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Integrating 4IR Technologies into Higher Education in South Africa: Opportunities, Challenges, and Strategies

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Abstract. The study emphasizes the critical need for South African universities to adapt to technological advancements while addressing digital inequalities to ensure equitable access to education and employment. It employs a systematic literature review methodology to investigate the integration of Fourth Industrial Revolution (4IR) technologies into higher education curricula in South Africa. The review process involved a comprehensive search of relevant databases, including Google Scholar, JSTOR, ScienceDirect, and EBSCOhost, yielding 1258 articles published between 2014 and 2024. Consequently, 42 peer-reviewed journal articles, conference proceedings, and book chapters were included in the final analysis. The findings revealed significant opportunities for enhancing the relevance of education to industry demands and improving employment outcomes for graduates through the integration of technologies such as artificial intelligence, blockchain, and the Internet of Things. However, challenges persist, including resource constraints, digital divides, and the need for pedagogical shifts towards innovative, technology-enhanced learning models. This study shows that by aligning curricula with the demands of the 4IR, South African universities can better prepare graduates for the future workforce, thereby contributing to national development and economic growth.

Keywords: 4IR Technologies; Fourth Industrial Revolution; Industry 4.0; Curriculum Integration; Higher education; Education Relevance; Employment outcomes; AI; higher education South Africa.

1. Introduction

The onset of the Fourth Industrial Revolution (4IR) signifies a transformative period marked by the amalgamation of digital, biological, and physical innovations (Schwab, 2016). This era, marked by progressions in artificial

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intelligence (AI), robotics, the Internet of Things (IoT), and other emergent technologies, offers both significant opportunities and intricate challenges for global educational institutions. Universities in South Africa must integrate 4IR technologies into their curricula to enhance the relevance of higher education and improve graduates' employment prospects (Thirunavukarasu et al., 2020). The advent of the 4IR has brought about profound transformations across various sectors, including education (Levin, 2018). The 4IR is reshaping the way individuals learn, work, and interact with technology. In the realm of education, this revolution presents both opportunities and challenges as institutions strive to adapt their curricula to meet the evolving needs of students and the demands of the rapidly changing workforce (Ghani & Muhammad, 2019). As such, understanding the implications of 4IR technologies on education is crucial for ensuring higher education institutions' continued relevance and effectiveness.

Integrating 4IR technologies into higher education holds significant promise for enhancing the relevance of education to industry demands and improving employment outcomes for graduates (Penprase, 2018). By incorporating emerging technologies such as artificial intelligence, blockchain, and the Internet of Things into the curriculum, universities can equip students with the skills and knowledge needed to thrive in the digital economy (Hadgraft & Kolmos, 2020). Moreover, exposure to these technologies fosters critical thinking, problem-solving, and innovation, attributes that are highly valued by employers in today's competitive job market (Wahi et al., 2019). Consequently, integrating 4IR technologies into higher education is not only essential for preparing students for future careers but also for ensuring the continued competitiveness and sustainability of educational institutions (Oke & Fernandes, 2020). This integration is pivotal in South Africa, a nation where socioeconomic disparities and historical inequities persistently influence access to quality education and employment (Mine, 2019).

The demand for a digitally literate workforce that can flourish in a technologically advanced economy is increasingly critical (Chisango & Lesame, 2017). Consequently, the role of higher education in furnishing students with the requisite skills and competencies for the 4IR is both a national priority and a strategic imperative (S. N. Lubinga et al., 2023). Despite the acknowledged significance, the integration of 4IR technologies into university curricula poses several challenges. These encompass resource constraints, digital divides, and the need for pedagogical shifts from conventional to more innovative, technology-enhanced learning models (S. Arek-Bawa & O. Reddy, 2022). It is noteworthy that the COVID-19 pandemic expedited the urgency of this transformation, revealing gaps in digital infrastructure and readiness across higher education institutions (Rof et al., 2022).

This study employed a systematic literature review methodology to compile and analyse relevant research on the topic. The review process included a search strategy, selection criteria, data extraction, and analysis. The literature search was executed using specific search strings designed to capture a broad spectrum of studies on 4IR technologies and higher education. The primary databases searched included Google Scholar, JSTOR, ScienceDirect, and EBSCOhost. The

databases were chosen for this systematic literature review as they are well-suited for exploring the challenges and opportunities of integrating the 4IR into the higher education curricula in South Africa. The Google Scholar provides broad access to diverse scholarly works, including those from the Global South, while JSTOR focuses on social sciences and humanities, offering relevant insights into the educational implications of 4IR (Ghani & Muhammad, 2019). On the other hand, ScienceDirect specializes in peer-reviewed research in science and technology, crucial for understanding the technological aspects of 4IR (Chigbu et al., 2023). Lastly, EBSCOhost encompasses multiple subject-specific databases, ensuring comprehensive coverage of educational research, including studies from South Africa (Chisango & Lesame, 2017). Together, these databases facilitated a thorough synthesis of high-quality literature on the topic, with a strong emphasis on research relevant to the Global South. The objectives of this literature review were to synthesise existing research on the integration of 4IR technologies into higher education curricula with a focus on South African universities. The study aimed to identify the challenges and obstacles encountered by South African universities in this transformative process and to propose actionable strategies that can enhance the relevance of higher education in the digital age of 4IR technologies and improve employment outcomes for graduates in the context of the 4IR. The primary research question is thus stated “What challenges do South African universities face in integrating 4IR technologies into higher education?”
The objectives of this literature review were threefold:
1. To synthesize existing research on the integration of 4IR technologies into higher education curricula in South Africa.
2. To identify the principal challenges encountered by universities in this transformative process.
3. To propose actionable strategies that can enhance the relevance of higher education and improve employment outcomes for graduates in the context of the 4IR.

2. Methodology

This study utilized a systematic literature review methodology to compile and analyse pertinent research. The review process entailed the following steps:

2.1 Search Strategy: The literature search used specific search strings designed to capture a broad spectrum of studies on 4IR technologies and higher education. The primary databases searched included Google Scholar, JSTOR, ScienceDirect, and EBSCOhost. Key search strings utilized were: “4IR Technologies", "4IR", "Industry 4.0", "Curriculum Integration", "Higher education", "Education Relevance", "Employment outcomes", "4IR and higher education in South Africa” "curriculum transformation," "pedagogy," "digital technology," "artificial intelligence," and "machine learning”.

