowledge systems and cultural, vernacular designs (Videla et al., 2024).

4.1 Implications of the Concentric Model for STEAM and Environmental Justice Integration for research and practice

The Concentric Model for STEAM and Environmental Justice Integration was developed based on earlier frameworks cited in the literature and the need to integrate EJ in STEAM education. These are frameworks that are equally in their initial development phases (Deak & Kumar, 2024; Mpofu & Mutseekwa, 2023; Ng et al., 2022). Currently, there are very few frameworks on STEAM education that have achieved the "tried and tested" status. Globally, STEAM practitioners, school leaders, curriculum planners, and researchers are therefore grappling with the available frameworks, experimenting through the trial and error approach to find out which ones work best in their context.

The practical application of the Concentric Model for STEAM and Environmental Justice Integration requires educators to be conscious about reforming science education. This is because the Concentric Model for STEAM and Environmental Justice Integration combines complex integration strategies from diverse frameworks to demonstrate how commonalities between STEAM education and EJ can be explored for learners' richer and deeper engagement. For instance, practitioners using the current model need critical consciousness about the possible integration approaches, Environmental Justice education, and CPP.

The work of a STEAM teacher educator is challenging given the multiple demands at different levels, such as delineating the demands of a STEAM education curriculum, knowledge of best STEM teaching and STEAM integration practices, and addressing requisite social justice issues embedded in disciplines (Slavit et al., 2016). Understanding these unique STEAM teaching approaches will depend much on the educators' competences and beliefs. Empirical evidence has shown that teacher's beliefs are critical to the conceptualization and reformation of science education because teachers' beliefs about the nature of science and science teaching influence the enactment approaches they employ in their practice since beliefs serve as filters through which actions are viewed and decisions are made (Sampson et al., 2013).

Ideal teacher competences consist of possession of good subject matter knowledge (SMK), and pedagogical reasoning, an understanding of the learners' preferred ways of learning, ability to select/design and deploy learning media accordingly, performing effective communication skills, an appreciation of effective classroom interactive dynamics, having the correct attitude and characteristics, and holding the positive assumptions about STEAM teaching (Beskese, 2019). Furthermore, Beskese (2019) identified collaborating with colleagues, collaborating with experts and other professionals, possession of adaptive life-long learning skills, creativity, and innovation, ability to integrate concepts and flexibility with teaching approaches, appreciation of the Arts, and having various hobbies as some of the most important STEAM teacher competences. Carter et al. (2021 p. 8) say:

> … the integration of STEAM qualities, capacities, and mindset is not only relevant between different people but also for each participant; i.e. being radically open to and actively engaged in learning and changing as part of STEAM ventures. Thus, STEAM 'connecting' and connectedness is more than forming relationships between disciplines, extending to all kinds of linkages between people/learners, environment(s), and philosophies to generate exciting new perspectives, methods, and approaches to thinking and working.

In support, Vosnjak et al. (2023) posit that STEAM teachers need to possess certain characteristics, such as engaging in continuous professional development, a transformative mindset, being open to change, seeing failure as an opportunity to learn, and believing in the need to provide equitable and inclusive place-based learning opportunities for all students.

The integration of multiple frameworks and teaching approaches can significantly hinder the efficacy of the Concentric Model for STEAM and Environmental Justice. Belbase et al. (2017) highlight that many STEAM initiatives face critical implementation challenges. Firstly, without a profound understanding of the intricacies and objectives of these initiatives, teachers pose substantial risks to effective implementation. Secondly, many educators are inadequately prepared to teach, plan, create materials, and collaborate within an interdisciplinary STEAM curriculum. To address these issues, institutions must transform into learning organizations.

A learning organisation aims to empower its members by constantly opening opportunities for professional advancement, creating a positive and risk-taking climate for its staff, establish a culture and structures that encapsulate all of the personal, interpersonal, and non-personal behaviors of an organization (Fischer & Roben, 2001). Carter et al. (2021, p. 11) posit that a Higher Education approach to STEAM (potentially) involves:

• a culture (or cultures) that values the Arts and Sciences equally
• functioning within a framework that is driven by processes, centered around learners, comprehensive, and allows for risk-taking while embracing uncertain outcomes
• being inclusive, diverse, and conducted in safe environments
• cultivating a mindset of radical openness, adaptability, reflection, experimentation, and curiosity
• fostering qualities that enhance learning, collaboration, and multimodal approaches
• encouraging transdisciplinary practices, focusing on prototyping and making, while taking assessment methods into account
• building competencies in design thinking, innovation, communication, and creativity while exploring how these can be utilized to devise solutions.

Learning organizations should be able to create conducive environments fostering life-long learning, inclusive of aspects highlighted by Carter et al. (2021).

Future research endeavors can focus on field application of the Concentric Model for STEAM and Environmental Justice Integration, investigating integration feasibility and assessing the possibility of co-opting Environmental Education as a core subject of the school curriculum.

