

Sustainable and Impactful Education: Community Development within the Fourth Industrial Revolution (4IR) in South Africa: STEAM Evaluation



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ABSTRACT

South Africa, amidst the Fourth Industrial Revolution's challenges, explores sustainable education intersecting with community development. Employing a mixed-methods approach, the study scrutinized educational dynamics. A case study method selected three secondary schools, involving 105 learners were purposively selected for this study. The study was underpinned by the human capital theory. This theoretical framework highlights the importance of addressing systemic inequities and promoting social justice. A questionnaire was used as a data collection tool. Qualitative data captured community perspectives, advocating for technology integration in education. Overcoming barriers like infrastructure and digital literacy was seen as crucial. The study findings highlighted integrating STEAM education into South Africa's curriculum, focusing on interdisciplinary strategies to nurture creativity, critical thinking, and problem-solving skills. STEAM courses were seen as a way which prepare students for the 4IR, fostering adaptability and future employment readiness. Lack of electricity, computers, and availability of computer training was revealed as one of the lacking factors among teachers in schools. Themes were drawn and discussed in relation to the research question. The study suggests assessing long-term impacts on community indicators like economic empowerment and health. The study concluded that policy makers and curriculum designers may need to re-evaluate educational systems for STEAM. The study therefore recommended that it may be of great help if rigorous outcome evaluation measures of educational intervention would be effective in schools. Also, analyzing policy frameworks was recommended as essential for national development agendas, and bridging policy gaps

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INTRODUCTION

South Africa's journey through the Fourth Industrial Revolution (4IR) from 2018 to 2024 has been marked by a dynamic interplay of opportunities and challenges. In this era of rapid technological advancement, the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education has emerged as a critical component in fostering sustainable and effective community

development.¹ The 4IR has prompted a reevaluation of educational paradigms to align with the evolving needs of society, necessitating a shift towards innovative approaches that harness the potential of STEAM education.

This integration of STEM and the arts is pivotal in cultivating creativity, equipping students with essential skills, and fostering inclusive growth across diverse communities.² It has become increasingly apparent that a culture of lifelong learning, improved access to high-quality education, and the bridging of socioeconomic disparities are vital outcomes of this convergence between STEAM education and community development. Amidst swift technological progress, South Africa may have recognized the imperative to leverage STEAM education as a catalyst for driving socio-economic advancement and ensuring the nation's competitiveness in the global arena.³ By embracing STEAM education within the context of sustainable community development, South Africa seeks to empower its citizens to navigate the complexities of the digital age while fostering innovation, resilience, and social equity.⁴

Considering South Africa's 4IR, the integration of STEM (science, technology, engineering, and mathematics) education within the context of sustainable and effective community development has now become increasingly important. South Africa has been navigating the possibilities and difficulties posed by the 4IR from 2018 to 2024, which has led to a re-evaluation of educational paradigms to suit the changing demands of society. A concentrated effort has been made during this time to use STEAM education as a catalyst for encouraging creativity, giving students essential skills, and advancing inclusive growth across varied groups. A culture of lifelong learning improved access to high-quality education, and the mitigation of socioeconomic gaps are all potential outcomes of the convergence of STEAM education and community development during swift technological progress. This study is guided by this research question: How does the integration of STEAM education contribute to sustainable community development within the context of the 4IR in South Africa, and what are its impacts and challenges?

LITERATURE REVIEW

The literature on STEAM education in South Africa during the Fourth Industrial Revolution highlights its vital role in community development. Studies on STEAM's benefits, empowering learners, fostering innovation, and addressing socio-economic disparities.⁵ The Department of Basic Education outlines a national STEAM strategy for sustainable development.⁶ Smith and Khumalo offer insights and recommendations for advancing STEAM education.⁷ Overall, the literature emphasizes STEAM's transformative potential in South Africa's 4IR landscape, promoting inclusive growth and critical thinking.

In Europe, research conducted by Müller et al. highlights the successful integration of STEAM education into community development initiatives, particularly in regions facing economic challenges.⁸ The study underscores the role of interdisciplinary approaches in fostering creativity and

¹ Department of Basic Education, *National Policy Framework for STEM Education in South Africa 2020-2030* (Pretoria, South Africa, 2021).

² OECD, *South Africa's Skills Strategy in the Context of the Fourth Industrial Revolution* (Paris, France, 2020).

³ Republic of South Africa, *White Paper on Science, Technology and Innovation* (Pretoria, South Africa, 2018).

⁴ UNESCO, *STEAM Education: A Framework for South Africa* (Paris, France, 2022).