The search generated 1258 articles, which were screened based on their abstracts and keywords. Only peer-reviewed journal articles, conference proceedings, and book chapters investigating the integration of 4IR capabilities into higher education curricula were included in the study. Studies published between 2014 and 2024 were selected to ensure relevance to the current 4IR landscape as this period marks a critical phase in which the 4IR gained prominence in academic discourse and policy, particularly in South Africa. Starting in 2014, there has been a significant increase in research focused on the implications of 4IR technologies for higher education, especially as institutions adapted their curricula and teaching methods. Additionally, the analysis of literature up to 2024 allowed for a comprehensive analysis of recent developments, including the impact of the COVID-19 pandemic on digital transformation in education. This timeframe also facilitates the identification of evolving trends, opportunities, and challenges universities face in integrating 4IR technologies.

By examining this decade-long span, the study aimed to provide insights into the strategies employed by institutions and their effects on educational outcomes and graduate employability. We selected studies themed in the impact of 4IR on higher education, particularly in curriculum transformation, pedagogical approaches, and student outcomes as they were the most relevant to the research objective. Except for seminal articles on the topic, all the selected papers had a particular focus on the Southern African Higher Education landscape or provided a benchmark for the papers that discussed similar integration of 4IR into curricula from other countries. Full-text reviews were conducted on articles, conference proceedings and book chapters that met the inclusion criteria. This rigorous selection process ensured that only the most pertinent and high-quality studies were included in the final review. Only studies published in English were included, as they are more readily accessible and widely cited in the academic literature.

2.2 Exclusion Criteria: Several exclusion criteria were applied to the study. First, papers not written in English were omitted. Secondly, the time frame of publication was strictly adhered to; thus, papers published before 2014 were excluded. The papers' focus was also a crucial factor; hence, papers that did not concentrate on integrating 4IR capabilities into the curriculum were excluded. The publication type was also considered, whereby editorials, opinion pieces, book reviews, and conference abstracts were excluded due to their lack of comprehensive data for a literature review. Papers that were not fully accessible were also excluded. Lastly, to avoid repetition of data, duplicate studies were removed. These exclusion criteria were carefully considered to maintain the study's integrity, transparency, and replicability.

2.3 Data Extraction and Analysis:. The analysis focused on identifying themes related to the processes, strategies, and outcomes of integrating 4IR technologies into university curricula. Particular attention was given to studies that discussed the implications for employment outcomes and the digital divide in the South African context. Figure 1 below depicts the review process.

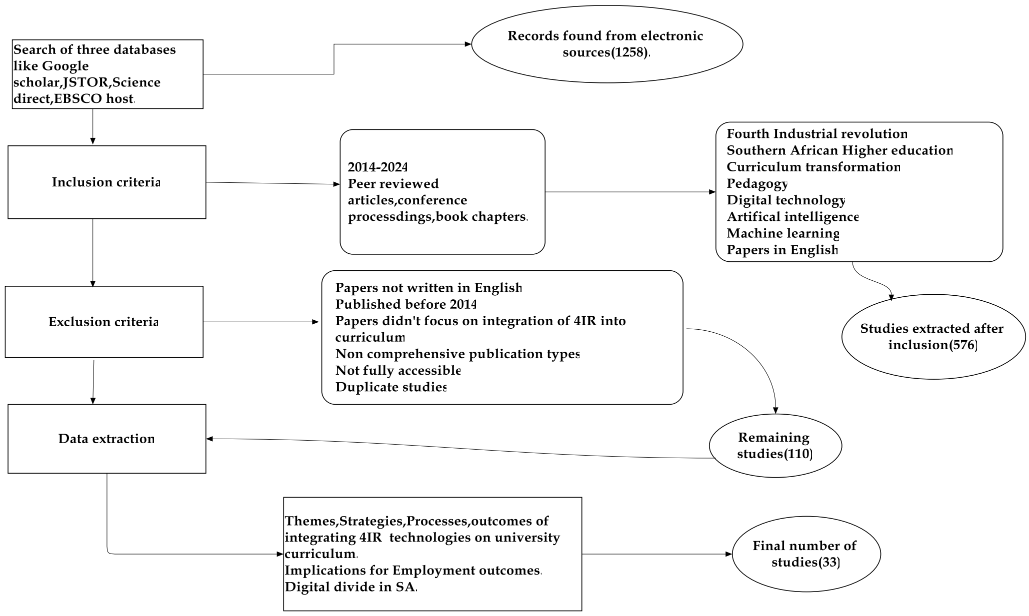

Figure 1: Source: Olaitan, Vijayalekshmi & Vinoth-Kumar (2024)

3. Literature review

The 4IR has transformed the landscape of higher education globally, presenting both opportunities and challenges for institutions to adapt and thrive (Chisango & Lesame, 2017). In the same light, the integration of 4IR technologies into curriculum design and teaching practices is crucial for enhancing the relevance and employment outcomes of graduates from South African universities (Ramnund-Mansingh & Reddy, 2021). (Cele et al., 2023) stressed the importance of integrating digital technologies into current curricula to prepare students for the 4IR workplace. These authors emphasized the necessity of utilizing technology-based tools and platforms for teaching and learning, highlighting the role of digital learning experiences. Embracing such technology can better equip students for the challenges of the 4IR era, where rapid technological advancements demand current skills and knowledge. However, the implementation of 4IR technologies in higher education faces challenges, including the need for quality and relevant education that prepares students for the future job market (S. Lubinga et al., 2023). In the South African context, the transformation of higher education curricula has been driven by the need to redress historical imbalances and adaption to the 4IR global technological advancements. These historical imbalances are exemplified by the ongoing dominance of Eurocentric epistemologies and the marginalization of indigenous knowledge systems, as highlighted by the #MustFall movements advocating for curriculum transformation since 2015 (Boughey & McKenna, 2021). It is worth noting that the COVID-19 pandemic has accelerated the push for digital transformation in Higher Education Institutions (HEIs) (Aruleba et al., 2022). (Boughey & McKenna, 2021)

Several studies have highlighted the importance of integrating 4IR technologies into teaching and learning to enhance student engagement, pedagogy, and assessment methods (Mashiyi and Baleni, 2023). (Mashiyi & Baleni, 2023) found that lecturers in South African universities use digital tools such as WhatsApp, Learning Management Systems (LMSs), and video-conferencing tools to ensure students achieve "epistemological access" despite challenges with digital infrastructure and digital literacy. Additionally, the South African Department of Basic Education has recognized the potential of 4IR in education, with initiatives such as the Open and Distance Learning (ODL) project aimed at integrating education technologies into classrooms to improve educational outcomes (Madumo & Kimaro, 2021). Similarly, (Shonhe et al., 2023) explored students' experiences with 4IR technologies in online learning in Botswana and Zambia, emphasizing the need for consistent capacity building and training to support the effective integration of these technologies.