5. Conclusion

As we consider the integration of Environmental Justice (EJ) with STEAM education, the Concentric Model of Pedagogy (CPP) emerges as a powerful tool to facilitate this process. Critical pedagogies of place emphasize how societal power imbalances shape and define environments, influencing individuals' positions within various spatial contexts, as these relationships of power and domination are embedded within material spaces. This chapter underscores the interconnected aspects of EJ, STEAM education, and CPP. UNESCO highlights the necessity of an interdisciplinary approach in STEAM education to achieve Sustainable Development Goals (Rodriguez-Silver & Alsina, 2023). Consequently, pursuing sustainable development requires specific mindsets and the collaboration of multiple disciplines (STEAM), alongside community-based action (EJ) to address environmental inequities, informed by Critical Pedagogies of Place, and to seek solutions grounded in social justice.

The chapter proposes the Concentric Model for integrating STEAM and Environmental Justice, arguing for (i) a connection that fosters synergistic relationships between STEAM education, Environmental Justice, and CPP, and (ii) a recognition that methodologies for navigating STEAM integration must value the preservation of material heritage sites, historical venues, cultural artifacts, and the intangible narratives and memories of communities (Videla et al., 2024). While the practical application of the model may prove challenging, the chapter recommends that STEAM educators cultivate certain characteristics: commitment to continuous professional development, a transformative mindset, openness to change, viewing failure as a learning opportunity, and a belief in the necessity of providing equitable and inclusive place-based learning experiences for all students.

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Chapter 5: STEAM Participatory Models for Change: Community-Driven Initiatives

1 Introduction

Through participatory STEAM models, educators can transform their classrooms by utilizing local perspectives and collaborative problem-solving to connect with community voices. By utilizing co-design, transdisciplinary integration, and critical pedagogy principles, these models challenge traditional, standardized systems by providing opportunities for marginalized and indigenous groups to shape their learning experiences. Learning is a dynamic, iterative process that is grounded in practical challenges and cultural contexts, taking place in adaptable, decentralized environments with guidance from local professionals. Through the integration of Indigenous Knowledge Systems, lived experience, and models that incorporate science, technology, engineering, arts, or mathematics, education is positioned as a vehicle for collective empowerment and systemic change, emphasizing equity, resilience, etc.

1.1. Participatory Action Research and Co-Creation.

Participatory Action Research (PAR) offers a novel approach to rethinking the creation, dissemination and utilization of knowledge, particularly in areas where school systems have historically excluded local perspectives. In a democratic and collaborative approach, PAR challenges the traditional separation between researchers and participants by considering community members as co-researchers and equal partners in the knowledge-production process (Kemmis & McTaggart 2005; Pant et al, 2023). Additionally: Community expertise, cultural norms, and local priorities are key factors that contribute to the effectiveness of this approach in STEAM education (Pant et al, 2023).

PAR has been instrumental in promoting Indigenous Knowledge Systems (IKS) in various communities across Southern Africa, shifting the epistemic focus from Eurocentric models of science and education. By assisting communities in identifying issues such as environmental sustainability, food security, and technological empowerment through PAR, participants can become more involved by engaging with the issue and develop their own agency. The principles of dialogic education that adhere to the Freirean philosophy of dialogue and reflection are closely tied to practice in liberatory learning (Freire, 1976). Both a methodological and political position, PAR opposes top-down education and promotes communal learning through respect for others (Belgrave et al, 2022; Pant et al., 2023).

As a complementary framework, co-creation involves the collaborative design of educational content and tools by educators (Bhatta et al., 2025), learners, and community stakeholders. The principle of mutual respect and reciprocity is the foundation of STEAM co-creation, which recognizes that all participants bring valuable knowledge and lived experiences to the process. The need for inclusivity is particularly significant in underprivileged communities, where dominant educational models tend to ignore socio-cultural factors.

Co-creation processes in practice involve iterative cycles of dialogue, prototyping, testing, and refinement (Durall et al, 2019; Zorenböhmer, & 2022). A STEAM module focused on agriculture could be co-developed by scientists and farmers, with local artisans providing knowledge of traditional irrigation techniques, soil management practices, and climate adaptation strategies. The approach ensures that learning is not abstract and absent from learners' lives, but rather embedded in their socio-cultural and environmental surroundings.

Models of co-creation have been successful in different domains within the Southern African context. In Zimbabwe, agroecology programs have integrated traditional ecological knowledge with modern scientific approaches to enhance food sovereignty. Also co-creation promotes sustainability and scalability. The presence of local ownership in co-designed programs is particularly notable, as it helps them to be more resilient and adaptable to changes in funding or policy (Zorenböhmer et al, 2022). By involving local mentors, elders and youth leaders in implementation and evaluation processes, these models also promote long-term capacity building.

The foundational pillars of community-driven STEAM education include Participatory Action Research and co-creation. The relationship between education and community is redefined as a dynamic process of mutual learning and empowerment, rather than limiting it to rote transmission. When paired with decolonial approaches to education and personal beliefs, these frameworks provide robust means for developing educational systems that are both relevant and transformative.

