



Education reimaged: South Africa's journey through the 4IR and beyond

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The Fourth Industrial Revolution (4IR) is transforming global education, posing significant challenges and opportunities for higher education in South Africa. This revolution is driving a shift in teaching methodologies, curriculum design, and the integration of advanced technologies. This study systematically investigates how South Africa's higher education sector is adapting to the demands and opportunities of the 4IR. The research focuses on South African higher education institutions operating within a complex socio-economic environment. These institutions are navigating historical disparities and emerging technological trends to remain competitive and inclusive. Utilising the PRISMA framework for systematic reviews, this study synthesises existing literature on the adoption of 4IR technologies, such as artificial intelligence, big data analytics, and blockchain in higher education. Peer-reviewed articles, conference papers, and official reports published between 2010 and 2024 were critically evaluated to identify themes of technological integration, curriculum reform, and policy development. The review reveals a progressive integration of 4IR technologies across South African institutions. Key findings indicate significant curriculum updates to include 4IR competencies, ongoing faculty training to improve digital literacy, and the development of strategic partnerships with industry. However, persistent challenges such as resource constraints, digital inclusivity issues, and gaps in policy frameworks continue to hinder full adaptation.

Contribution: Strategic investments in digital infrastructure, inclusive policy frameworks, and continuous professional development are critical for sustaining South Africa's higher education transformation in the 4IR era. Addressing these challenges will ensure that institutions are well-equipped to encourage innovation and meet the evolving demands of the digital economy.

Keywords: Fourth Industrial Revolution; higher education; South Africa; artificial intelligence; systematic literature review.

Introduction

The education system in South Africa is currently undergoing significant transformations because of the challenges and opportunities presented by the Fourth Industrial Revolution (4IR) and beyond. An important factor to consider is the influence of the 4IR on the field of education economics. This is especially significant when considering the movement of students and the incorporation of emerging technology (Obidile, Oluchi & Ikpat 2023; Sekiyama 2020). The coronavirus disease 2019 (COVID-19) outbreak has accelerated the urgency to understand how global crises, such as this one, impact the progress of the 4IR in Southern Africa (Ojo-Fafare, Aigbavboa & Thwala 2021). The competence of teachers in 4IR technologies and their integration into the curriculum is key (Alshaikh 2022).

South African Higher Education Institutions (HEIs) are facing challenges in adopting the 4IR, as highlighted by Lubinga, Maramura and Masiya (2023). This emphasises the need for educators to possess the requisite skills and knowledge to navigate this new era. Cobo and Rankhumise (2022) state that the promotion of digital entrepreneurship in South Africa is a prominent area of interest. This highlights the importance of human capital in driving innovation and economic development. However, it is necessary to re-evaluate African-centred intellectual traditions inside formal education in order to narrow the divide with the present industrial transformation (Fomunyan 2020).

Literature review

Addressing gaps in existing research and the need for this study

There are significant gaps in research regarding how South African Higher education adapts to and transforms in response to the 4IR. Although previous research has investigated a variety of

aspects of higher education in South Africa, it frequently fails to consider the comprehensive integration of 4IR technologies within the educational framework, particularly in the context of curriculum development and employability skills. For instance, Bozalek and Boughey (2012) emphasise the historical misrepresentation of higher education issues, alleging that contemporary analyses may continue to be influenced by antiquated paradigms that neglect the rapid technological advancements of the 4IR. Additionally, Mtotywa et al. (2022) address the socio-economic implications of the 4IR but do not provide a comprehensive examination of the specific impact of these changes on the educational landscape and the preparedness of graduates for the changing job market.

Furthermore, although certain studies, including those conducted by Nwosu et al. (2023) and Gudyanga (2023), have begun to examine the role of 4IR tools in improving teaching and learning, there is a scarcity of systematic literature reviews that synthesise these findings to offer a comprehensive understanding of the challenges and opportunities presented by the 4IR in South African higher education. This is especially important because the educational sector is required to adjust to the requirements of a rapidly evolving economy that is defined by automation and digitalisation (Alphonse 2023). The focus on employability skills, as articulated by Winterton and Turner (2019), emphasises the urgent need for HEIs to partner with industry stakeholders to maintain the relevance and responsiveness of curricula to labour market demands.

The historical context of South African higher education, which has been influenced by apartheid-era policies that continue to influence current educational practices and access, further emphasises the necessity of this study (Bozalek & Boughey 2012). The significance of incorporating local knowledge and perspectives into educational frameworks is emphasised by the call for decolonisation of the curriculum (Ajani & Gamede 2021). This is important for the development of a more inclusive and equitable higher education system in the 4IR era. Furthermore, the examination of workplace dynamics, including the experiences of academic staff with respect to workplace bullying (Badenhorst & Botha 2022), emphasises the significance of a supportive environment that can facilitate the successful implementation of 4IR strategies in educational institutions.

Contextualisation of the Fourth Industrial Revolution globally and in South Africa

The 4IR signifies a significant global shift characterised by the fusion of digital, physical and biological technologies, leading to transformative changes in various sectors (Marwala 2023).

This revolution, often associated with the concept of Industrial 4.0, emphasises the integration of advanced technologies like the Internet of Things (IoT) into manufacturing processes

(Wang et al. 2016). The 4IR is not merely an extension of previous industrial revolutions but a distinct era marked by its scale, scope and complexity (Marwala 2023).

The implementation of 4IR technology in South Africa poses both obstacles and opportunities, especially in HEIs (Lubinga et al. 2023). The nation is confronted with the imperative to provide educators with the key competencies to manage this emerging technology environment. A strong framework for the development of educators' competencies is required because of the integration of emerging technologies in education. Mulyadi et al. (2023) have emphasised that technology mastery is significantly influenced by teacher competence, which implies that educators' skills in this domain will be significantly improved through targeted training programs. Furthermore, Truskavetska et al. emphasise the pressing requirement of professional development initiatives that serve as a bridge between educators' preparedness and the rapid pace of technological advancements (Truskavetska et al. 2024). To cultivate active learning environments and improve pedagogical efficacy, Silva-Díaz et al. propose comprehensive training pathways that integrate emerging technologies (Silva-Díaz et al. 2023). Also, educators must be equipped with a multifaceted approach that includes continuous professional development and hands-on training in order to thrive in a technology-rich educational landscape (Valverde-Berrococo et al. 2021).