Consequently, the education system should strive to redefine the traditional roles of teachers and students to adopt the 4IR technology to provide immediate interventions (Oke & Fernandes, 2020). This approach advocates for personalized teaching tailored to each student's needs, focusing on Science, Technology, Engineering and Mathematics (STEM) curricula that emphasize IoT and blockchain technology skills. Furthermore, Oke & Fernandes (2020) emphasised the use of interactive platforms for better learning experiences, highlighting synchronous and asynchronous interactions to improve communication roles of teachers and students while preserving personalised teaching. According to (Yusuf et al., 2020), educational institutions are urged to incorporate 4IR technologies, including Artificial Intelligence (AI) and Massive Open Online Courses (MOOCs), utilising Learning Management Systems (LMS). Integrating AI and MOOCs with traditional education is deemed crucial for enhancing the quality of education in the 4IR. Unlike blended learning, which combines in-person and online instruction within a single course, integrating MOOCs with traditional education enhances the curriculum by providing access to diverse content and expertise as supplementary resources.

Ilori and Ajagunna (2020) suggested combining MOOCs with flipped classrooms for teaching Human Morphology in alignment with the Medical Education curriculum to address challenges in traditional teaching and fosters student participation (Ilori & Ajagunna, 2020). The effectiveness of social robots and intelligent agents in educational settings is also being explored. Examples of social robots and intelligent agents being explored in educational settings include using humanoid robots like NAO for interactive learning and AI-driven tutoring systems that provide personalised feedback to students (Augello et al., 2020). Innovations such as Career and Technical Education (CTE) courses are recommended to equip students with practical skills and cross-functional competencies necessary for success in the evolving labour market of the 4IR, as recognised by the World Economic Forum (WEF) (Schwab, 2016). The combination of MOOCs with flipped classrooms, an instructional strategy where students learn lecture materials at home and use class time for interactive activities can foster student participation and engagement (Ilori & Ajagunna, 2020). Furthermore, CTE courses can provide students with practical skills and cross-functional competencies necessary for success in the 4IR labour market (Schwab, 2016). The World Economic Forum (WEF) recognises the importance of these innovations in preparing students for the future (Yusuf et al., 2020). Therefore, integrating 4IR technologies into the South African higher education curriculum is essential for equipping students with skills for the labour market.

4. Integration of 4IR into the curriculum in South Africa

This study focused on exploring South African universities' strategies for integrating 4IR technologies into their curriculum to enhance engagement and practical skills. This integration is exemplified by a study by (S. Arek-Bawa & O. Reddy, 2022) examined how the Bachelor of Education (B. Ed) curriculum at the University of KwaZulu-Natal (UKZN) has been digitally transformed to prepare students for the 4IR classroom. The B. Ed program at the University of KwaZulu-Natal (UKZN) integrated 4IR technologies into its curriculum using module templates and corresponding moderator reports. The templates provide a structured approach to teaching and learning, with each weekly session specifying the learning outcome and planned mode of delivery. This included using PowerPoint slides with audio, notes, reading texts/articles, Zoom lectures, YouTube links, and WhatsApp discussions. The module on teaching methods focuses on developing students' skills in interrogating curriculum documents, engaging with lesson planning and preparation, integrating teaching and learning resources, and reflecting on professional practice. A sample of the model template is presented in Table 1.

Table 1:Integration of 4IR into the curriculum in South Africa(O. Arek-Bawa & S. Reddy, 2022)

Cluster	Language & Arts Education	Science & Technology Education
Levels	**Two**	**Two**
Module Name	**English Education: Method 1 Introductory concepts**	**Life Science Education Method 1**
Module Aim	To prepare student teachers to meet teaching challenges and develop own knowledge and understanding of English.	-This module aims to familiarise students with learning theories relevant to the discipline, as well as the school's life sciences curriculum, with special reference to the specific aims of the Curriculum Assessment Policy Statements (CAPS) curriculum. Furthermore, the module will focus on developing skills, including the use of Information and Communications Technology (ICT), related to teaching the topics covered in Biological Science Education content modules of the CAPS curriculum.

Learning Outcome	To: -Introduce concepts and constructs associated with becoming a teacher of English in South African landscape, -Interrogate documents, engage with lesson planning and preparation, and integrate teaching and learning resources. -focus on first and second language acquisition.	-Demonstrate an understanding of the specific aims of the biology curriculum and how these aims shape the curriculum -Identify different learning theories in different teaching and learning strategies -Use diagrams appropriately in lesson planning Demonstrate understanding of the use of models in Biology Education -Use laboratory equipment appropriately in Biology Education -Reflect on own professional practice
Content topic (extract)	-Teaching of English: Understanding and responding to the South African landscape -Interrogating the National Education Teacher Framework – for the teacher of English; Interrogating curriculum documents) FET English) (3wks) -Lesson Planning and Preparation (FET)	-Exploring the curriculum document CAPS -Understanding Lesson Planning -Exploring lesson presentation -Exploring Assessment in Life Science -The role of diagrams in teaching Biology -The use of models in teaching Biology -Laboratory work and equipment in science teaching and learning
Mode of delivery	PowerPoint with audio, notes, and reading text/articles	-Zoom Lecture, -YouTube links -WhatsApp discussions
Assessments	2 Assignment (50%) 2 MCQ (50%)	-8 Assignments & Tasks - 50% -Main Task- 50%
Communication	Moodle, WhatsApp, emails, and Zoom for clarification	Moodle, WhatsApp, and Skype