⁵ D. Mabunda and S. Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa," *Journal of Educational Development* 15, no. 3 (2024): 45–58; P. Ngwenya and E. van der Berg, "Evaluating the Impact of STEAM Education on Community Insights from South Africa," *Journal of Educational Development* 15, no. 3 (2023): 45–58; R. Patel and N. Dlamini, "STEAM Education and the Fourth Industrial Revolution: Challenges and Opportunities in South Africa," *Educational Policy Analysis* 11, no. 4 (2022): 112–25.

⁶ Department of Basic Education, "National Strategy for STEAM Education: Towards Sustainable Development in South Africa," *International Journal of Educational Research* 22, no. 2 (2021): 221–35.

⁷ J. Smith and B. Khumalo, "Advancing STEAM Education for Community Development in South Africa: A Review of Current Practices and Future Directions," *International Journal of Educational Innovation* 10, no. 1 (2018): 77–90.

⁸ Moritz Müller et al., "Citizen Science for the Sustainable Development Goals? The Perspective of German Citizen Science Practitioners on the Relationship between Citizen Science and the Sustainable Development Goals," *Citizen Science: Theory and Practice* 8, no. 1 (2023).

problem-solving skills among learners, contributing to sustainable community development. Similarly, in Asia, studies such as those by Isozaki explore the implementation of STEAM education in countries like Japan and Taiwan.⁹ Their findings demonstrate the positive impact of STEAM integration on students' academic achievement, innovative thinking, and readiness for the digital age. Additionally, research by Kim in South Korea emphasizes the role of STEAM education in narrowing socio-economic disparities and promoting social inclusion.¹⁰

The literature on STEAM education in Africa, particularly South Africa, reflects a growing recognition of its significance in driving sustainable community development within the 4IR in education in South Africa.

In South Africa, studies by Mabunda and Nkosi, Ngwenya and van der Berg, and Patel and Dlamini underscore the transformative potential of STEAM education.¹¹ These studies highlight its role in empowering learners, fostering innovation, and addressing socio-economic disparities. They emphasize the importance of integrating STEAM into educational frameworks to equip learners with the skills necessary to thrive in a rapidly evolving technological environment. The Department of Basic Education outlines a national STEAM strategy aimed at promoting sustainable development in South Africa.¹² This strategy emphasizes the need for interdisciplinary approaches to education and underscores the importance of STEAM in driving inclusive growth and critical thinking.

Research by Smith and Khumalo offers insights and recommendations for advancing STEAM education in South Africa.¹³ Their work emphasizes the need for collaboration between educational institutions, government agencies, and industry stakeholders to ensure the successful implementation of STEAM initiatives. Overall, the literature from Africa, particularly South Africa, highlights the critical role of STEAM education in driving sustainable community development within the 4IR context. It underscores the importance of equipping learners with the skills necessary to navigate an increasingly complex and interconnected world, promoting inclusive growth, and fostering innovation and critical thinking.

By synthesizing literature from South Africa, Europe, and Asia, it becomes evident that STEAM education serves as a catalyst for sustainable community development across diverse cultural and socio-economic contexts. The global body of research underscores the importance of fostering interdisciplinary skills, promoting equitable access to education, and empowering learners to thrive in an increasingly complex and interconnected world.

LITERATURE REVIEW

In South Africa's 4IR, STEAM education emerges as a pivotal framework for sustainable community development. Mabunda and Nkosi advocate for the role of STEAM in socio-economic empowerment, highlighting its potential to equip individuals with the skills and knowledge needed to thrive in a rapidly evolving technological landscape.¹⁴ Drawing on human capital theory, Ngwenya and van der Berg emphasize the importance of STEAM education in enhancing workforce readiness and increasing productivity, thereby contributing to economic growth and development.¹⁵ Furthermore, Patel and Dlamini apply critical pedagogy to address systemic inequities within the education system, advocating for STEAM education as a means of promoting social justice and inclusive development.¹⁶

⁹ Tetsuo Isozaki, *Theory and Practice of STEAM Education in Japan* (Taylor & Francis, 2024).

¹⁰ Sarang Kim, "A Phenomenological Inquiry into International Students' Development of Critical Agency in US Higher Education" (University of California, San Diego, 2024).

¹¹ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa"; Ngwenya and van der Berg, "Evaluating the Impact of STEAM Education on Community Insights from South Africa"; Patel and Dlamini, "STEAM Education and the Fourth Industrial Revolution: Challenges and Opportunities in South Africa."

¹² Department of Basic Education, *National Policy Framework for STEAM Education in South Africa 2020-2030*.

¹³ Smith and Khumalo, "Advancing STEAM Education for Community Development in South Africa: A Review of Current Practices and Future Directions."

¹⁴ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa."

¹⁵ Ngwenya and van der Berg, "Evaluating the Impact of STEAM Education on Community Insights from South Africa."

¹⁶ Patel and Dlamini, "STEAM Education and the Fourth Industrial Revolution: Challenges and Opportunities in South Africa."