The 4th Industrial Revolution (4IR) has a wide-ranging impact on South African society, going beyond just schooling. It brings about significant changes in areas such as manufacturing and labour conditions, as noted by Mtotywa et al. (2022b) and Min et al. (2019). Nevertheless, there is a divergence of viewpoints regarding the essence of this revolution, since several experts cast doubt on the presence of a discernible technological revolution (Moll 2023).

Hlatshwayo (2022) and Bosch and Rossouw (2021) highlight the wide-ranging effects of technical improvements within several sectors, particularly the South African public transport system and the strategic placement of industries in the context of the 4IR. In addition, the importance of educators in utilising blended learning methods to improve STEM (Science, Technology, Engineering, Mathematics) education in the context of the 4IR is vital (Naidoo & Singh-Pillay 2020a). STEM is an interdisciplinary approach that integrates these fields to encourage analytical thinking, creativity, and problem-solving abilities. STEM education is instrumental in the preparation of students for innovative careers and the promotion of economic growth and technological advancements. In order to adapt to the changing technological environment, a comprehensive evaluation is required to determine the preparedness of global companies for the 4IR (Tripathi & Gupta 2021).

As South Africa progresses through the 4IR, it is key to consider this technological change in the context of the country's distinct socio-economic environment. Gaining a

comprehensive understanding of the worldwide and regional consequences of the 4IR is key for rethinking educational institutions to equip individuals with the necessary skills for the challenges of the digital era.

The influence of artificial technologies on higher education

The 4IR is distinguished by the rapid integration of advanced technologies, particularly artificial intelligence (AI), into a variety of sectors, including education. This transformation presents both opportunities and challenges for HEIs, particularly in South Africa, where it is important to adapt to these technologies to improve educational outcomes and maintain relevance in a globalised world. Innovative pedagogical approaches that have the potential to transform the educational landscape are exemplified by the emergence of AI tools, such as ChatGPT. The integration of AI technologies in education has been demonstrated to improve learning outcomes and experiences.

For example, Nkosi acknowledges the importance of South African HEIs adopting 4IR technologies to improve educational infrastructure and resolve existing sectoral challenges (Nkosi 2023). The review emphasises that the implementation of digital tools could improve personalised learning experiences, thereby improving student engagement and academic performance. Chawla et al. assert that simulation models and digital technologies can markedly improve training and educational methodologies, especially in specialised domains like neurosurgery (Chawla et al. 2022). These findings highlight the significance of utilising technology to develop more efficient and captivating educational settings.

The transition to a technology-enhanced educational framework presents several challenges. Oyetade, Zuva and Harmse (2020) argued that despite the increasing popularity of e-learning and mobile learning, the effective implementation of these technologies is impeded by factors such as affordability, access to reliable internet, and the absence of technical support for educators. This is especially pertinent in the South African context, where disparities in technology access can exacerbate pre-existing inequalities in education. Additionally, Ruiz-Ramírez, Olarte-Arias and Morales (2021) emphasises the challenges to the integration of technological tools in health education, emphasising the need of additional research into the facilitators and impediments that influence the utilisation of technology in educational environments (Ruiz-Ramírez et al. 2021).

Schönberger (2023) stated that the analysis of ChatGPT in higher education, AI has the potential to improve learning by providing personalised feedback and support. However, it also raises concerns about academic integrity and the potential for over-reliance on technology. This duality requires meticulous evaluation of the integration of AI tools into curricula, ensuring they augment rather than supplant conventional educational methods. Ngoc et al. (2020) suggested that the successful integration of emerging technologies in education is contingent upon a variety of

factors, such as educators' attitudes towards these technologies and their readiness to adopt them (Ngoc et al. 2020). The results of Männistö et al. (2019) are consistent with this, as they have indicated that digital collaborative learning methods can be as effective as traditional approaches when educators are adequately trained and supported in their implementation.

The importance of the higher education sector in adapting to these changes

In South Africa in particular, the higher education sector is necessary to the country's ability to adjust to the worldwide effects of the 4IR. In the context of the 4IR, which involves the integration of digital technologies, higher education institutions have the responsibility of equipping students with the necessary skills to meet the changing expectations of the workforce (Nwosu et al. 2023b). In order to adapt to the 4IR, it is vital to reassess educational curricula and teaching methods in order to provide learners with the key skills required in this era of digital advancement (YÜCeol 2021).

Higher education institutions play a key role in assisting South Africa's transition to the 4IR. Proficiency in 4IR technologies is key for educators in these institutions to efficiently transmit knowledge and skills to students. It is key for higher education curricula to be adaptable in order to meet the requirements of the 4IR and ensure that graduates are well-prepared to succeed in a constantly evolving technological environment (Truong & Diep 2023).

However, the higher education sector has a key role in cultivating employability skills that are required for achieving success in the 4IR. Higher education institutions can improve students' preparedness for the changing job market by incorporating industry-specific skills and knowledge into their curriculum (Obidile et al. 2023). Ensuring the relevance and efficacy of educational programmes in higher education is key for anticipating and addressing the evolving needs of industry in the 4IR (Odetoeye & Odetoeye 2021).

Adaptation of higher education to the Fourth Industrial Revolution

For higher education systems, the 4IR presents both opportunities and challenges, particularly in South Africa, where disparities in quality and access persist. Strategies such as curriculum reform, faculty development and collaboration with industry are indispensable in order to rectify these disparities and guarantee that all students capitalise on 4IR advancements. By aligning educational outcomes with the changing demands of the labour market and cultivating an environment that encourages innovation and entrepreneurship, these strategies can establish a more inclusive and accessible education system.