The content modules in Table 1 demonstrate an understanding of specific curriculum aims, different learning theories and teaching strategies, and the appropriate use of diagrams, models, and laboratory equipment. Assessments include assignments, tasks, and main projects, with communication facilitated through Moodle, WhatsApp, emails, Zoom, and Skype. This structured approach to teaching and learning has paved the way for incorporating 4IR technologies into the curriculum, ensuring that students are equipped with the skills and knowledge required to thrive in the 4IR workplace (S. Arek-Bawa & O. Reddy, 2022). These authors outline how the Math module template aids academics in planning content delivery and assists students in understanding weekly expectations, while the accounting module template specifies recorded lectures on Moodle and Zoom class meetings for assessing online video presentations. Additionally, the Life Sciences programme at the University of KwaZulu-Natal (UKZN) places significant emphasis on developing students' ICT skills, recognizing the importance of fostering digital competence. This involves students controlling and utilizing ICT in various aspects of learning, including knowledge acquisition, communication, creation, and learning. This approach reflects a competency-based digitised curriculum, which is essential for preparing students for the 4IRworkplace (S. Arek-Bawa & O. Reddy, 2022).

The 4IR transformation involves integrating digital technologies like PowerPoint, Zoom, YouTube, WhatsApp, Moodle, Microsoft Teams, and Google Classroom to enhance student learning experiences and prepare them for the 4IR workplace (S. Arek-Bawa & O. Reddy, 2022). In summary, these authors provide evidence of how the B. Ed curriculum at UKZN has been digitally transformed by incorporating digital technologies into program delivery, embedding digital learning experiences, and aligning assessments and communication with the requirements of the 4IR classroom (Hadiyanto et al., 2021).The approach articulated by Arek-Bawa and Reddy (2022) aligns with the findings of Hadiyanto et al. (2021), who examined the incorporation of 4IR competencies into the curriculum at an Indonesian university, thereby highlighting a broader trend in educational reform aimed at enhancing the relevance of higher education in the context of the 4IR.

One approach to this integration was developing a model for students' Soft Skills, Hard Skills, and Competitiveness (SHC). This model, developed using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) approach, was designed to incorporate 4IR skills into the curriculum (Hadiyanto et al., 2021). The model included three main phases: Input (course content and SHC components), Process (blended course design and student engagement), and Output (achievement of soft/hard skills and competitiveness). This model emphasized the need for graduates to possess 21st-century skills, such as problem-solving and critical thinking, to meet the demands of the 4IR. The model underwent user validation, indicating its acceptability and applicability for implementation in higher education curricula to prepare students for the challenges of the4IR.

(S. Arek-Bawa & O. Reddy, 2022) discussed several challenges in making the curriculum relevant to the 4IR including unequal access to digital resources and the abrupt shift to online learning, which highlighted the disparity among students regarding access to conducive learning environments. Some students were grappling with social challenges like overcrowded homes and limited internet connectivity. This digital divide created an epistemological gap, making it difficult for some students to engage effectively with a digitalized curriculum. Furthermore, the difference between performance-based and competency-based curricula presented as a challenge. Some curriculum templates promote passive learning, while others encourage interactive and collaborative learning, leading to varied preparedness among students for the 4IR economy. (S. Arek-Bawa & O. Reddy, 2022) further highlighted the need for orientation programs, digital literacy initiatives, and regular ICT training to improve students' digital competence. Lastly, quality assurance was considered a crucial challenge in online assessments, necessitating closer investigation to guarantee credibility and fairness in the evaluation process. (Hadiyanto et al., 2021) also found that successfully implementing this model requires a comprehensive understanding of the specific demands of the 4IR and the ability to adapt the curriculum to meet these demands.

Cele et al. (2023) examined undergraduate students' perceptions and knowledge of 4IR about their accounting curriculum and careers at HEIs in KwaZulu-Natal using a census approach. The study was conducted online with a total population of 257 exit-level students from the Diploma in Accounting programme. The findings from the study revealed that while students are aware of the 4IR and its potential impact on the accounting profession, their understanding of 4IR is limited. According to the data analysis, only 56.4% of the students sampled clearly understood the key 4IR concepts such as big data, artificial intelligence, and the Internet of Things (IoT).

Interestingly, the study found that 68.6% of the students agreed that the shift from manual to digital accounting systems could negatively impact future employment opportunities and careers in Financial Accounting. This suggests that as routine accounting tasks become increasingly automated, the accountant's role is evolving to include higher-order thinking skills such as critical thinking, problem-solving, and analytical skills, which are becoming increasingly important in a job market transformed by technological advancements. The study also revealed that there is a need to close the knowledge gap between the Financial Accounting students' knowledge of 4IR trends like big data, artificial intelligence (AI), and the Internet of Things (IoT) and curriculum content (Cele et al., 2023). The study further highlighted the importance of incorporating real-time classroom technologies into higher education institutions to better prepare students for the 4IR era. They used the Context, Input, Process, Product (CIPP) model to assess students' digital learning experiences and identified various digital elements in the curriculum to enhance digital literacy and competence. Therefore, the curriculum was designed to prepare future teachers with Technological Pedagogical and Content Knowledge (TPACK) and cross-functional abilities essential for effective teaching in the 4IR era. The authors suggest that incorporating real-time classroom technologies such as learning management systems (LMS) could improve the learning experience by facilitating interactive and instant interaction between educators and students. The process could help bridge the digital gap among students and ensure access to digital learning crucial for the 4IR classroom (Cele et al., 2023).

(Mokgatla & Moseley, 2022) explored the opportunities and challenges associated with integrating 4IR technologies into a South African university's undergraduate Industrial Design (ID) curriculum. The researchers collaborated across two practical modules and used the results to propose instructional changes and/or follow-up iterations in their undergraduate modules. The researchers employed an Action Research (AR) approach, where participants and researchers cogenerated knowledge through collaborative and communicative processes in which all participants' contributions were considered. Staff and student participation, engagement, and reflection were key aspects of the process and findings. First-year students were chosen for the study because they had a minimal foundation and formative skills related to specific technologies/tools and were likely to be more receptive to the experimental and exploratory methods of the study. Furthermore, the lack of experience across the year group in any of the methods eliminated the problem of methodological bias (Mokgatla & Moseley, 2022).