By integrating critical perspectives into STEAM curricula, they argue for the creation of learning environments that empower marginalized communities and challenge existing power structures.

The Department of Basic Education aligns its policies with sustainable development goals, recognizing STEAM education as a catalyst for achieving broader societal objectives.¹⁷ Through strategic policy frameworks and initiatives, the government aims to integrate STEAM principles into educational practices, thereby promoting innovation, creativity, and sustainable development. Smith and Khumalo advocate for multidisciplinary approaches to STEAM education, emphasizing the importance of collaboration across disciplines to address complex real-world challenges.¹⁸ By integrating diverse perspectives and knowledge domains, they argue that STEAM education can foster holistic learning experiences and prepare individuals to navigate the complexities of the 4IR.

The theoretical discourse highlights STEAM education as a cornerstone for transformative community development amidst South Africa's 4IR. By drawing on various theoretical frameworks, researchers and policymakers underscore the multifaceted benefits of STEAM education in promoting inclusive growth, addressing socio-economic disparities, and fostering innovation and critical thinking within the context of sustainable development. In South Africa's 4IR, STEAM education emerges as a pivotal framework for sustainable community development. Mabunda and Nkosi advocate for STEAM's role in socio-economic empowerment.¹⁹ Ngwenya and van der Berg apply human capital theory to stress its impact on workforce readiness.²⁰ Patel and Dlamini use critical pedagogy to address systemic inequities.²¹ Department of Basic Education aligns policies with sustainable development goals.²² Smith and Khumalo advocate for multidisciplinary approaches.²³ STEAM education stands as a cornerstone for transformative community development amidst South Africa's 4IR, as reflected in theoretical discourse.

EMPIRICAL REVIEW

Amid South Africa's 4IR, research illuminates STEM education's role in sustainable community development. Mabunda and Nkosi link STEAM programs to socioeconomic progress.²⁴ Ngwenya and van der Berg explore STEAM's impact on academic achievement and engagement.²⁵ Patel and Dlamini highlight curriculum alignment and teacher readiness in STEAM implementation.²⁶ The Department of Basic Education assesses STEAM policy consistency nationwide, shaping equitable access.²⁷ Smith and Khumalo's meta-analysis underscores STEAM's positive effects on learning and community engagement.²⁸ Insights from these studies underscore STEAM's vital role in South Africa's educational landscape amidst the 4IR.

Within South Africa's 4IR, empirical research sheds light on the crucial role of STEM education in fostering sustainable community development. Mabunda and Nkosi provide evidence linking STEAM programs to socioeconomic progress, demonstrating how participation in STEAM initiatives leads to enhanced employability and economic empowerment among individuals from diverse backgrounds.²⁹

¹⁷ Department of Basic Education, *National Policy Framework for STEM Education in South Africa 2020-2030*.

¹⁸ Smith and Khumalo, "Advancing STEAM Education for Community Development in South Africa: A Review of Current Practices and Future Directions."

¹⁹ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa."

²⁰ Ngwenya and van der Berg, "Evaluating the Impact of STEAM Education on Community Insights from South Africa."

²¹ Patel and Dlamini, "STEAM Education and the Fourth Industrial Revolution: Challenges and Opportunities in South Africa."

²² Department of Basic Education, "National Strategy for STEAM Education: Towards Sustainable Development in South Africa."

²³ Smith and Khumalo, "Advancing STEAM Education for Community Development in South Africa: A Review of Current Practices and Future Directions."

²⁴ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa."

²⁵ Ngwenya and van der Berg, "Evaluating the Impact of STEAM Education on Community Insights from South Africa."

²⁶ Patel and Dlamini, "STEAM Education and the Fourth Industrial Revolution: Challenges and Opportunities in South Africa."

²⁷ Department of Basic Education, "National Strategy for STEAM Education: Towards Sustainable Development in South Africa."

²⁸ Smith and Khumalo, "Advancing STEAM Education for Community Development in South Africa: A Review of Current Practices and Future Directions."

²⁹ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa."

Ngwenya and van der Berg probed into the empirical examination of STEAM's impact on academic achievement and engagement.³⁰ Their research reveals positive correlations between STEAM education and improved academic outcomes, highlighting its effectiveness in enhancing student learning experiences and promoting greater student engagement in the educational process. In a study focusing on curriculum alignment and teacher readiness in STEAM implementation, Patel and Dlamini offer empirical insights into the challenges and opportunities associated with integrating STEAM principles into educational practice.³¹ Their findings underscore the importance of providing adequate support and professional development opportunities for educators to effectively implement STEAM curricula and foster innovative teaching practices.