In the context of 4IR, 'Curriculum Reform' is a critical strategy for promoting educational equity. Educational institutions can significantly improve the preparation of students for the

complexities of contemporary workplaces by modifying curricula to incorporate digital literacy, critical thinking, and problem-solving abilities. Research suggests that the relevance of education and its ability to adapt to industry demands can be significantly improved by involving external stakeholders in the development of curricula (Fagrell et al. 2020). For example, Fagrell et al. (2020) emphasised the significance of stakeholder perspectives in curriculum development, promoting a collaborative approach that aligns educational objectives with market demands (Fagrell et al. 2020). This alignment not only improves employability but also guarantees that diverse student populations have access to pertinent skills and knowledge, thereby reducing inequality in educational outcomes (Collet, Hine & Plessis 2015).

Faculty development is an additional important element in the establishment of an inclusive education system. To effectively instruct students on emerging technologies and pedagogical methods, faculty members must possess the necessary skills and knowledge. Educators can cultivate a culture of lifelong learning by participating in continuous professional development programs, which can assist them in remaining informed about industry trends and pedagogical innovations (Ramraj 2023). Additionally, engaging faculty in research and industry collaborations can improve their teaching practices and offer students practical insights. Mykhaylyova emphasised that proficient administration of higher education institutions, encompassing faculty development, is crucial for cultivating a cooperative educational atmosphere that satisfies the requirements of both students and industry (Mykhaylyova 2023).

The integration of practical skills into academic programs is facilitated by Collaboration with Industry, which serves as a bridge between education and the labour market. Universities and industries are able to improve the quality and relevance of education by establishing partnerships that offer students the chance to participate in internships, cooperative programs, and hands-on projects (Wedekind & Mutereko 2016). These partnerships not only improve the employability of students but also allow educational institutions to modify their programs in response to technological advancements and labour market changes (Ramraj 2023). For instance, Nikonova et al. (2016) demonstrated that the employability of graduates can be improved by the establishment of social partnerships between universities and industrial enterprises, which can result in a more precise alignment of educational outcomes with employer expectations. In addition, the establishment of entrepreneurial incubators within universities can encourage innovation and entrepreneurship, thereby enabling students from a variety of backgrounds to participate in the 4IR economy (Awad & Salameh 2023).

Overview of social transformation trends influenced by the Fourth Industrial Revolution in the educational sector

The 4IR has led to significant social transformation trends in the educational sector globally and in South Africa. The

disruptive technologies associated with the 4IR are reshaping teaching and learning practices, necessitating a deeper understanding of the facilitating conditions and social contexts that influence the adoption of these technologies (Oke & Fernandes 2020). The COVID-19 pandemic has accelerated the digital transformation of education, emphasising the importance of leveraging 4IR technologies to improve access and excellence in learning (Mhlanga & Moloji 2020).

In South African higher education, a 20-year journey influenced by global trends and national development goals has resulted in significant changes in teaching and learning practices, driven by the demands of a digitally networked world (Ng'ambi et al. 2016). The integration of technology-improved teaching and learning approaches has become key in preparing students for the challenges of the 4IR (Saura, Reyes-Menendez & Bennett 2019). However, the influence of the 4IR on organisational culture within educational institutions highlights the need for effective leadership and education strategies to navigate these transformations (Singaram & Mayer 2022). Technological developments in tertiary education are reshaping traditional teaching methods, underscoring the importance of understanding the underlying technology trends driving this transformation (Truong & Diep 2023). Teachers' acceptance of 4IR-related technologies is key for successful adoption in educational settings, emphasising the need for educators to embrace tools such as augmented reality (AR), robotics and cloud computing in their teaching practices (Jalil, Rajakumar & Zaremohzzabieh 2022).

Research question: *How is the higher education sector in South Africa adapting to the demands and opportunities of the Fourth Industrial Revolution?*

Research objective: To systematically review and thematically analyse the existing literature on the adaptation and transformation of the South African higher education sector in response to the 4IR.

Research methods and design

Overview of the PRISMA method

The PRISMA framework facilitates systematic reviews and meta-analyses with precision, transparency, and rigour. It is excellent for investigating the way the higher education sector of South Africa adjusts to the 4IR. PRISMA facilitates the analysis of 4IR applications in higher education in the face of socio-economic challenges by methodically gathering, assessing, and summarising evidence. This structured methodology guarantees the reliability and replicability of the results obtained from the synthesis of literature regarding the impact of 4IR (Rethlefsen et al. 2021).

By adopting the PRISMA method, the article aims to thoroughly evaluate the impact of 4IR technologies on higher education, especially in places that are dealing with major pedagogical and technological difficulties. This system guarantees a transparent and unambiguous reporting process,

from the initial identification of studies to their final inclusion, by employing a standardised checklist and flowchart. An exhaustive methodology is key for fully understanding the scope and intricacy of present-day research, identifying shortcomings and establishing sound conclusions that can inform future educational strategies and policymaking in the South African context (Rethlefsen et al. 2021).

Selection criteria and databases used

This systematic literature review on the adaptation of higher education in South Africa to the 4IR employed several databases, including Scopus and Google Scholar, to guarantee the inclusion of peer-reviewed articles of high quality. Scopus was chosen due to its comprehensive repository and detailed citation tracking, which effectively captured the diverse effects of 4IR. Google Scholar's extensive coverage included grey literature and dissertations, whereas Web of Science emphasised interdisciplinary research. ERIC was chosen for its significance in educational policy research. The research strategy focussed on studies investigating the adaptation of higher education to 4IR technologies in South Africa.