In the first approach, students engaged with traditional handmade methods. They used materials such as Y2-Klay and air-drying clays to create master patterns. This intuitive approach allowed students to manipulate the materials to achieve their design goals physically. The second approach involved using 3D Computer-Aided Design (CAD) and 3D printing. Students created 3D digital models using software like SOLIDWORKS that were then brought to life using 3D printers, providing a tangible representation of their designs. The third approach entailed students utilizing 2D CAD software and laser cutting to create linework, which was laser cut into layers, allowing students to build up their designs piece by piece (Mokgatla & Moseley, 2022). The fourth approach was more experimental, involving Virtual Reality (VR). Students used VR headsets and software like Gravity Sketch to create 3D models in a virtual environment. This immersive approach provided a new perspective on the design process (Mokgatla & Moseley, 2022).

Mokgatla and Moseley (2022) also highlighted several challenges that served as limitations to implementing 4IR processes in the design curriculum. First, high implementation costs, including the cost of 4IR technologies like VR headsets and 3D printers, were significant barriers to their adoption. The financial burden was exacerbated by running costs such as maintenance, proprietary software, internet, and electricity. This is particularly challenging in the South African context, where there are limited departmental budgets and significant income disparity among students (Mokgatla & Moseley, 2022). Secondly, infrastructure issues posed a major challenge. The significant digital divide in Africa, with only 24% of the continent's population accessing the internet compared to the 51% global average, highlights the need for stable internet and power connectivity needed for the effective use of 4IR technologies (Mokgatla & Moseley, 2022). Additionally, South Africa experiences disrupted power connectivity, through load shedding, which affects the productivity of students relying on digital fabrication technologies (Mokgatla & Moseley, 2022). Lastly, the current VR design tools face technological limitations, hindering the precision and accuracy needed for industrial design outputs. The software interfaces and devices are still in the early stages of development, limiting the complexity and accuracy of the designs produced. Consequently, addressing these challenges and barriers is crucial in the 4IR era, where students must be equipped with the necessary technological skills and knowledge (Mokgatla & Moseley, 2022). Overcoming these barriers will ensure that students are well-prepared for the rapidly changing industry and can effectively contribute to world of work (Mokgatla & Moseley, 2022). A phased hybrid approach, combining traditional methods with newer technologies, could help bridge the gap and provide students with the exposure and experience needed to thrive in this new era (Mokgatla & Moseley, 2022).

(Chigbu et al., 2023) discussed several attempts by lecturers and faculty to innovate pedagogy and introduce 4IR technologies into their curricula. One significant innovation was adopting online learning platforms during the COVID-19 pandemic lockdown. The study investigated the effects of this innovation on participant and non-participant respondents. The focus was on analysing their problem-solving and critical thinking skills. The researchers also discussed the integration of 4IR technology in science pedagogy, utilizing online platforms for learning and promoting economic activities. They further emphasised the need for new flexible curricula and teaching approaches for diverse contexts to prepare students for the demands and challenges of the 4IR technology. This involves moving away from a teleological view of skills (Menon & Castrillón, 2019, p. 1), considering that the 4IR builds on computerization from 3IR with more IT-hungry applications like cognitive computing or AI, the Internet of Things, and big data analytics. The authors suggest that integrating 4IR into the curriculum could improve student employability by providing them with the necessary technological skills and knowledge (Chigbu et al., 2023).

(Chigbu et al., 2023) also documented the approaches adopted by different universities in South Africa to refine teaching and learning in a way that accommodates the technological age to give the student an edge in the world of work. For example, the University of Pretoria (UP) has been implementing a hybrid teaching and learning approach to teaching and learning for over two decades, combining traditional face-to-face instruction with online learning to cater to the diverse needs of student. Additionally, the University of the Witwatersrand (WITs) has adopted blended teaching and learning, aligning instruction and technology to achieve quality education. By incorporating digital resources, WITs has enhanced the learning experience, catering to the digital natives of today. Furthermore, the University of Western Cape (UWC) combined e-tools and technology with traditional classroom activities, making blended learning a widespread practice (Chigbu et al., 2023). This approach enhances the learning experience and prepares students for the digital world. Moreover, the University of Cape Town (UCT) has implemented the flipped classroom model, shifting the classroom from a teacher-centred to a learner-centred environment. Most lectures are offered online, requiring students to engage in practical experiences on campus. These innovative pedagogical approaches not only enhance the learning experience but also equip students with the necessary skills for the digital age, preparing them for the future of work in the 4IR era (Chigbu et al., 2023).

Contrary to possibilities of empowering students with the necessary skills for work in the 4IR digital age, the researchers discussed several challenges encountered in the attempt to digitize teaching and learning and improve pedagogical practices, particularly in South Africa (Chigbu et al., 2023). According to the authors, a significant challenge was the slow adaptation to Higher

Education 4.0 (HE4.0) pedagogy in developing countries, including South Africa (Chigbu et al., 2023). The education sector in South Africa has been unprepared for the 4IR, and there has been a lack of attention to global advancements in teaching and learning processes. This has resulted in a dismal adaptation to HE4.0 pedagogy, with gradual improvements made over time. In addition, the academics' resistance to integrate technology into their teaching practices, despite the availability of Learning Management Systems (LMS) and other digital tools, has hindered the adoption of innovative teaching methods that could enhance students' learning experiences. For instance, before the COVID-19 pandemic, many South African universities used LMS for course materials and communication, but there was limited use of technology for interactive and engaging learning activities (Chigbu et al., 2023).

Besides academic challenges, the COVID-19 pandemic also highlighted the challenges of digitizing teaching and learning. The sudden shift to online education created an emergency leap in pedagogy, forcing universities to adopt digital tools and remote learning methods rapidly. However, the transition to online learning faced numerous challenges, including limited internet access and electronic devices, impacting students' participation. Additionally, the lack of immediate responses to students' questions during home learning in the flipped classroom model led to confusion and frustration among students (Chigbu et al., 2023). Furthermore, the cost of developing and maintaining E-learning tools and the potential for technical problems were significant barriers to the digitization of education. These challenges made it difficult for institutions to provide consistent and reliable digital learning experiences. Despite these obstacles, the researchers emphasized the need for South African Higher Education Institutions (HEIs) to adopt flexible, inclusive, effective, and sustainable pedagogical approaches to meet the demands of the 4IR and improve student-centred learning outcomes. (Chigbu et al., 2023).