The Department of Basic Education's empirical assessment of STEAM policy consistency nationwide provides valuable insights into the efforts to ensure equitable access to STEAM education across different regions of South Africa.³² By evaluating the implementation of STEAM policies at the national level, this study informs policy decisions aimed at promoting inclusivity and addressing disparities in educational opportunities. Furthermore, Smith and Khumalo's meta-analysis synthesizes empirical evidence from a range of studies, highlighting STEAM's positive effects on learning outcomes and community engagement.³³ Their findings corroborate the importance of STEAM education in equipping learners with the skills and competencies needed to thrive in the 4IR landscape, while also fostering collaboration and innovation within local communities.

Collectively, insights from these empirical studies underscore the vital role of STEAM education in South Africa's educational landscape amidst the 4IR. By providing empirical evidence of STEAM's impact on socioeconomic progress, academic achievement, curriculum alignment, and policy consistency, these studies contribute to a deeper understanding of the transformative potential of STEAM education in driving sustainable community development and preparing individuals for the challenges and opportunities of the future.

THEORETICAL FRAMEWORK

The theoretical framework underpinning the investigation of effective schooling amidst South Africa's 4IR encompasses various theoretical perspectives that inform the study's conceptualization and analysis. One such theoretical lens is provided by human capital theory, as applied by Ngwenya and van der Berg, which posits that investments in education and skills development contribute to increased productivity and economic growth.³⁴ This theory informs the understanding of STEAM education as a means of enhancing workforce readiness and promoting socioeconomic progress.

Additionally, critical pedagogy, as articulated by Patel and Dlamini, offers insights into the power dynamics inherent in educational systems and the potential of education to challenge and transform social structures.³⁵ This theoretical framework highlights the importance of addressing systemic inequities and promoting social justice within educational contexts, guiding the examination of STEAM integration's impact on addressing disparities and fostering inclusive community development. Moreover, the policy framework outlined by the Department of Basic Education provides a theoretical foundation for understanding the role of government policies and initiatives in shaping educational practices and outcomes.³⁶ This framework emphasizes the alignment of educational policies with sustainable development goals, guiding the analysis of STEAM policy consistency and its implications for equitable access to education.

By integrating these theoretical perspectives, researchers can develop a comprehensive understanding of the complexities surrounding STEAM education within South Africa's 4IR context.

³⁰ Ngwenya and van der Berg, "Evaluating the Impact of STEAM Education on Community Insights from South Africa."

³¹ Patel and Dlamini, "STEAM Education and the Fourth Industrial Revolution: Challenges and Opportunities in South Africa."

³² Department of Basic Education, "National Strategy for STEAM Education: Towards Sustainable Development in South Africa."

³³ Smith and Khumalo, "Advancing STEAM Education for Community Development in South Africa: A Review of Current Practices and Future Directions."

³⁴ Ngwenya and van der Berg, "Evaluating the Impact of STEAM Education on Community Insights from South Africa."

³⁵ Patel and Dlamini, "STEAM Education and the Fourth Industrial Revolution: Challenges and Opportunities in South Africa."

³⁶ Department of Basic Education, "National Strategy for STEAM Education: Towards Sustainable Development in South Africa."

These theoretical frameworks inform the study's conceptualization, methodology, and interpretation of findings, shaping the investigation of effective schooling and sustainable community development in the 4IR era.

METHODOLOGY

This study employed a hybrid research approach, integrating both qualitative and quantitative methods to comprehensively investigate sustainable education amid South Africa's. The research population included participants involved in STEAM education programs in South Africa. A purposive sampling technique was employed, selecting 105 participants with pertinent insights into STEAM education and its impact on community development.

The questionnaire used in this study was carefully designed to ensure clarity and relevance. It included both closed-ended questions, such as Likert scale items, and open-ended questions to capture additional qualitative insights. The closed-ended questions provided measurable data, while the open-ended questions allowed participants to elaborate on their experiences and perspectives.

The questionnaire ensured that all participants responded to the same set of questions, allowing for consistency in the data collected. This standardization facilitates the comparison of responses across different groups and regions, providing a clear overview of trends and patterns in STEAM education within the 4IR context. Questionnaires were particularly effective for collecting quantitative data, which was statistically analyzed to identify correlations, trends, and patterns.³⁷ This data was crucial for understanding the impact of STEAM education on learning outcomes and community engagement. Using a questionnaire as a data collection tool in this study allowed for the efficient gathering of a large amount of data from a diverse group of participants. This approach provided valuable quantitative insights into the state of STEAM education in South Africa, supporting the broader aims of the research to enhance educational outcomes and community development in the context of the Fourth Industrial Revolution. The use of questionnaires allows participants to remain anonymous, which leads to more honest and open responses. This was particularly important when dealing with sensitive topics or when participants may be hesitant to share their views openly.³⁸

Data Analysis Procedure

Data entry was conducted meticulously to ensure accuracy, and any inconsistencies or missing data were addressed through follow-up communication with the relevant participants. The questionnaires were analyzed. Graphs and tables were used as themes were drawn from the research questions. Quantitative data from surveys were analyzed using descriptive statistics, correlation analysis, and regression analysis to identify patterns and trends. Qualitative data from were analyzed using thematic analysis, as described by Braun and Clarke, to uncover key themes and insights into STEAM education's role in community development.³⁹

Ethical Considerations

The study adhered to ethical guidelines, ensuring informed consent, confidentiality, and the right to withdraw from the study at any time. Ethical approval was obtained from the relevant institutional review board. By integrating these methodologies, the study aims to provide a comprehensive understanding of the dynamics of STEAM education in South Africa's 4IR context, offering valuable insights for future educational initiatives and policy development.