1.2. Community Participation in STEAM

The core of community-driven STEAM initiatives lies in the idea that education and innovation are most transformative when they are deeply rooted in local, regional, national, and global contexts (Aguayo et al, 2023). Instead of relying on top-down knowledge, these participatory models encourage mutual education and shared agency, as well as respect for diverse worldviews. Identifying local knowledge systems as legitimate and advantageous is one of the key principles of these approaches (Mutsvangwa, 2023). Despite their informal or informal nature, traditional ecological knowledge, Indigenous science, and everyday practices are considered rigorous, tested, contextually grounded bodies of knowledge (Mutsvangwa, 2023). Advanced comprehensions of natural processes, sustainability, and resource management are frequently present in these systems, which can greatly enhance and guide modern scientific inquiry.

The models acknowledge the role of both young and old in generating knowledge.' The elderly offer guidance, recollection, and historical viewpoints, while the younger generation offers creativity, digital skills, or knowledge. A dynamic learning environment is created by collaboration between generations, allowing knowledge to flow in various directions. Instead of assuming the teacher as the supreme authority, this perspective promotes learning in a communal manner.

It is not viewed as an isolated or technical process, but rather as a collaborative and contextual approach to problem-solving. Communities are proactive in recognizing their own issues, such as climate stability, education, health, or sustainable livelihoods, and work together to create and implement solutions that address their specific needs. Community-based problem solving strengthens the ability to make choices, and ensures that interventions are both relevant and effective.

Effective education must prioritize cultural relevance (Mutsvangwa, 2023). Through the inclusion of cultural practices like storytelling, music and visual arts alongside international and indigenous cosmologies, STEAM education is not only more engaging but also more inclusive of students' identities and backgrounds (Chen, 2021). Confidence, belonging, and a greater interest in learning are enhanced by cultural grounding.

These models challenge the legacy of hierarchical and extractive practices in STEAM development by involving communities as equal partners in their design, implementation, and evaluation. They are both feminist and anti-IT movements. Rather, they allow for inclusive, radical paradigms grounded in equity, reciprocity, and respect. The involvement of the community ensures that STEAM is not solely focused on knowledge creation or technology advancement, but also on restoring relationships to shape identities and co-creating fair, sustainable, and value-based futures.

2. Features of Participatory STEAM Models.

Communities are empowered by inclusive principles in all stages of learning and innovation through participatory STEAM education models. Co-design and co-ownership are key features of these models, which ensure that the educational experience is shaped by collaboration between learners, teachers, and members of the community. The model emphasizes collaborative approaches to learning. Science, technology, engineering, arts, and mathematics are integrated through transdisciplinary integration of local knowledge systems and lived experiences. Their focus on decentralized infrastructure has enabled them to create accessible, context-sensitive learning environments. It is an iterative learning and feedback system that enables ongoing adaptation, reflection in adaptability (and consequently relevance)).. Together, these characteristics foster dynamic, fair and culturally grounded STEAM environments that balance education with local needs and aspirations.

2.1. Co-Design and Co-Ownership.

The principle of co-designing inclusive STEAM models is based on the idea that members of the community are not passive consumers of educational content or technological solutions, but rather active participants from the beginning. In this model, the direction and structure of STEAM initiatives are shaped by various local voices: students; parents; teachers; artisans; farmers; and elders. Rather than adopting a pre-established curriculum or project outline, facilitators inquire about the significance of various challenges and already existing resources and knowledge systems in their vicinity.

Communities priorities are reflected in their initiatives through collaborative design. The process is successful. As an illustration, a project focused on food insecurity could be developed by engaging with local farmers and involving young learners in the creation of environmentally friendly irrigation systems. Traditional knowledge of climate cycles or soil conservation techniques may be passed down from elders, while artisans use locally available materials to build prototypes. Through this process, the solutions are not only more effective but also more likely to be embraced and sustained by society (Durall et al., 2019).

Co-ownership is an extension of co-design. The involvement of community members in shaping the vision results in a sense of pride and responsibility. This leads to increased sustainability, as locally owned projects are less reliant on external funding and oversight. Rather than being beneficiaries, co-ownership can encourage skill development and innovation among community members who are leaders in their own right but also role models and creators of new ideas. The power to influence the issues at hand is shifted from external experts and institutions to those under co-design and co–ownership (Durall et al, 2019). The democratic implementation of STEAM turns education into a collective effort that emphasizes respect, relevance, and mutual learning.

2.2. Transdisciplinary Integration.

The rejection of strict disciplinary boundaries by participatory STEAM models leads to holistic approaches that accurately reflect how problems are experienced and solved by communities (Saimon et al, 2025). The problems of water scarcity, public health, and sustainable agriculture are not restricted to a single field of study but rather multifaceted, interdependent, or need different sources of knowledge. The integration of science, engineering, the arts, and Indigenous knowledge systems is embraced by participatory models through their promotion of transdisciplinary integration (Lage-Gómez & Ros, 2021; Saimon et al, 2005).