The selection of keywords and phrases such as 'Fourth Industrial Revolution', '4IR', 'higher education', 'South Africa', 'digital transformation' and 'systematic literature review' was deliberate in order to cover a broad spectrum of relevant applications and effects. This intentional methodology guarantees the incorporation of research that offers a valuable understanding of how HEIs are addressing the problems and opportunities brought about by the 4IR. This includes examining curriculum changes, instructional tactics, infrastructure developments and policy adjustments. The rationale for utilising these databases is their capacity to offer a thorough, multidisciplinary and excellent collection of research. This methodology ensures that the evaluation includes a broad range of studies, allowing for a thorough and trustworthy analysis of how the higher education sector in South Africa is adapting to the 4IR landscape. This systematic literature review intends to conduct a comprehensive and informative study of South Africa's progress in the higher education environment during the 4IR. It will achieve this by strictly following stringent selection criteria and utilising the strengths of several databases.

The following search string was employed to extract the relevant records. ('Fourth Industrial Revolution' OR '4IR' OR 'Industry 4.0') AND ('higher education' OR 'universities' OR 'tertiary education') AND ('South Africa') AND ('adaptation' OR 'transformation' OR 'integration' OR 'implementation' OR 'digital transformation' OR 'technology adoption' OR 'educational technology') AND ('challenges' OR 'opportunities' OR 'strategies' OR 'responses' OR 'impact').

Selection and exclusion criteria

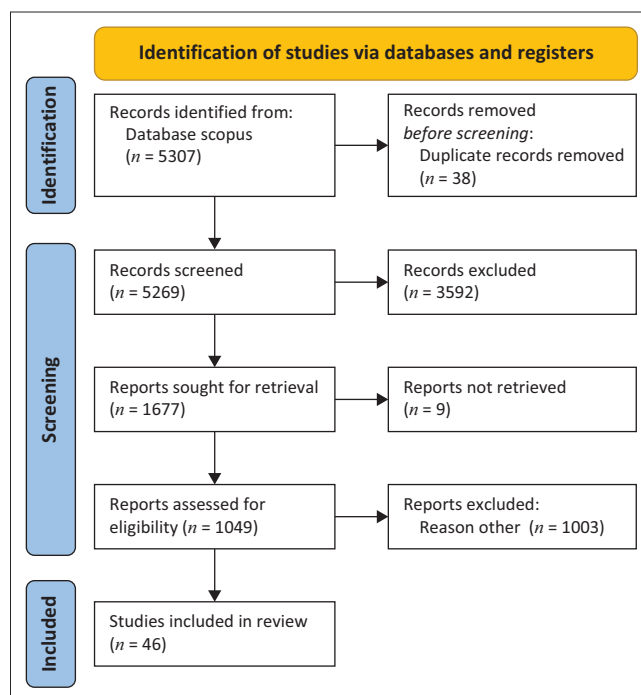
The selection criteria focussed on studies examining the integration of 4IR technologies in South Africa's higher

education sector. Eligible research included empirical studies, theoretical analyses and reviews that addressed adaptation strategies, challenges and opportunities. Only peer-reviewed journal articles, conference papers and official reports written in English between 2010 and 2024 were included. Studies without empirical evidence, significant theoretical analysis or those unrelated to 4IR in South African higher education were excluded, along with grey literature and opinion pieces.

The PRISMA framework guided the review process to ensure transparency. Initial database searches yielded 5307 documents, with 5269 entries meeting the 2018–2024 range. After relevance screening, 1677 records remained, of which 1049 full-text articles were assessed. A comprehensive review led to the elimination of 581 articles, leaving 468 focussed on South Africa. Ultimately, 46 studies were included in the final evaluation, demonstrating a systematic and reproducible approach (Figure 1).

Use of ATLAS.ti for thematic analysis

The use of ATLAS.ti in conducting thematic analysis for the systematic review offers a sophisticated methodological tool to efficiently handle, categorise and examine the qualitative data collected from the chosen studies. This software facilitates the efficient identification, analysis and reporting of patterns in data. It is key for synthesising complex information about the adaptation strategies and challenges encountered by South Africa's higher education sector in the context of the 4IR.



Source: Rethlefsen, M.L., Kirtley, S., Waffenschmidt, S., Ayala, A.P., Moher, D., Page, M.J. et al., 2021, 'PRISMA-5: An extension to the PRISMA statement for reporting literature searches in systematic reviews', *Systematic Reviews* 10(1), 1–19. <https://doi.org/10.1186/s13643-020-01542-z>

FIGURE 1: Preferred reporting items for systematic reviews and meta-analyses 2020 flow diagram.

Researchers can utilise ATLAS.ti to systematically organise and visualise extensive datasets, guaranteeing a thorough comprehension of the dominant patterns and topics in the current literature. This methodological approach allows for the condensation of extensive qualitative data into significant insights that are key for addressing the research question: How is the higher education sector in South Africa adapting to the demands and opportunities of the 4IR?

The software's capacity to provide a thorough analysis of textual data corresponds to the study's need to reveal comprehensive insights into the disruptive effects of 4IR technologies on higher education (Friese 2019; Sotiriadou, Brouwers & Le 2014).

Ethical considerations

This article followed all ethical standards for research without direct contact with human or animal subjects.

Results

Employing the thematic analysis methodology proposed by Soratto, Pires and Friese (2020), 46 publications were evaluated in three phases: pre-analysis, material exploration and interpretation. The articles were reviewed and encoded by researchers using ATLAS-ti software during the pre-analysis phase. Key patterns and themes that were specifically focussed on the sector's response were identified during the material exploration phase. The analysis stage identified opportunities, challenges, and adaptation strategies. This method yielded insights into institutional strategies, emphasising the sector's adaptation to technological innovations and changing requirements.

Presentation of the findings from the systematic review

Figure 2 presents a word cloud that visually represents the frequency of keywords in the literature evaluated in this systematic literature review. The visualisation highlights the key terms that are vital for understanding the adaptation of the higher education sector in South Africa to the demands and prospects of the 4IR. The word cloud prominently displays terms such as 'Innovation', 'Healthcare', 'Competitive Advantage' and 'Technology' in larger fonts, indicating their importance in the research. The literature predominantly centres on the importance of innovation and technology in higher education, emphasising the influence of technological progress on educational methodologies and competitive superiority. E-learning, digital healthcare, and COVID-19 illustrate the trend towards online services and digital technologies that is being driven by global events. These terms emphasise the increasing transition from conventional methods to digital platforms in the fields of education and healthcare.