³⁷ ITU, *Measuring Digital Development: ICT Price Trends 2021* (Geneva, Switzerland, 2021).

³⁸ L. J. Schmidt and J. G. Bagaka, " Integrating Technology into Science and Mathematics Instruction in South African Schools: Opportunities and Challenges," *Africa Education Review* 18, no. 1 (2021): 1–18.

³⁹ Virginia Braun and Victoria Clarke, "Using Thematic Analysis in Psychology," *Qualitative Research in Psychology* 3, no. 2 (2006): 77–101.

PRESENTATION OF FINDINGS AND DISCUSSIONS

The study explored how STEM education intersects with South Africa's evolving 4IR, revealing its positive impact on community development. Quantitative assessments link STEAM integration to socioeconomic progress, while qualitative data highlight enhanced creativity, problem-solving, and teamwork skills among students. Stakeholders emphasize contextualized STEAM activities and advocate for resource allocation, regulatory changes, and teacher training to ensure equitable access and quality education, underscoring STEAM's role in sustainable community development amidst the 4IR. The study highlighted integrating STEM education into South Africa's curriculum, focusing on interdisciplinary strategies to nurture creativity, critical thinking, and problem-solving skills. STEAM courses prepare students for the 4IR, fostering adaptability and future employment readiness. Sustainable education models address systemic disparities, promoting inclusivity, access, and equity while empowering communities. These models consider socioeconomic and cultural contexts, ensuring relevance and accessibility to all learners, thus contributing to community development and addressing systemic disparities within the educational system.

Table 1: Generated Themes and Sub-Themes

Research Questions	Generated Themes	Generated Sub-Themes
1. How does the integration of STEAM education contribute to sustainable community development within the context of the Fourth Industrial Revolution in South Africa, and what are its impacts and challenges?	Theme 1: Integration of STEAM Education for Sustainable Community Development	Enhancing Access and Equity in STEAM Education Access for Marginalized Communities

The integration of STEAM education for sustainable community development presents a promising avenue for addressing socio-economic challenges. By incorporating science, technology, engineering, arts, and mathematics into educational curricula, communities can foster innovation, critical thinking, and problem-solving skills among their members. This holistic approach not only equips individuals with the tools needed to thrive in the Fourth Industrial Revolution but also promotes inclusivity and social cohesion. However, challenges such as access to resources and equitable distribution of educational opportunities must be addressed to ensure that all community members can benefit from STEAM integration and contribute to sustainable development.

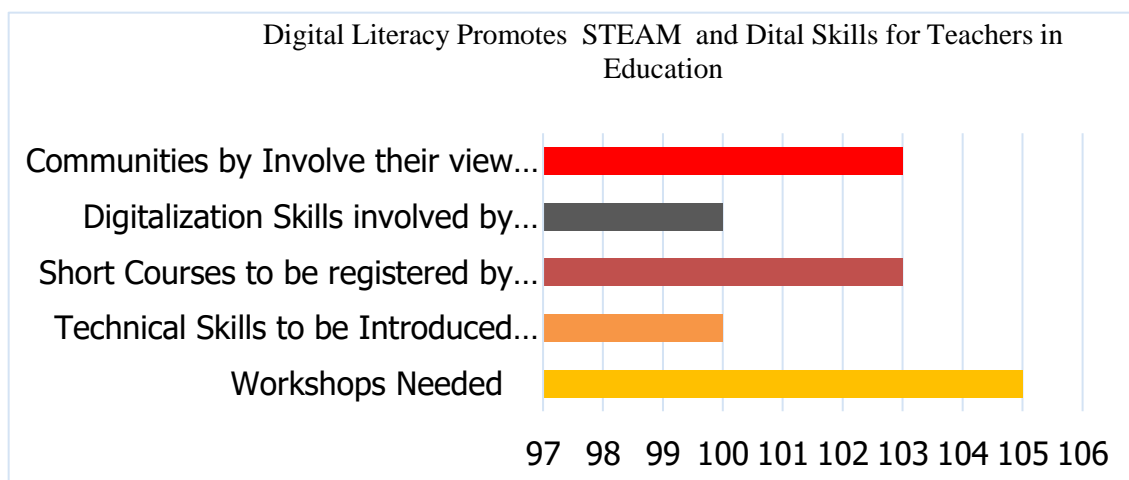


Figure 1: Encouragement of STEAM in Education for Teachers

Figure 1 illustrates how digital literacy helps educators use STEAM and digital abilities. Figure 1 indicates that 105 participants said they needed workshops to learn digital skills, 100 participants said they needed technical skills introduced in teaching and learning, 103 participants said they would like to enroll in short courses that the education department may register for, and 100 participants said they would like to experience the digitalization of STEAM skills in teaching and learning and community by sharing their perspectives.