A community-based water purification project could involve students and elders collaborating to evaluate the efficacy of various filtration methods. The options may involve utilizing basic chemistry and biology to identify contaminants, incorporating traditional practices like the use of charcoal or medicinal plants, and creating filtration systems using materials found in the area. In order to ensure the solution is well understood and adopted, participants may create public awareness campaigns using storytelling or drama or visual arts based on local languages and cultural expressions.

This type of integration not only fosters creativity or engagement but also bridges the gap between knowledge systems (Lage-Gómez & Ros, 2021; Saimon et al, 2005). Indigenous ecological knowledge, which has been shaped by generations of observation and practice, is considered equal to modern scientific understanding. By making technical knowledge relatable, emotionally relevant and culturally grounded in the arts, this is a crucial function. Learners can enhance their ability to think about systems and comprehend its effects across different fields through transdisciplinary work. (Lage-Gómez & Ros, 2021) Rather than training only specialist-level experts, participatory STEAM prepares participants to engage in diverse thinking processes that can process uncertainty, collaborate across differences, and design for real-world complexity. Transdisciplinary integration doesn't weaken STEAM, but rather it enhances it. This approach fosters a more comprehensive and relevant education that is sensitive to the social, cultural, and environmental factors of the societies it serves (Lage-Gómez & Ros, 2021). It not only helps to solve problems but also affirms the dignity and intelligence of different traditions that share knowledge.'

2.3. Decentralized Infrastructure.

Participatory STEAM models are successful in decentralized, community-based infrastructures that allow for greater accessibility to learning and innovation. In these models, instead of concentrating resources in elite institutions or metropolitan areas, the distribution of tools, technologies and opportunities is done through schools, libraries by community halls, and grassroots organizations (Aguayo et al., 2023). Mobile labs, maker spaces and tech hub in these everyday environments are catalysts for inclusive learning and experimentation (Aguayo et al, 2023; Lanouette & et al., 2025).

Typically, these decentralized spaces are affordable, modular, and can be customized to meet local needs. Solar panels, laptops, microscopes and craft materials could be packed into a mobile STEAM van to remote schools so that students can carry out experiments and build prototypes wherever they are (Aguayo et al, 2023; Lanouette & al., 2025).

The democratization of infrastructure not only expands access but also shifts the locus of innovation. When learners engage with real tools in familiar environments, they begin to see themselves as scientists, engineers, and artists not abstract ideals, but active roles they can embody (Lanouette et al., 2025). This localized access also makes it easier for community members to engage consistently, build ownership, and mentor one another.

Besides, decentralized infrastructures enhance resilience (Lanouette et al, 2025). Community-based STEAM spaces are more flexible than centralized systems, which can be affected by funding cuts or political instability, and often depend on various support networks such as local governments, NGOs,and traditional leadership structures. This is in contrast to the former situation. Adaptableness in meeting community changing needs can result in longer-term sustainability. Decentralized access to tools and learning environments is achieved through participatory STEAM models, which removes barriers of geography, class division, and language by bringing innovation to the most critical areas and empower communities to pursue their own educational journeys. (Lanouette et al, 2025).

2.4. Iterative Learning and Feedback.

The emphasis of the participatory STEAM model is on iterative learning, which involves an ongoing experimentation and reflection to adjust to new ideas (Melissa-Sue et al, 2018). Unlike traditional education systems that prioritize right answers and linear progression, participatory approaches recognize the dynamic nature of knowledge and allow for continuous changes. Both modern engineering's agile design methodologies and traditional indigenous practices of learning through observation, storytelling, and adaptation to changing environments are reflected in this.

Practically, this could resemble a solar cooking project led by students that start off with basic designs and goes on to refine as people say they try. The prototypes are put to the test by community members who provide feedback on their own experiences, such as how long it takes to cook food, and whether children can handle the environment, while also contributing to improving the design. This feedback loop enables the community to become active users and co-developers of the technology, while also emphasizing that mistakes are part of learning.

The use of this iterative model is a powerful tool for fostering learning freedom, as it allows learners to take risks without fear of failure, builds resilience, and inspires curiosity (Melissa-Sue et al., 2018). Not only are the outcomes evaluated but students are also judged for their capacity to observe, ask questions, respond to criticism, and persevere in a challenging environment. Consequently, it fosters the development of both critical thinking and emotional intelligence skills that are necessary for innovation and collaboration. Furthermore, Indigenous knowledge systems tend to be circular, meaning that understanding emerges gradually through careful consideration of patterns, seasons, and community feedback (Melissa-Sué et al, 2018). It values a learning pace that is both context-sensitive and relational, rather than hasty or uniform. Booces et al., (2021) highlight that STEAM education becomes more reflective, relevant, and adaptive by emphasizing iteration. Communities are equipped to tackle immediate issues and engage in lifelong learning and improvement, utilizing both traditional wisdom and modern innovation.