(Mosia, 2023) also discussed the importance of incorporating 4IR technologies into the curriculum, particularly in industrial engineering. The researcher highlighted the complex challenges that industrial engineers often face, which require intricate analyses and a significant amount of data collection and organisation. The author argued that the computational power required to implement the mathematical models used by industrial engineers often exceeds manual capabilities. Advancements in computing technology have empowered industrial engineers to perform various iterations of complex simulations, access complex data, and engage in decision analyses. This has resulted in implementing decision support systems processes to overcome engineering challenges. (Mosia, 2023) contends that these developments imply that students must be schooled in such systems to be relevant in the modern workplace. There are numerous modelling packages available for industrial engineering practice, some of which are general-purpose analytical software such as Microsoft Excel. (Mosia, 2023) stressed the need for an increased emphasis on applying these technologies in educating industrial engineers. These computing power tools were used by industrial engineers in problem-solving areas such as management decision-making, quantitative and statistical analyses, and production and operations management models. According to the author, Universities of Technology in South Africa need to adopt a realistic approach to increasing the use of technology in educating industrial engineers.

(Mosia, 2023) concluded by stating that integrating 4IR technologies in education is not just a trend but a necessity in today's rapidly evolving world. Findings from the study revealed that the current curriculum in universities of technology (UoTs) is not preparing students adequately for the high-tech environment they will encounter in their future careers. The literature reveals a gap between the current curriculum and modern work environment demands, emphasizing the need for advanced technologies and pedagogies in IE education. However, the author noted that the IE profession is in danger of losing its identity because other professions are encroaching on the IE's traditional areas (Mosia, 2023). (Mosia, 2023) also argues that the impact of 4IR technologies on work characteristics includes changes in work tasks, work demands, and the necessary competencies for IE professionals. For instance, technologies could substitute different operations or tasks, leaving room for other activities. This change in work tasks defines the necessary competencies, which include the potential capacity to carry out a job. Additionally, the introduction of 4IR technologies also leads to new work demands that require IE professionals to develop specific competencies. For example, there is an increasing demand for cognitive and digital skills in automated systems, as well as time and attention management strategies to cope with the intrusive features of technology.

To address the gap between the current curriculum and the demands of the modern work environment, IE education needs to transform its curriculum to incorporate more advanced technologies and pedagogies. The gaps identified include the insufficient integration of advanced technologies, such as artificial intelligence and data analytics, and the lack of innovative pedagogical approaches that align with the evolving demands of the modern work environment. The Engineering Council of South Africa (ECSA) has emphasised the need for IE programs to apply capabilities of Information Technology and has declared that it will not give accreditation to IE programs that do not apply these capabilities (Mosia, 2023). Therefore, it is essential to transform the IE curriculum to incorporate more advanced technologies and pedagogies, ensuring that IE professionals are equipped to adapt to the changing work environment and take advantage of the opportunities presented by 4IR technologies (Mosia, 2023). (Nithyanandam et al., 2022)The findings correlate with research by Nithyanandam et al. (2022) on the integration of 4IR into the curriculum, particularly through a collaborative project between PSG College in Coimbatore, India, and Newcastle University in the UK, aimed at developing strategies for aligning educational programs with Industry 4.0. The strategy involved several steps, including benchmarking successful practices from other institutions related to Industry 4.0, identifying technologies that enable the local development of Industry 4.0, and creating student-led projects that intersect with various digital manufacturing technologies. These projects were then applied in a context relevant to the industry. The outcome of this approach was a high level of student engagement in the technology-focused project, demonstrating the potential of such projects as prototype "testbeds" that could attract industrial interest and encourage broader adoption of these technologies. This instance further supported the feasibility and benefits of incorporating 4IR into the educational curriculum.

(Seshoka et al., 2023) stated that the 4IR is causing significant changes to the global workforce, necessitating a swift response from higher education institutions to prepare students for this new era. In the study they conducted at the University of South Africa, they reviewed the skill set required for the employment of South African graduates in the 4IR. The researchers conducted a scoping review of published research on teaching and learning practices to identify the skills needed to prepare graduates for the 4IR workforce. They identified a set of 25 skills across seven categories. Additionally, they performed a content analysis on the 2022 yearbooks of three qualifications (in Science, Social Science, and Commerce) at the University of Johannesburg to determine which of the identified 4IR skills were included in these programs. They established that the University of Johannesburg (UJ) has incorporated complex problem-solving and critical-thinking skills into various undergraduate programs. These skills were included in the BSc Computer Science and Informatics with AI curriculum and the BA in Politics, Economics, and Technology and BCom Accounting curricula. Notably, the BA program lacked logical reasoning skills, which complex problem-solving aimed to address (Seshoka et al., 2023). The researchers also found that none of the qualifications, including the BSc in Computer Science and Informatics with Artificial Intelligence, incorporated all the identified skills for the 4IR. As a result, the researchers recommended introducing fundamental modules that will cover all the 4IR skills not currently included in the curricula (Seshoka et al., 2023). The authors reported that at the University of Johannesburg, 48% of the 4IR skills were not included in the BSC curriculum, skills from psychology, human resources, and management. Thus, they posited that students may have difficulties adapting to the culture and getting along with fellow employees in the future (Seshoka et al., 2023, p. 57).

Seshoka et al. (2023) also discussed the current regulatory framework in higher education and criticized it for being too focused on compliance, slow, and inflexible, which challenges institutions to adapt to the rapid changes brought about by the 4IR (Seshoka et al., 2023). The inflexibility of the education system has been exacerbated by the challenges of updating its regulatory, policy, and compliance aspects in response to environmental changes. Over the last two decades, regulators and policymakers have not adequately addressed the widespread integration of technology into education, leading to rigid quality assurance processes. To tackle these issues, the article suggests that educators should develop innovative teaching methods to encourage independent learning beyond traditional classroom settings (Seshoka et al., 2023).