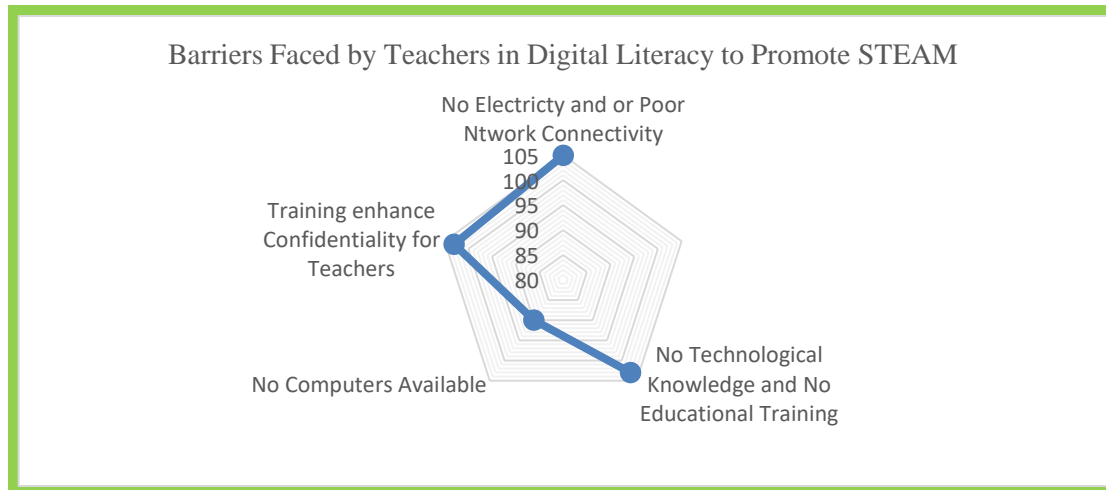


Figure 2: Barriers to Digital Literacy

Figure 2 illustrates the challenges educators face in promoting STEAM through digital literacy. From Figure 2, One hundred and five participants indicated that most schools lacked electricity, eighty-five indicated that teacher training could improve teaching and learning, seventy-nine indicated that there were no computers available in the classroom to aid in teaching and learning, and seventy-five indicated that they lacked technological knowledge and computer science education. The findings are depicted and supported by Mabunda and Nkosi emphasize the importance of STEAM integration for sustainable community development, citing its ability to cultivate critical thinking skills and promote inclusive growth.⁴⁰

DISCUSSIONS

The findings of this study provide valuable insights into the integration of STEAM (Science, Technology, Engineering, Arts, and Mathematics) education for sustainable community development, particularly in enhancing access and equity for marginalized communities. These results are discussed within the context of the identified research themes and sub-themes from Table 1.

Theme 1: Integration of STEAM Education for Sustainable Community Development

The results indicate a strong consensus among participants regarding the importance of integrating STEAM education into community development initiatives. This finding resonates with the literature, which emphasizes the transformative potential of STEAM education in promoting innovation, critical thinking, and inclusive growth.⁴¹ By equipping learners with interdisciplinary skills and knowledge, STEAM education emerges as a catalyst for driving sustainable development within South Africa's 4IR landscape.

⁴⁰ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa."

⁴¹ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa."

Sub-theme: Enhancing Access and Equity in STEAM Education Access for Marginalized Communities

Despite the recognition of STEAM's importance, the findings also reveal significant barriers to access and equity, particularly for marginalized communities. Challenges such as the lack of electricity in schools, insufficient teacher training, and the absence of computers in classrooms hinder the effective implementation of STEAM education initiatives.⁴² This highlights the urgent need for targeted interventions to address these disparities and ensure equitable access to quality STEAM education for all learners. Furthermore, the findings highlight the critical role of policy frameworks and strategic initiatives in promoting access and equity in STEAM education. The Department of Basic Education's national policy framework for STEM education outlines a comprehensive strategy for promoting inclusivity and addressing disparities in educational opportunities.⁴³ However, further efforts are needed to translate these policy commitments into tangible actions that benefit marginalized communities. The results of this study emphasize the importance of integrating STEAM education into community development efforts and addressing access and equity challenges to ensure that all learners have the opportunity to benefit from STEAM education in South Africa's 4IR landscape.