3. Community-Driven STEAM: Strategies for Change.

The development of STEAM models that prioritize local relevance, participation, and equity is crucial for community-based initiatives. The existing strengths and knowledge systems in communities are often overlooked in traditional top-down approaches. Rather than that, participatory models prioritize collaboration, leverage existing resources, and foster innovative practices that are sustainable and culturally appropriate. Asset-Based Community Development (ABCD) is focused on mobilizing local skills and resources. Educational outreach from the Learning Ecosystems Framework encompasses more than just schools: families, cultural institutions, and natural settings. 3.5. Iterative, collaborative development is the primary focus of DBIR, which emphasizes its use in real-world applications. Collective Impact Model - where different stakeholders are aligned around common goals of systemic change. Practical frameworks for STEAM inclusion and localization are provided by these models.

3.1. Asset-Based Community Development (ABCD)

The ABCD model is a revolutionary approach that seeks to identify and utilize the existing assets in varying communities to promote sustainable change (Nel, 2020). ABCD differs from conventional development methods in that it begins with what the community already possesses: skills, relationships, institutions, cultural practices, and physical resources (Nel, 2020; Shaikh et al. Community-driven STEAM involves recognizing that local individuals are not passive recipients of knowledge or assistance but crucial sources of expertise and lived experience.

A rural community may not have access to modern laboratory equipment, but it could be rich in ecological knowledge thanks to elders, skilled craftspeople who can build tools from recycled materials, and passionate science-themed or story-driven teachers. ABCD advocates for mapping out these assets and creating STEAM projects that are influenced by them.' A STEAM program that incorporates ABCD principles could result in youth documenting traditional irrigation techniques, elders discussing lunar planting seasons or community craftsmen collaborating with students to create water-harvesting prototypes using resources from the area.

This approach promotes ownership and pride. Shaikh et al,2023) communities are more likely to maintain the program beyond external funding cycles if they consider their stories and skills as central to the project. By promoting internal leadership development, ABCD empowers its members to take on the role of mentors and scale the initiative from their local peers (Nel, 2020). ABCD alters the narrative from one of enslavement to one that emphasizes both aptitude and creativity. This statement is in complete agreement with participatory STEAM as it highlights the presence of meaningful learning and innovation within communities. Educational change can be not only relevant to the local environment but also long-lasting through external partners acting as facilitators and connectors instead of instructors (Nel, 2020).

3.2. Learning Ecosystems Framework.

The Learning Ecosystems Framework aims to provide a comprehensive and relational approach to education, acknowledging that learning is not limited to schools but encompasses broader interconnectedness and environments (Kummanee et al, 2020). In this model, education is seen as a networked ecosystem that includes both formal institutions (schools and universities), non-formal spaces like libraries or museums with maker spaces to facilitate communication and exchange ideas among students. The validity of this model is evident in a community-driven STEAM context, as it validates multiple knowledge production sites and bridges the gap between formal and informal learning (Haas et al, 2022).

The experiences of learners are shaped by the involvement of various nodes, such as teachers, grandparents, artists, or online learning platforms. Students could pursue a STEAM learning program at school, use it to create digital art with onsite designer, ask elders about the science of indigenous construction methods, and showcase their results in exhibited exhibitions within the Learning Ecosystem (Haas et al, 2021). Having multiple learning environments promotes increased participation as learners acknowledge the importance of STEAM in their daily routines and cultural surroundings.

Additionally, learning ecosystems exhibit variability and changeability (Kummaney et al, 2020). Adaptation to local needs, technological advancements, and environmental changes leads to their development. The use of this framework in a STEAM program may cater to changing circumstances, such as seasonal changes or cultural events, while also keeping learning relevant and current (Haas et al, 2022). Schools collaborate with local NGOs, while families share stories and materials, and local businesses offer mentorship or resources. (Kummanee et al, 2020) The model emphasizes partnerships and collaboration. Communities build resilience and sustainability through their educational initiatives by nurturing relationships throughout the ecosystem (Kummanee et al., 2020). Knowledge is transmitted from one direction to another, and learners are facilitated by a network of connections. The Learning Ecosystem Framework highlights that to truly empower communities through STEAM, we must activate and connect the full spectrum of their educational landscapes (Haas, et al, 2022).

3. 3. Design-Based Implementation Research (DBIR)

DBIR is a collaborative, iterative approach that links educational research to practical application (Underwood & Kararo, 2021; Koren et al, 2003). It. This model emphasizes the collaboration of researchers, teachers and local populations in producing knowledge that can be used to create scalable and sustainable educational systems. Rather than testing solutions in controlled, isolated settings, DBIR is more valuable for participatory STEAM initiatives because it allows for the design and implementation of ideas within complex, real-world scenarios (Underwood& Kararo, 2021).

The fundamental process of DBIR involves a series of stages such as design, testing, feedback, and refinement (Koren et al, 2023). The locality could collaborate on a STEAM program that centers on renewable energy, create solar cookers with students and community builders, and then assess the materials' effectiveness and comprehension. This would be considered community-based innovation. How does this work? The process isn't fixed and can be modified as new insights or problems develop (Underwood & Kararo, 2021). However, it doesn' all happen overnight.