The frequent occurrence of terms like "IoT", "Robotics", and "Digital innovations" provides the significance of emerging



FIGURE 2: Word cloud.

technology in transforming educational paradigms. However, the terms "Uncertainty" and "Disruption" accurately depict the difficulties and ever-changing environment associated with incorporating new technology into the education sector. The examination of the word cloud exposes a diverse and complex study landscape, highlighting the complex interaction of innovation, technology, and educational practices. The word cloud demonstrates a complex and diverse research area. It illustrates the interaction between educational practices, technology, and innovation. The emphasis on digital healthcare and e-learning demonstrates a progressive mindset, acknowledging the capacity of digital technologies to improve educational results.

Table 1 presents a concise summary of the extracted codes organised into cohesive themes. It offers a systematic overview of the significant findings regarding the adaptation of the higher education sector in South Africa to the demands and opportunities of the 4IR. Each finding is supported by a quote from the reviewed literature. The results, derived from the comprehensive examination and analysis, are organised into four primary themes that capture the core of this adaptation. These themes encompass technology integration, curriculum and skills development, industry and policy development and challenges and opportunities.

Discussion

Technology integration

Technology integration plays a key role in South Africa's higher education sector as it adapts to the demands and opportunities of the 4IR. The use of AI in education has been extensively studied, focusing on its ability to provide personalised learning experiences and revolutionise teaching and learning methods (Zawacki-Richter et al. 2019). The use of large-scale data and AI in the field of education introduces novel issues and avenues, influencing research, policy formulation and industry methodologies (Luan et al. 2020).

The integration of AI technology in education can improve the acquisition of knowledge and enable focused instruction, thus broadening the reach of education (Hua 2022). When integrating technology into education systems, it is important to also address the digital infrastructure. There has been a

TABLE 1: Main themes, the codes and short quotes.

| Main themes | Codes | Short quotes |
|-----------------------------------|---------------------------|---|
| Technological integration | Artificial intelligence | 'Against this backdrop, the current study reviewed, discussed, and synthesised the applications, prospects, and challenges of artificial intelligence (AI), robotics, and blockchain at given higher education institutions (HEIs) between 2013 and 2019 as reported by 26 selected journal articles' 'The contribution of this work lies in the statistical validation of the theoretical framework, which provides insight regarding the role of institutional pressures on resources and their effects on the adoption of big data analytics-powered artificial intelligence ...' |
| | Blockchain | 'Thirdly, some of the applications of blockchain relate to digital grading, digital credentialing and digital certification, and to real-time contracting and time stamping of learning' |
| | Bid data | 'To address this gap, our study employs institutional theory and resource-based view theory to elucidate the way in which automotive firms configure tangible resources and workforce skills to drive technological enablement and improve sustainable manufacturing practices and furthermore develop circular economy capabilities' |
| | Digital infrastructure | 'Much has been written about the Fourth Industrial Revolution's (4IR) contributions to and its impact on higher education (HE)' |
| Curriculum and skills development | Curriculum reform | 'The objective of this research is to appraise the level of entrepreneurial activity in South Africa and to identify the challenges to implementation of the 4IR that obstruct the leveraging of 4IR technologies to increase entrepreneurial activity in the country' |
| | Faculty training | 'The significance of big data analytics-powered artificial intelligence (AI) and how this affects sustainable manufacturing and circular economy capabilities under the moderating effects of organisational flexibility and industry dynamism' |
| | Student preparedness | 'These results signal the need to ensure a synchronised effort by all relevant spheres of government to address the 4IR implementation challenges and improve entrepreneurial activity for South Africa's economy' |
| | Skills improvement | 'To address this gap, our study employs institutional theory and resource-based view theory to elucidate the way in which automotive firms configure tangible resources and workforce skills to drive technological enablement and improve sustainable manufacturing practices and furthermore develop circular economy capabilities' |
| Industry and policy engagement | Industry collaboration | 'Partnerships with industries to ensure curriculum relevance and provide practical exposure to students' |
| | Policy development | 'Development of policies and frameworks to guide the integration of Fourth Industrial Revolution principles' |
| | Institutional pressures | 'The contribution of this work lies in the statistical validation of the theoretical framework, which provides insight regarding the role of institutional pressures on resources ...' |
| | Governance frameworks | 'The role of institutional pressures on resources and their effects on the adoption of big data analytics-powered artificial intelligence ...' |
| Challenges and opportunities | Implementation challenges | 'The objective of this research is to appraise the level of entrepreneurial activity in South Africa and to identify the challenges to implementation of the 4IR ...' |
| | Inclusivity | 'Efforts to ensure that all students, regardless of background, benefit from technological developments' |
| | Accessibility | 'These results signal the need to ensure a synchronised effort by all relevant spheres of government to address the 4IR implementation challenges ...' |
| | Resource constraints | 'To address this gap, our study employs institutional theory and resource-based view theory to elucidate the way in which automotive firms configure tangible resources ...' |

focus on the expanding importance of digital data and the key role of data infrastructures in education. This highlights the need for energy infrastructure to meet the increasing digital requirements in schools and educational systems (McKenzie 2023).

However, the integration of AI and IoT technologies has been suggested, highlighting the possibility of sophisticated systems in many educational fields, such as health education and music instruction (Zhao & Fu 2022). The conversation about incorporating technology into education also includes podcasting. In this context, digital infrastructures in education refer to the examination of online platforms that are changing universities and discussions about employability.

It also involves studying how big data and algorithms interact with governance (Brehm 2022). The utilisation of AI in diverse areas including haematology training and sports education highlights the prospects and difficulties linked to incorporating AI into specialised professions (Chai, Hayat & Flaherty 2022).