The findings from Figure 2 highlight several key insights into the needs and preferences of participants regarding the integration of digital skills and technical competencies into teaching and learning practices, as well as their interest in enrolling in short courses and experiencing digitalization within the STEAM education framework. 105 participants expressed a need for workshops to learn digital skills underscoring the growing recognition of the importance of digital literacy in the 4IR era. This finding resonates with existing literature, which emphasizes the essential role of digital skills in preparing individuals for the challenges and opportunities of the digital age.⁴⁴

Similarly, the response from 100 participants indicating a need for the introduction of technical skills in teaching and learning aligns with research highlighting the significance of technical competencies in STEAM education. Studies by Schmidt and Bagaka emphasize the importance of equipping educators with technical skills to effectively integrate technology into instructional practices and enhance student learning experiences.⁴⁵ Moreover, the interest shown by 103 participants in enrolling in short courses registered by the education department suggests a strong desire for continuous professional development and upskilling opportunities. This finding is consistent with the literature on lifelong learning, which emphasizes the importance of ongoing education and skill development in navigating the evolving demands of the 4IR.⁴⁶ Lastly, the response from 100 participants expressing interest in experiencing the digitalization of STEAM skills underscores the potential of digital technologies to enhance teaching, learning, and community engagement within the STEAM education framework. Research by Huijser et al. highlights the transformative impact of digitalization on education, emphasizing its potential to facilitate collaborative learning experiences and foster innovation in teaching and learning practices.⁴⁷

The findings presented in Figure 2 shed light on the challenges faced by participants regarding the availability of resources and training opportunities necessary for effective STEAM integration in educational settings. These findings underscore the critical need for infrastructure development, teacher training, and technological literacy to facilitate the successful implementation of STEAM education programs.

The response from 105 participants indicated that most schools lack electricity highlighting a significant infrastructural barrier that hinders the integration of technology into teaching and learning

⁴² ITU, *Measuring Digital Development: ICT Price Trends 2021*; UNESCO, *Teacher Training in the Digital Age: A Global Framework for Professional Development* (Paris, France, 2020).

⁴³ Department of Basic Education, *National Policy Framework for STEM Education in South Africa 2020-2030*.

⁴⁴ World Economic Forum, *The Future of Jobs Report 2020* (Geneva, Switzerland, 2020).

⁴⁵ Schmidt and Bagaka, "Integrating Technology into Science and Mathematics Instruction in South African Schools: Opportunities and Challenges."

⁴⁶ European Commission, *Digital Education Action Plan: Resetting Education and Training for the Digital Age* (Brussels, Belgium, 2020).

⁴⁷ H Huijser, D. Westerheijden, and L. Goedegebuure, "The Digitalization of Higher Education: Potential Impacts on Access, Quality, and Efficiency," *Higher Education Quarterly* 76, no. 1 (2022): 3–20.

practices. This finding aligns with existing literature on the digital divide, which emphasizes the importance of access to electricity and reliable internet connectivity in enabling equitable access to digital resources and educational opportunities.⁴⁸ Moreover, the finding that 85 participants believe teacher training could improve teaching and learning indicates the importance of professional development in enhancing educators' pedagogical skills and capacity to effectively integrate STEAM principles into instructional practices. Research by UNESCO emphasizes the need for comprehensive teacher training programs that equip educators with the knowledge and skills necessary to leverage digital technologies and promote innovative teaching approaches.⁴⁹ Additionally, the responses from 79 participants indicating the absence of computers in classrooms and 75 participants lacking technological knowledge and computer science education highlight the critical shortage of resources and expertise needed to support STEAM education initiatives. This finding resonates with Mabunda and Nkosi's emphasis on the importance of STEAM integration for sustainable community development, as access to technology and digital literacy skills are essential for fostering innovation, critical thinking, and inclusive growth.⁵⁰

The findings indicate the multifaceted challenges facing STEAM education in South Africa, including infrastructural limitations, inadequate teacher training, and the lack of technological resources and expertise. Addressing these challenges requires coordinated efforts to improve infrastructure, enhance teacher capacity, and promote digital literacy, thereby enabling equitable access to quality education and advancing sustainable community development. The importance of addressing the digital skills gap, integrating technical competencies into educational practices, providing opportunities for continuous professional development, and harnessing digital technologies to enhance STEAM education and community engagement in the 4IR era was revealed.