(Magenuka & Sibanda, 2023) stated that the current electrical engineering curriculum lacks an interdisciplinary approach, thereby failing to equip students with a comprehensive understanding of how electrical engineering intersects with other fields, a critical requirement in the context of the 4IR. The curriculum emphasized core electrical engineering concepts, often neglecting essential soft skills such as communication, creativity, and problem-solving, which were indispensable in the 4IR landscape. Furthermore, the curriculum was not updated with sufficient frequency to keep pace with the rapid advancements and innovations in electrical engineering technologies and their applications in the 4IR, including blockchain, digital privacy, satellites, the metaverse, and climate technologies. Additionally, the curriculum lacked flexibility and choice, thereby limiting students' ability to explore their interests and passions in the ethical, social, environmental, and economic implications of electrical engineering technologies and solutions in the 4IR.

(Steenekamp et al., 2020) discussed the integration of the 21st-century processes to create an effective framework for implementing these skills in education, where the curriculum caters to academic and non-academic needs, by empowering students with specific qualifications. They argued that these can be achieved through project-based learning, real-world problem-solving scenarios, and cognitive, emotional, and behavioural development opportunities. Examples included using AI for data analysis or blockchain for accounting tasks and collaborating with departments like computer science for exposure to 4IR technologies (Steenekamp et al., 2020). Incorporating 4IR technologies into the curriculum requires skilful planning and reflection. This involves aligning with competency frameworks of relevant professional bodies and preparing students for the evolving job market. Automation may replace some roles and create new ones that require different skills, such as creative and critical thinking. Therefore, students are encouraged to actively adapt to these changes with institutional support (Steenekamp et al., 2020).

(Ilori & Ajagunna, 2020) discussed the growing need for STEM graduates, which has resulted in a greater focus on STEM education. The authors also discussed the concept of Science, Technology, Engineering, Arts and Mathematics (STEAM), which combines arts with STEM to encourage creativity and critical thinking. Additionally, a recognised need was to cultivate non-cognitive skills alongside academic knowledge. The authors described the incorporation of Massive Open Online Courses (MOOCs) into higher education as an opportunity that offers accessible learning for students worldwide. They also discussed how the 4IR will increase the need for individuals with interdisciplinary skills. This shift required moving from the traditional focus on narrow disciplines to a curriculum that promotes critical thinking, independence, soft skills, and creativity. Furthermore, there was a challenge in teaching new learning skills and motivating students to develop problem-solving abilities (Ilori & Ajagunna, 2020). They emphasized the need for a two-pronged approach: integrating technology into humanities and social sciences curricula and engaging science students in social science fields. There was also a gap between industry needs and graduate skills, highlighting the necessity for a comprehensive ICT skills framework to address this disparity and align curricula with industry demands. The absence of an ICT taxonomy and skills framework in South Africa further complicated these challenges. These authors identified two main challenges in adapting education to the 4IR. First, the convergence of digital, physical, and biological domains complicated the creation of integrated curricula encompassing all 4IR technologies. Secondly, there were significant infrastructural challenges in Africa, such as insufficient electricity, low teledensity, and limited internet and broadband access, which hindered the implementation of advanced technological education (Oke & Fernandes, 2020).

(Gwangwava, 2019; Uleanya, 2023)Gwangwava (2019) highlighted several challenges at the Botswana International University of Science and Technology (BIUST), including a lack of qualified personnel, insufficient funding, inadequate equipment, and a misalignment between school curricula and the demands of the 4IR. Similarly, Uleanya (2023) corroborated these findings, indicating that additional obstacles encompass significant gaps in infrastructure, skills, innovation, institutional frameworks, and regulatory environments. BIUST has incorporate active learning, personalized data-driven education, and lifelong learning skills into their winter school curriculum for engineering students, which aligns with the skills for the 4IR workforce (Gwangwava, 2019).

This study reviewed several studies to identify particular instances of 4IR incorporation into curricula and the challenges faced in the process. The subsequent discussion section elaborates on the key themes and findings from the literature.

5. Discussion

This research was guided by the primary research question, which is: "What challenges do South African universities face in integrating 4IR technologies into higher education?" This inquiry is supported by three main objectives: to synthesize existing research on the integration of 4IR technologies into higher education curricula in South Africa, to identify the principal challenges encountered by universities during this transformative process, and to propose actionable strategies that can enhance the relevance of higher education and improve employment outcomes for graduates in the context of the 4IR. The integration of 4IR technologies into education is recognized as essential for equipping students with the skills necessary to thrive in a rapidly evolving job market. The literature indicates that effective integration can significantly enhance student employability by providing skills in critical areas such as the Internet of Things (IoT), blockchain, and artificial intelligence (AI) (Ilori & Ajagunna, 2020). However, various challenges must be addressed to facilitate this transition. A key issue identified in the literature is the need for more flexible and inclusive curricula that can respond to the dynamic nature of 4IR technologies, as highlighted by Mtotywa et al. (2024). The successful incorporation of these technologies relies heavily on educators' willingness and ability to adopt new teaching methods and tools. Many South African universities face significant resource constraints, which hinder their ability to integrate 4IR technologies effectively. Greyling (2023) notes that the technical skills required for 4IR are among the scarcest in South Africa, compounded by inadequate school infrastructure, where more than half lack computer labs.

While South Africa and the global South universities are still adapting to the 4IR, the Fifth Industrial Revolution is already underway, bringing more changes and different skill sets that might be needed for future employability. Therefore, universities must constantly assess their curricula and amend them where necessary as new skills are needed, and new careers emerge with these societal changes. Understanding the technological revolution is crucial, especially in light of the numerous social injustices people are currently facing (Seshoka et al., 2023). Incorporating 4IR technologies can significantly enhance student employability by developing skills in areas like IoT, blockchain, and AI (Ilori & Ajagunna, 2020). Integrating 4IR technologies also offers significant benefits, preparing students for success in the digital economy while fostering critical thinking and innovation, which are highly valued by employers (Harmse & Wadee, 2019). 4IR technologies are crucial for preparing students for the job market, but challenges like flexible curricula, technology adoption, and adequate infrastructure need to be addressed (Mtotywa et al., 2024). However, critics caution that overemphasising 4IR technologies may overshadow the development of essential soft skills like communication and teamwork (Cele et al., 2023). Challenges such as resource constraints and digital divides hinder integration, particularly in developing countries like South Africa. To navigate these challenges, collaboration between educators and policymakers is crucial to develop innovative teaching methods and provide institutional support for students (Ally & Wark, 2020; Cele et al., 2023; Menon & Castrillón, 2019). Partnerships with industry and government are recommended to secure necessary resources and bridge digital divides, while pedagogical shifts towards innovative learning models are essential (Arek-Bawa & Reddy, 2022). Addressing these challenges is vital for preparing students for future careers and enhancing the relevance of higher education, ultimately contributing to national development and economic growth. The following section provides recommendations to address these challenges.