Curriculum and skills development

Within the framework of South Africa's higher education system, there are several prominent issues that are key for curriculum and skills development in response to the demands and opportunities presented by the 4IR. Curriculum reform is essential to synchronise educational offerings with the demands of the 4IR (Lubinga et al. 2023). This reform should prioritise not only the transmission of knowledge but also the development of skills in order to align with the demands of society (Teane 2020). The successful transformation of the higher education curriculum requires a meticulous equilibrium between the transmission of knowledge and the provision of key skills to students (Ramonyai et al. 2022).

Faculty training is key in ensuring that educators are adequately equipped to present a curriculum that is in line with the requirements of the 4IR (Ogunlela & Tengeh 2021). Providing additional training to lecturers is essential for effectively managing disruptions caused by the Fourth Industrial Revolution (4IR) and ensuring the successful implementation of new curricula (Ogunlela & Tengeh, 2021). Similarly, the significance of professional development for teachers is highlighted as crucial for transforming teaching methods and improving learning outcomes (Naidoo & Singh-Pillay, 2020).

The readiness of students is another key issue that requires consideration. Fomunyam (2019) emphasises the need for South African institutions to improve their readiness in order to address the issue of student quality in higher education. The disparity between the abilities that graduates possess and the skills that are demanded by the labour market highlights the need of equipping graduates with the

necessary preparation for work readiness (Winterton & Turner 2019).

Improving skills is essential for adjusting to the 4IR. Including industrial input into curriculum design is a strategy to address skills disparities and enhance graduates' job prospects (Teane 2020). Hack-Polay (2020) suggests incorporating numeracy skills into degree programmes to tackle the issue of graduates having inadequate numeracy abilities and improving their chances of finding employment.

The integration of 4IR instruments in HEIs can optimise the process of teaching and learning, leading to improved student experiences and improved outcomes (Nwosu et al. 2023).

Industry and policy engagement

Industry collaboration, policy development, institutional pressures, and governance frameworks play a vital role in industry and policy engagement. This is particularly true in South African's higher education sector as it adjusts to the demands and opportunities of the 4IR. The 4IR requires collaboration between industry and educational institutions to facilitate the integration of digital technologies and innovative approaches into the curriculum resulting in significant changes in teaching and learning practices (Nwosu et al. 2023; Oke & Fernandes 2020). Cooperation is key in establishing enduring educational settings, particularly in remote schools, where the proficient integration of information and communication technologies (ICTs) can augment the standard of teaching (Alex 2021).

Policy development is key in determining how the higher education industry can respond to the challenges and opportunities brought about by the 4IR. Factors such as the absence of appropriate policies, insufficient expertise in 4IR technologies, poor infrastructure and the need for stakeholder participation have been recognised as challenges to the efficient use of 4IR technologies for sustainable development in Africa (Kibe et al. 2023). It is key for South African HEIs to comprehend the educational extent linked to 4IR in order to tackle challenges and effectively exploit the advantages of the 4IR (Lubinga et al. 2023).

The response of HEIs in South Africa to the demands of the 4IR is influenced by institutional pressures and governance frameworks. The presence of challenges such as insufficient institutional backing, a lack of e-learning culture, academia being excluded from e-learning development initiatives and inadequate ICT support underlines the need for institutions to adjust and adopt technology improvement in the field of teaching and learning (Cant 2021). The changes in South African higher education resulting from legislative interventions and community engagement efforts highlight the significance of aligning institutional practices with the demands of the 4IR (Thomson et al. 2010).

Challenges and opportunities

The South African higher education industry is currently encountering numerous challenges and opportunities as it adapts to the demands and potentialities brought about by the 4IR. South Africa has made significant improvements in harmonising with global imperatives and national priorities in the implementation of inclusive education (Bell & Swart 2018). Regulatory frameworks offer key direction for the execution of inclusive education, highlighting the significance of engagement from diverse stakeholders, such as parents (Engelbrecht et al. 2005). Nevertheless, there are also challenges that remain, such as limitations in resources and the need to address equity issues, particularly in no fee schools. (Sayed & Motala, 2012).

In South Africa, the idea of inclusive education is closely connected to the concepts of social justice. The evaluation of the inclusive education model in this context takes into account the principles of distributive, retributive and recognitive justice (Hay & Beyers 2011). Although inclusive education is a policy priority, there are still deficiencies in understanding and practical application. Educators lack the requisite skills and knowledge to effectively apply inclusive practices (Legodi-Rakgalakane & Mokhampanyane 2022). Integrating inclusion into teacher education programmes is essential for fostering a more inclusive education environment (Nel et al. 2023).

The issue of providing free education in South Africa has been a subject of discussion and investigation within the context of higher education (Mlambo et al. 2018). An ongoing analysis assesses the practicality and consequences of implementing tuition-free higher education, considering the constitutional and legislative frameworks. After the end of apartheid, there has been a strong emphasis on the internationalisation of higher education in South Africa. This has been facilitated by policies that have guided the process and influenced the higher education system in the country (McLellan 2007; Rouhani 2007).

South Africa is currently facing the problems and opportunities brought about by the 4IR. It is key to focus on improving accessibility, diversity and resource limitations in the higher education sector. To effectively respond to the changing requirements of the 4IR and ensure equal access and high-quality education for everyone, South Africa can utilise legal frameworks, tackle equity issues and improve teacher education programmes.