All stakeholders are involved in DBIR during all phases of research and design (Koren et al, 2023). The democratization of knowledge production ensures that the project is influenced by the priorities of the community. When attempting to educate rural climate science in an area that does not conform to local values or practices, DBIR allows for modifications informed by community feedback instead of strict regulations. From the outset, local knowledge is incorporated and not overlooked.

DBIR's focus on innovation and implementation is another positive aspect of the initiative (Koren et al, 2023). Creating a good idea is not the end goal; instead, the model emphasizes the importance of embedding it in systems to ensure its sustainability. In under-resourced settings, educational innovations must be affordable, flexible, and sustained. By emphasizing collaboration, contextual significance and long-term viability (Underwood & Kararo, 2021), DBIR provides a strong starting point for participatory STEAM. Research becomes a dynamic and ongoing activity that is closely tied to its intended audience (Koren et al, 2023).

3.4. Collective Impact Model.

By utilizing the Collective Impact Model, social challenges like educational inequality can be tackled through coordinated and cross-sector collaboration (Panjwani et al, 2023), providing a strategic solution. Instead of working in isolation, the model brings together various stakeholders, such as governments, NGOs, educators, families, funders, and cultural leaders, to work towards a common vision and set of goals (Panjwani et al, 2023). Communities based on STEAM work must follow this model, which ensures that their efforts are not fragmented or duplicative.

Five key factors that shape Collective Impact are a shared agenda, measurement systems, mutually reinforcing activities, continuous communication (Panjwani et al, 2023), and backbone support organizations. A regional STEAM initiative that aims to improve digital literacy involves schools providing in-class instruction, libraries hosting after-school maker sessions, local businesses mentoring and interning students, and parents participating in community coding nights. The actors function in different, yet related ways to provide complete aid to students.'".

The strength of this model lies in the ability to harmonize disparate viewpoints while maintaining a balance between individual stakeholder interests. Many communities do not have government departments that work together with traditional leaders or grassroots innovators. By encouraging regular dialogue and building trust among these groups, Collective Impact facilitates the development of culturally relevant, systems-level solutions (Panjwani et al, 2023). It also provides long-term funding and policy support, as stakeholders can exhibit unified impact and collective accountability. Collective Impact initiatives are data-driven and iterative. Continuous improvement is made possible through the use of shared metrics, enabling adaptive learning. Through regular meetings and feedback loops, stakeholders can evaluate their efforts, identify gaps in progress, and reevaluate potential actions.

This model is well-suited for community-driven STEAM projects that aim to expand the impact across regions or address multi-dimensional issues such as the digital divide, gender inclusion, or environmental education. Through the development of an educational impact model that emphasizes collaboration, openness, and collective leadership, the Collective Impact Model facilitates a cohesive movement for change.

4. Success Stories from Southern Africa.

4.1. Botswana's Community Science Hubs.

Botswana is witnessing a surge in the number of libraries and community centres being transformed into STEAM learning centers, providing inclusive and hands-on education for young people (Nthogo Lekoko, 2021; Denson & Bayati, 2004). The spaces are often situated in rural or underserved areas and are intended to address specific local issues such as water shortages, food availability/use, and energy needs. In contrast, the hubs prioritize affordable, eco-friendly tools over costly imported equipment. Youth individuals construct prototypes from recycled materials, experiment with indigenous technologies, and explore science through practical applications (Denson & Bayati, 2024).

Local knowledge-based and community mentors guide learners through collaborative problem-solving projects (Nthogo Lekoko, 2021). To demonstrate, students could create solar cookers using reflective materials and cardboard, or they could construct water filters that mimic old-fashioned purification techniques. The development of technical and scientific expertise is complemented by cultural significance and relevance through these activities. Additionally, these centers have become hubs of intergenerational communication, where elders pass on wisdom and younger individuals bring innovative ideas and the internet to share.

The implementation of sustainability and integration into broader educational strategies is ensured through partnerships with local schools, NGOs, and government agencies. Botswana's Community Science Hubs demonstrate the potential of STEAM education being democratized, localized and made meaningful through community-based approaches.

4. 2. The Maker Movement in Townships of South Africa

STEAM and youth empowerment in South Africa have been revolutionized by the maker movement that has taken place in townships, serving as a model for innovation at the grassroots level. Communities run makerspaces, such as those in Khayelitsha and Soweto in Cape Town, provide access to digital fabrication tools, coding workshops, and robotics labs. These spaces are co-ordinated by local educators, artists, and technologists to ensure that activities align with the cultural and contextual context of participants.

Makerspaces promote creativity, experimentation, and social impact. The aim is for young people to come up with solutions to local issues, such as affordable mobile phone chargers, water-saving irrigation systems, or digitally-controlled community alarms. The STEAM learning projects are not only technically demanding but also entrepreneurial in nature, connecting it to local economic development and job creation.

Peer learning, mentorship, and collective ownership are key components of the maker movement. The youth's education is based on practical experiences, often involving teaching and sharing their creations through local events. This model of participation promotes trust, collaboration, and the ability to act independently. Additionally, the movement's emphasis on digital literacy and innovation within everyday community contexts eliminates barriers to technology access and alters perspectives on what qualifies as an inventor or engineer. The township maker movement in South Africa is a prime example of inclusive, bottom-up STEAM education.