The literature also emphasizes the impact of the digital divide, which exacerbates existing inequalities in educational outcomes. The gap between those with and without access to digital technologies poses a significant barrier to the effective implementation of 4IR initiatives. Additionally, a teacher-centered approach where students take a passive role may not be suitable for conveying the complexities of 4IR technologies, necessitating a shift towards more innovative, technology-enhanced learning models. This transition may face resistance from educators and students accustomed to conventional teaching approaches (Arek-Bawa & Reddy, 2022). Collaboration among educators and policymakers is a vital factor in overcoming these challenges. Developing innovative teaching methods and providing institutional support will enable students to adapt to the changing job market (Ally & Wark, 2020; Cele et al., 2023; Menon & Castrillón, 2019). Furthermore, universities should seek partnerships with industry and government to secure the necessary resources for digital transformation. In addition to technical skills, the literature emphasizes the importance of fostering essential soft skills, such as communication, teamwork, and leadership, which are equally crucial for career success. While integrating 4IR technologies, universities must ensure that they do not overlook the development of these competencies, as they are highly valued by employers in today’s competitive job market (Cele et al., 2023). Integrating 4IR technologies into university curricula is a critical step in preparing students for the future workforce and ensuring the competitiveness and sustainability of educational institutions. The literature underscores the need for proactive measures to address the identified challenges, enhancing the relevance of higher education and improving employment outcomes for graduates.

Integration of 4IR technologies in South Africa's higher education can improve relevance and employment outcomes, but challenges need to be addressed through partnerships and innovation, ensuring students have necessary skills.

6. Conclusion

The integration of 4IR technologies into higher education in South Africa presents an opportunity to enhance education's relevance and improve graduates' employment outcomes. Higher education institutions are crucial in equipping students with the necessary skills and competencies for success in an increasingly technological world; they serve as innovation hubs, providing hands-on learning opportunities. Therefore, South African universities need to develop and update curricula to include essential 4IR skills, such as those related to the Internet of Things (IoT), blockchain, and artificial intelligence (AI), while also incorporating soft skills like critical thinking and creativity (Ilori & Ajagunna, 2020). Universities investing in developing and maintaining E-learning tools and ensuring consistent and reliable digital learning experiences will support students' ongoing learning journeys. Additionally, universities collaboration with industry and government will align educational outcomes with market needs, facilitating internships and research opportunities to prepare graduates for the rapidly changing job market (Ally & Wark, 2020; Cele et al., 2023; Menon & Castrillón, 2019).

South African universities must foster a lifelong learning culture to prepare graduates for technological change and job market demands through flexible, inclusive curricula, catering to academic and non-academic needs. The integration of 4IR technologies also necessitates interdisciplinary collaboration between different academic disciplines and universities, industry, and policymakers, providing remote learning opportunities and enhance the quality of education. Ethical frameworks and digital literacy are crucial for responsible student preparation, as integrating 4IR technologies into curricula raises ethical concerns about privacy, data security, and algorithmic bias (Chan, 2023). Notably, equitably integrating 4IR technologies and digital resources for all students, regardless of socioeconomic status, is crucial by providing affordable devices and internet access. By embracing these strategies, universities can better prepare their graduates for the future workforce, thereby contributing to national development and economic growth.

7. Recommendations

To effectively integrate 4IR technologies into higher education curricula, the following recommendations are proposed:

First, there is a need to develop flexible and inclusive curricula catering to academic and non-academic needs. These curricula should prepare students for the workforce by empowering them with specific qualifications through project-based learning, real-world problem-solving scenarios, and opportunities for cognitive, emotional, and behavioural development (Steenekamp et al., 2020).

Secondly, educators should be encouraged to adopt technology-based tools and platforms for teaching and learning. This is particularly relevant for STEM curricula, emphasising 4IR technologies, such as IoT, machine learning, and blockchain technology skills.

Thirdly, higher education institutions should provide adequate infrastructure and resources to support schools with smart devices like tablets and smartphones to fully leverage technology (Oke & Fernandes, 2020). Additionally, universities need to invest in developing and maintaining E-learning tools to ensure consistent and reliable digital learning experiences (Arek-Bawa & Reddy, 2022).

Fourthly, universities should prioritise institutional support for students to assist students in adapting to the changing job market by providing training in essential soft skills such as communication, creativity, and problem-solving.

Fifthly, an interdisciplinary approach to curricula should be adopted so that integrating multiple disciplines, such as electrical engineering, computer science, and humanities, will give students a broad understanding of how different fields interact in the context of 4IR. Moreover, universities should develop a comprehensive ICT skills framework to address the gap between industry needs and graduate skills, ensuring that curricula align with current industry demands. Universities should also commit to continuous curriculum updates (Ilori & Ajagunna, 2020) by regularly assessing and amending their programs as new skills emerge and new careers develop in response to societal changes. Additionally, collaborations and partnerships with universities abroad and industry partners should be fostered to provide remote learning opportunities and enhance the quality of education.

Finally, it is also important to address infrastructural challenges by tackling significant issues in South Africa, such as insufficient electricity, low tele-density, and limited internet access, to facilitate advanced technological education. The implementation of policy changes to encourage the adoption of technology over traditional methods of teaching and the provision of immediate interventions and support for educators to integrate technology into their teaching practices is critical to achieving an integrated approach.

While these recommendations could significantly enhance the integration of 4IR technologies into higher education curricula, it is essential to acknowledge potential resistance from some educators and institutions. Concerns may arise regarding the displacement of traditional knowledge and the marginalization of students lacking access to digital resources. Additionally, scepticism about the impact of these technologies on improving employment outcomes for graduates' impact on improving graduates' employment outcomes, especially in an uncertain economic context, may persist. However, a well-structured and integrated approach will effectively address these challenges.

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