Proposing an innovative model: Integrated education transformation model

We introduce the Integrated Education Transformation Model (IETM) labelled Figure 3, and this model aims to provide a comprehensive framework for adapting South Africa's higher education sector to the 4IR. This model integrates key components, including, a technological integration hub, curriculum and skills development, industry and policy engagement platform, inclusive access and

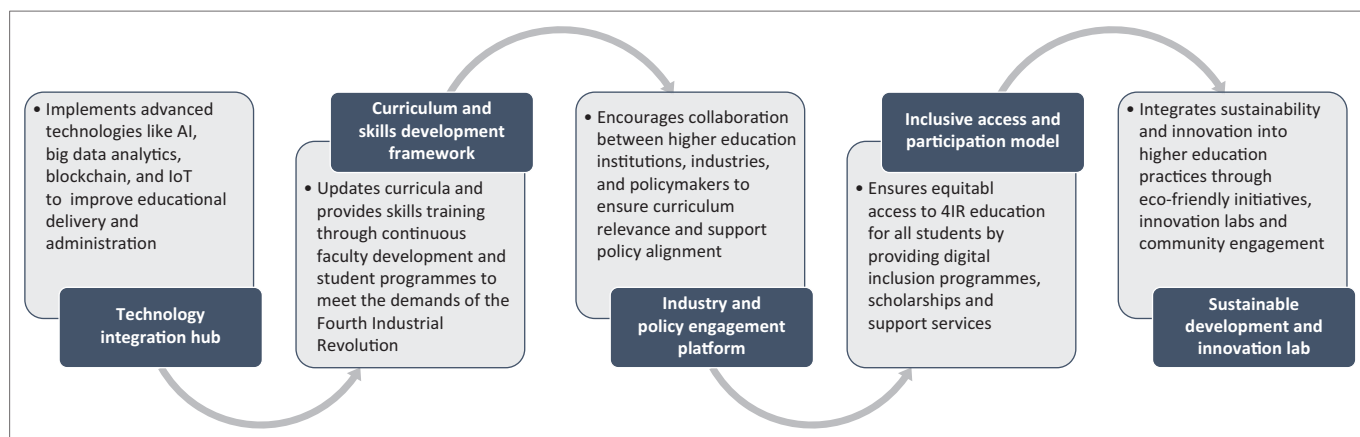


FIGURE 3: The integrated education transformation model.

participation model, and a sustainable development and innovative lab. The Integrated Education Transformation Model (IETM) provides a comprehensive and systematic approach to reimagining higher education in South Africa in the context of the 4IR. By focusing on technological integration, curriculum reform, industry engagement, inclusive access, and sustainability, this model aims to create a resilient and forward-thinking higher education sector that can meet the demands and opportunities of 4IR and beyond.

Technological integration hub

Within the framework of the 4IR, South Africa's higher education sector is utilising sophisticated technologies to improve the delivery and management of education. The technological integration hub plays a major role in this change by merging AI-driven customised learning systems and big data analytics. These tools facilitate the monitoring of student performance and offer predictive analysis to discover potential areas for improvement, therefore tailoring the learning experience to match the specific needs of each student. Blockchain technology is being employed for the purpose of secure digital credentialing, grading and certification, guaranteeing the integrity and genuineness of academic records. The implementation of IoT technology on campuses improves the efficient allocation of resources and promotes a connected educational atmosphere. This comprehensive strategy not only improves operational efficiency but also encourages a more captivating and participatory educational experience for both students and staff.

Curriculum and skills development framework

For South Africa's HEIs to fulfil the needs of the 4IR, it is key to update curricula and improve skills training. The Curriculum and Skills Development Framework aims to include 4IR-related subjects, including AI, machine learning, robotics and data science, into current academic programmes.

This integration guarantees that students possess the key information and abilities required to excel in a digitally sophisticated environment. Continuous professional development is key for educators, as it ensures that they are proficient in teaching new subjects. This can be achieved

through faculty training programmes. Programmes such as boot camps, hackathons and internships are created to equip students with the necessary skills and experience for the future employment market. These practical experiences help students connect theoretical knowledge with real-world applications, improving their preparedness for problems in the market.

Industry and policy engagement platform

Effective collaboration among HEIs, industries and policymakers is key to ensure that the curriculum remains relevant and aligns with policies in the era of the 4IR. The industry and policy engagement platform facilitates these collaborations by forming alliances with industries to improve curriculum development, provide internships and conduct research initiatives. These collaborations guarantee that academic programmes are synchronised with the requirements of the industry and offer students hands-on experience. However, it is key to collaborate with governmental entities in order to formulate regulations that facilitate the incorporation of 4IR principles into higher education. Establishing governance structures to supervise the implementation and monitoring of 4IR projects guarantees that these improvements are methodically implemented and consistently improved. This platform not only improves the standard of education but also guarantees that graduates are adequately equipped to satisfy the requirements of the industry.

Inclusive access and participation model

South Africa's higher education strategy prioritises providing 4IR education and opportunities to all students, irrespective of their background. The inclusive access and participation model tackles this requirement by establishing digital inclusion initiatives that grant access to digital devices and high-speed Internet, particularly for students from underprivileged backgrounds. Students are provided with scholarships and financial aid to facilitate their enrolment in courses and programmes connected to the 4IR. Support services such as mentoring, counselling and academic support are created to help students direct their educational path. The purpose of these steps is to establish a fair learning environment that allows all students to take advantage of

technology improvements, hence encouraging inclusivity and diversity in education.

Sustainable development and innovation lab

Incorporating sustainability and innovation into higher education methods is key for tackling wider societal and environmental issues. The Sustainable Development and Innovation Lab aims to encourage environmentally conscious practices on campuses and stimulate research in the field of sustainability. Innovation laboratories are created to offer environments where students and teachers can participate in inventive endeavours with the goal of addressing practical issues in the real world. These laboratories cultivate an environment that encourages innovation and exploration, leading to progressive ideas that may be used throughout different industries. However, collaborating with local communities to tackle societal issues through teaching and research improves the bond between institutions and the communities they cater to. This method not only improves the educational experience but also promotes sustainable development and social responsibility (Figure 3).

Implications

Transformative potential is present in the higher education system of South Africa despite the obstacles presented by the 4IR. To realise this potential, policymakers must prioritise digital literacy, critical thinking and innovation while also aligning educational frameworks with a technology-driven economy. This alignment requires investment in advanced technologies, infrastructure improvements and collaboration between academia and the technology sector. Educators are instrumental in the transformation of policies into practical learning experiences by engaging in ongoing professional development in AI, data analytics and contemporary teaching methods such as experiential and blended learning. For institutions, it is key to realign strategic priorities.