4.3. Zimbabwe's Agro-Tech Initiatives.

In Zimbabwe, agro-tech ventures are changing how scientists and technologists interact with rural communities by merging traditional agricultural knowledge into contemporary innovations. These programmes are developed through a participatory approach that involves the participation of farmers, educators, and researchers, with an emphasis on cultural relevance and community ownership. At the core of these efforts is the recognition that indigenous farming methods, including crop rotation, composting, and rainwater harvesting are valuable sources of science.

The integration of these practices with contemporary agro-tech tools like solar-powered irrigation systems, soil testing kits, and mobile-based weather forecasts is leading communities to develop sustainable and adaptable knowledge systems. Instruction is delivered in local languages and is based on everyday farming experiences, making it both accessible and easily applicable. Students studying soil pH and maintaining school gardens may engage in agro-tech projects while learning about plant biology from textbooks and traditional herbalists.

The programs also promote intergenerational education, with older individuals providing hands-on experience and younger individuals introducing digital tools and fresh perspectives. Additionally, Education and agricultural productivity are positively impacted by this dynamic.' Local NGOs and agricultural colleges are supporting the development of agro-tech programs in Zimbabwe, which showcase the potential of STEAM for promoting food security, environmental sustainability, and educational equity in rural areas.

5. STEAM Education Model: A Community-Driven Approach to Learning and Outreach.

Figure 5.1 highlights the Participatory Spiral STEAM Change Model, which involves communities participating in the creation of STEM education. The process takes five interconnected steps, beginning with community discussion and needs assessment to identify local priorities and validate Indigenous knowledge as valid and relevant. The co-design of curriculum is necessary to ensure learning that is culturally grounded and problem-oriented. The combination of hands-on implementation and mentoring facilitates learning by facilitating interaction between generations and encouraging adaptation through community reflection and feedback. Ultimately, the dissemination and preservation of knowledge enhances both impact and autonomy.

Figure 5.1 Participatory Spiral STEAM Change Model

5.1. Community Dialogue and Needs Assessment

Phase I of the spiral requires a genuine, non-formal dialogue with all stakeholders in the community: children and youth; elders; teachers; artisans; parents; and local leaders. Rather than collecting data, this stage is focused on developing shared understanding and trust, as well as a common goal. ". By means of critical listening, individuals in the community can provide feedback on their own lived experiences, local issues, cultural accomplishments, and educational goals. This process has led to the recognition of Indigenous Knowledge Systems (IKS) as valid and scientific, providing a foundation for learning that is grounded in local realities rather than imposed by external curriculum.(Zorenböhmer et al, 2022). Not all individuals are external experts, but facilitators function as listeners and learners. This stage is in agreement with Paulo Freire's view that dialogue is the key to liberation, as it is through conversation that people shape their world and transform it. The assessment transforms into a dynamic process that employs participatory action research (PAR) principles, encouraging collaborative inquiry and identifying areas for STEAM participation. Some of these issues may be centred on water supply, climate change or youth unemployment. The problems that need to be addressed are not external issues, but rather as a foundation for co-learning and cocreation. Participatory need assessment is the starting point for the entire spiral, guaranteeing that any STEAM project is relevant from day one and that it is owned by everyone as equals.

5.2. Co-Design of STEAM Curriculum.

In the second phase, community and educational facilitators work together to design the curriculum for STEAM. The collaborative design approach aims to ensure that learning content is culturally sensitive and also environmentally sustainable (Bang & Vossoughi, 2016; Belgrave und al, 2022). The creation of interdisciplinary learning experiences that combine scientific inquiry, Indigenous knowledge, traditional craftsmanship, and artistic expression is achieved by a group of educators, learners, elders, local experts (Belgrave et al, 2022). As an illustration, a thermodynamics lesson might involve designing improvised solar ovens using indigenous resources and traditional food preservation techniques. Additionally, the science of heat transfer could be covered in this lesson. Culturally sustaining pedagogy is the main focus of this phase, which asserts learners' identities and fosters respect for diverse ways of knowing. Howard Gardner's Multiple Intelligences model is applied to the curriculum, which incorporates various modalities such as visual, kinesthetic, interpersonal and linguistic approaches to promote holistic learning (Morgan, 2021). Booe et al, 2021; Zorenböhmer & al." add to the STEAM educational process through art, music, storytelling, and hands-on experiments. However, this process is not complete. Co-design allows for flexibility, enabling the curriculum to evolve in response to ongoing community feedback (Zorenböhmer et al, 2022). By treating the curriculum as an integrated, participatory work document, this phase ensures that STEAM education is relevant, meaningful, and empowering in preparing learners to solve real-world problems while respecting their cultural roots (Zorenböhmer et al, 2022).