RECOMMENDATIONS

To ensure the competitiveness and relevance of STEAM education in South Africa, it may be crucial to foster strategic alliances with organizations, professionals, and international educational institutions. This collaboration could facilitate the exchange of resources, best practices, and expertise, ultimately enhancing the quality and effectiveness of the program. One effective approach to achieving this goal is to participate in international STEAM education conferences and projects. These platforms provide a valuable opportunity to stay abreast of the latest developments in trends and technology, thereby enabling South Africa to stay competitive and aligned with international standards. By engaging in international collaborations, South Africa could establish a robust STEAM education system that prepares learners for the challenges and opportunities of the Fourth Industrial Revolution. This system may prioritize the development of skilled labor, innovative thinking, and sustainable development. To achieve this, it might be essential to integrate international best practices and expertise into the local curriculum, ensuring that learners are equipped with the necessary skills to thrive in a rapidly evolving global landscape.

The benefits of international collaboration in STEAM education are multifaceted. It may allow for the sharing of resources and expertise, enabling South Africa to leverage the strengths of international partners and enhance the quality of its own program. It might provide a platform for the exchange of best practices, enabling local educators to adopt innovative approaches and stay updated on the latest trends and technologies. International collaboration could foster a culture of innovation and creativity, encouraging students to think globally and develop solutions that address local and global challenges. It may be further recommended that establishing strong alliances with international organizations, professionals, and educational institutions could be crucial for the development of a competitive and relevant STEAM education system in South Africa. By participating in international conferences and projects, South Africa stays abreast of the latest developments in STEAM education

⁴⁸ ITU, *Measuring Digital Development: ICT Price Trends 2021*.

⁴⁹ UNESCO, *Teacher Training in the Digital Age: A Global Framework for Professional Development*.

⁵⁰ Mabunda and Nkosi, "STEAM Integration for Sustainable Community Development: Insights from South Africa."

and establishes a robust system that prepares students for the challenges and opportunities of the Fourth Industrial Revolution.

CONCLUSION

In light of the 4IR, enhancing STEAM education in South Africa is critical. By strategically addressing key areas, South Africa could equip its learners with the skills needed to thrive in a technologically driven world. Prioritizing ongoing training and professional development for educators might be essential. Equipping teachers with up-to-date knowledge and pedagogical techniques ensures effective STEAM content delivery, directly enhancing student engagement and academic performance. Additionally, a thorough curriculum review may be imperative. Integrating comprehensive STEAM components fosters interdisciplinary thinking and problem-solving, preparing learners for 4IR demands.

Adequate infrastructure, including well-equipped laboratories, technology resources, and conducive learning spaces, maybe a fundamental need. Investment in infrastructure ensures students have access to hands-on experiences and cutting-edge tools, bridging the digital divide. Outreach initiatives, such as workshops, competitions, and industry collaborations, spark student interest in STEAM fields. Public-private partnerships facilitate real-world exposure, encouraging innovation and lifelong learning.

Active engagement from parents, caregivers, and community members creates a supportive ecosystem. Encouraging parental participation in school activities and decision-making enhances student motivation and success. Policymakers must prioritize STEAM initiatives, allocating dedicated funding and resources. Ensuring equitable access, particularly for under-resourced areas, is crucial for reducing disparities and promoting inclusivity. Robust monitoring and evaluation mechanisms track progress, identify challenges, and inform evidence-based decision-making. Continuous improvement relies on data-driven insights and adaptive strategies. Promoting gender balance in STEAM education encourages diverse perspectives and talent, ensuring all students can participate fully and contribute meaningfully. Engaging with international partners and aligning with global educational standards fosters best practices and cross-cultural exchange, enhancing South Africa's competitiveness. A well-rounded STEAM education system directly contributes to sustainable development goals, positioning South Africa as a leader in the 4IR.

Implementing these recommendations could bridge the digital divide, cultivate a skilled workforce, spur innovation, and contribute to sustainable development. By fostering a robust, inclusive, and forward-thinking STEAM education system, South Africa could drive socio-economic progress and ensure a prosperous future for all its citizens.

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Dr. Limkani Sincuba is a distinguished Post-Doctoral Fellow in the Department of Education at Walter Sisulu University (WSU). She holds a Ph.D. in Education from Walter Sisulu University, South Africa. With over a decade of experience in educational research and teaching, Dr. Sincuba has made significant contributions in both urban and rural educational settings. Her research focuses on enhancing trilingual pedagogy in the teaching of dramatic arts, and her work has been recognized for its substantial impact on educational equity and inclusivity. Dr. Sincuba is deeply committed to her work and draws strength and support from her family, including her husband, Mthandwa Sincuba, and their adopted children: Sihle Zitywana, Loyiso Situnda, Philile Maseti, Lelethu Gwaji, Aphiwe Mtendeni, and Ntyantambo. She also acknowledges the support of her sister, Bongisa Mzilikazi, and Amanda Ntuli. In her free time, Dr. Sincuba enjoys reading historical novels and volunteering at local community centers, reflecting her dedication to both personal enrichment and community service.