This entails the redevelopment of curricula to integrate multidisciplinary approaches that are indicative of the convergence of physical, digital and biological systems that are characteristic of 4IR. Research and development in emerging technologies should be prioritised to cultivate a culture of entrepreneurship and innovation among students and faculty. Establishing strong partnerships with industry through research initiatives and internships will facilitate the alignment of academic programmes with labour market requirements. Institutions are required to invest in technological infrastructure and establish policies that encourage continuous evaluation of improvements to facilitate these changes.

New teaching techniques should be implemented by educators, who should also continuously improve their skills and utilise AI to optimise administrative efficiency and personalise learning experiences. Improving digital infrastructure, such as intelligent classrooms and dependable Internet, is key to facilitating this transformation.

The integration of virtual reality (VR) and AR provides immersive, practical experiences crucial in disciplines such as engineering and medicine. A transition to project-based, multidisciplinary education encourages the development of critical 4IR skills, including systems thinking and creativity, by promoting collaboration and addressing real-world challenges. Professional development programmes must provide educators with current knowledge of technological developments. The cultivation of a culture of innovation through centres for teaching excellence will enable institutions to adjust to rapid developments, thereby preparing students for a technology-driven, dynamic future. This comprehensive strategy will augment the global competitiveness and relevance of South Africa's higher education system.

Limitations and future research

This study emphasises significant limitations associated with its dependence on secondary data sources. The most recent developments or trends in higher education related to the 4IR may not be captured by systematic literature reviews, which are built upon existing research. This dependence may result in a delay in comprehending recent developments crucial for understanding the sector's changing dynamics. The inclusion criteria may result in the exclusion of pertinent studies, which could lead to the omission of certain significant perspectives. This is another limitation. The variety of research methodologies and theoretical frameworks in the literature hinders the synthesis of findings, resulting in possible biases.

The systematic review process has the potential to introduce selection bias, which is a limitation of this study. Despite the application of stringent inclusion and exclusion criteria, the dependence on databases and keywords may have unintentionally omitted pertinent studies. The findings are specific to South Africa, and their applicability to other regions with varying socio-economic and educational contexts may be restricted. Further studies may broaden its focus to incorporate comparative analyses with other nations to augment the global applicability and relevance of the findings.

Furthermore, the generalisability of the findings to other regions with distinct contexts may be restricted by the context-specific nature of the reviewed studies, particularly in South Africa's socio-economic and cultural landscape. Another challenge is the rapid pace of technological change within the 4IR, as the review's conclusions are based on a specific point in time and may become outdated as new innovations are introduced. Consequently, ongoing research and surveillance are crucial for sustaining relevance.

The significance of the proposed future research directions, particularly the implementation of longitudinal studies to investigate the influence of 4IR technologies on higher education, is acknowledged. These studies would offer valuable insights into the long-term impacts of these

technologies on educational outcomes, curriculum adaptability and workforce readiness. Enabling the development of stronger strategies for the effective integration of 4IR technologies, longitudinal research would also enable the tracking of the evolution of challenges and opportunities over time. The researchers strongly advocate for additional research in this field to improve the results of this study and to contribute to the ongoing transformation of the higher education sector in South Africa and beyond.

Future research should concentrate on the development of longitudinal studies to examine the long-term impacts of 4IR technologies, including AI, machine learning and blockchain, on employment prospects and educational outcomes. Exploring the potential of technologies such as adaptive learning platforms, VR and AR to improve teaching and learning is another critical area.

Research must prioritise inclusivity and accessibility to guarantee that all students reap the benefits of these developments. Furthermore, it is imperative to evaluate faculty development programmes that are designed to improve digital literacy and pedagogical abilities. This would offer insights into effective strategies for enabling educators to integrate 4IR technologies into their teaching methodologies. Lastly, future research could investigate specific interventions, including policies that improve infrastructure in underserved areas, subsidised technology initiatives and digital literacy programmes.

Conclusion

The research emphasises the urgent need for integrating technology, reforming curricula and promoting industry and policy engagement in South Africa's higher education. The integration of AI, big data, blockchain and IoT has the potential to transform the field of education by improving administrative efficiency and facilitating personalised learning. Revising curricula to emphasise 4IR competencies such as AI and data science is imperative for equipping students for a digital workforce. Faculty training and professional development are key to the successful implementation of these changes. While strong policy frameworks facilitate the integration of 4IR principles, industry collaboration guarantees that educational programmes are in line with market demands. Nonetheless, challenges such as resource constraints, digital accessibility issues and the pursuit of digital diversity persist. The establishment of an inclusive, technology-driven education system requires a collaborative effort among government, academia and industry. South Africa's higher education can be positioned as a leader in quality and socio-economic development amid the 4IR through continued investment in technology and innovative strategies.

Looking ahead, future research could investigate longitudinal studies to evaluate the long-term impact of 4IR technologies on higher education, with a particular emphasis on areas such as curriculum adaptability, faculty development and student

preparedness. A promising area for further investigation is the integration of AI for personalised learning, blockchain for secure academic credentialing and VR for immersive educational experiences, among other emerging trends. Furthermore, comparative studies between South Africa and other regions could offer a more comprehensive understanding of the ways in which the adoption of 4IR technologies is influenced by varying socio-economic contexts. Furthering the transformation of higher education in the 4IR era, future research can build upon the foundation established by this study by addressing these areas.

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Competing interests

The authors declare that there are no financial, personal or professional conflicts of interest that could have appeared to influence the work reported in this article. All affiliations and contributions have been clearly stated, and the research was conducted impartially and independently of any commercial or financial interests.

Authors' contributions

A.B.S. and U.S. contributed significantly to the conception, design, analysis and interpretation of this research article.

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Data availability

The data supporting the findings of this study are available within the article. Any additional data that support the findings of this study are available from the corresponding author, A.B.S., upon reasonable request. Because of privacy and ethical considerations, access to raw data may be restricted.

Disclaimer

The views and opinions expressed in this article are those of the authors and do not necessarily reflect the official policy or position of any affiliated agency of the authors.

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