5.3. Hands-on Implementation and Local Mentorship.

This stage converts the co-designed curriculum into practical, project-based learning.' It is executed in open-air environments, schools or libraries on the farm, and in community spaces such as farms or makerspaces. Active participation in experimentation, collaboration and creativity are encouraged to apply theoretical concepts to real problems (Belgrave et al, 2022; Bhatta & **et** al**.,** 2025**).** The process fosters critical thinking and innovation, whether it's designing a rainwater harvesting system, mapping the biodiversity, or creating prototypes of medical tools. The role of local mentors such as elders, artisans, technicians and trained youth facilit**ator are centrally important.** Not only do they foster learning in community values, but it also reinforces the notion that everyone is both a learner and teaches. A mentoring structure fosters self-assurance and bridges the gap between generations. This phase is based on the experiential learning theory of Kolb and the situated learning model of Lave and Wenger, with an emphasis on learning through practical experience (Bhatta et al, 2025). By encouraging questions, errors, repetition, and modification, it fosters learner agency. The use of critical pedagogy challenges knowledge hierarchies and empowers learners to take charge of both their education and community futures. By establishing the foundation for learning in local environments and encouraging participation at all levels, this phase enhances both individual abilities and teamwork.

5.4. Community Reflection and Feedback

Reflection is a crucial step towards maintaining the relevance and impact of STEAM initiatives. This stage is intended to facilitate a process of community-wide reflection on the learning, its acquisition, and its integration with local values and objectives. Reflection is not merely a final step in the project's development; it also takes place through storytelling circles, public exhibitions, feedback sessions, and intergenerational dialogues. Intangible transformations, such as student projects and digital skills, are evaluated by community members. Additionally, they evaluate whether tangible changes like cultural pride, confidence levels, and trust among generations exist (Zorenböhmer et al, 2022). Rather than testing, formal assessment tools are utilized to enhance growth by providing feedback in real-time that influences future assessments. This is the ultimate goal. Drawing on Freire's (1976; 1979) concept of praxis, this stage promotes critical reflection on the power dynamics, inclusivity, and social effects of STEAM education.[In summary, rediscovered practices may be a topic of discussion for elders, while youth may propose new tools or topics for use by facilitators to meet emerging needs. The spiral's dynamic and transformative nature is reinforced by the iterative feedback loop that sustains projects in its community-driven, adaptive, and responsive modes of change.

5.5. Knowledge Sharing and Sustainability.

The ultimate phase of the spiral aims to scale impact by sharing lessons and ensuring long-term sustainability. Digital storytelling, exhibitions, peer-to-peer learning exchanges and open-source repositories document success stories, project outcomes and innovations in accessible formats

(Zorenböhmer et al, 2022). Apart from celebrating successes, these serve as a source of inspiration for replicating and adapting to other cultures. Local and regional sharing of knowledge fosters cooperation and solidarity among communities. (Zorenböhmer et al, 2022). A supportive ecosystem of practice is created by creating STEAM hubs and networks that unite learners, mentors, educators, and innovators from various fields. By providing training for local leaders, creating resource toolkits, and obtaining micro-grants or local sponsorships to maintain continuity, sustainability is also embedded. Its goal is to build local capability without relieving communities, enabling them to adapt and grow their projects independently.' This phase also links STEAM learning to wider development goals such as health, environmental conservation, and economic progress. By balancing out educational outcomes with concrete improvements in quality of life, the model ensures that learning remains relevant and valuable (Zorenböhmer et al, 2022). This stage is necessary to finalize the spiral and open the door for a new period of dialogue and innovation that transforms STEAM as 'community driven' and collaborative.

STEAM education is based on the Participatory Spiral STAM Change Model, which promotes dialogue, co-creation, and ongoing reflection as a community-driven approach. It starts with community discussion and needs evaluation, emphasizing Indigenous Knowledge Systems and lived experiences. Culturally relevant curricula are created by communities through co-design. Practical implementation and mentorship are key components of the model, with an emphasis on linking knowledge to practical problems. By engaging in community feedback and reflection, adaptability and relevance are guaranteed, while knowledge sharing and sustainability fosters long-term impact and cross-community learning. Through the use of participatory action research and critical pedagogy, this model promotes equity, local agency, and innovation in an evolving educational ecosystem.

Conclusions

The Participatory Spiral of Change Model, which is a type of STEAM education focused on community collaboration and empowerment, provides broader perspectives on STAM through their ability to teach through community engagement. This model involves the participation of all members of the community (youth, youth and elders), educators as well as artisans in the design, implementation and reflection processes, resulting in a strong sense of ownership and relevance to education, making it both meaningful and sustainable. Indigenous Knowledge Systems (IKS) are utilized to enrich scientific inquiry and enhance the learning experience, blending traditional cultural practices with contemporary technology. Rather than emphasizing traditional hierarchical models of education, this approach promotes participatory and egalitarian methods that reflect the individual needs and aspirations of each community. Through the Participatory Spiral of Change Model, individuals can engage in a cycle of dialogue, co-design, hands-on learning, reflection, and knowledge sharing that promotes growth and empowers others to thrive. This model allows communities to adapt and thrive in response to changing circumstances. The education model emphasizes the importance of being culturally relevant and driven by individuals.

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