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Review Article

Leveraging Artificial Intelligence and Other 4IR Technologies for Driving Education 4.0 in South Africa: A Scoping Study

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Abstract: The advent of the fourth Industrial Revolution (4IR) has impacted human life across many disciplines including healthcare, agriculture, telecommunication, manufacturing, education etc. It is characterized by cyber physical systems thus enabling automation of processes, in which devices can autonomously communicate. Some of the technologies that drive 4IR include Artificial Intelligence (AI), Internet of Things (IoT), big data, drone technology, robotics and others. However, many nations are struggling with the challenge of harnessing 4IR potentials because a large number of their populations lack the required skills, thus necessitating the need for appropriate learning, unlearning and relearning. In this scoping study, we explored how to leverage AI as well as other 4IR technologies and their transformative effects in driving education 4.0 in South Africa. We followed scoping study guidelines by searching Scopus and Web of Science bibliographic databases for academic literature and obtained 111 articles from which 27 met all eligibility criteria and were thematically coded. The PRISMA-ScR protocol was adopted for systematic reporting. Findings obtained indicate that South Africa is active in academic research publications regarding 4IR, especially focusing on higher education. However, there is a lack of academic evidence on the upgrade of curricula across all education levels in South Africa for 4IR enabled education 4.0. We make informed recommendations to bridge this gap across different educational levels in the country. Ultimately, policy makers and education stakeholders could leverage our findings and recommendations to provide timely interventions to identified challenges with respect to actualizing 4IR compliant education in South Africa.

Keywords: Artificial Intelligence, Education, Development, Fourth Industrial Revolution, Skills, Technology

Introduction

John McCarthy defined Artificial Intelligence (AI) in 1956 as "the science and engineering of building intelligent machines". It leverages computers, machines, and computational methods to emulate intelligent capabilities in humans (Mondal, 2020). Examples of human intelligence capabilities are language understanding, learning, reasoning, problem solving, conversation, planning, etc. The two broad types of AI are weak AI and strong AI. Weak AI, which is also called Artificial Narrow Intelligence (ANI) is an AI system trained to perform a specific domain task for which it was trained. Such AI systems can become extremely efficient in their own task but lack generalization ability. Despite advances in the field, most of the existing intelligent systems up till October 2022 can at best be categorized as weak (or narrow) AI. Examples of such weak AI systems are autonomous vehicles, recommender systems, robots, spam filters, automated speech recognition and text-to-speech systems, etc. (Borana, 2015). On the other hand, Strong AI is also known as Artificial General Intelligence (AGI). It is a theoretical form of AI in which machines are envisioned to have intelligence equal to humans and will be able to assimilate information as well as modify their functions to autonomously reprogram themselves for general intelligent tasks.

Over the years, AI has gone through evolutionary epochs and the release of ChatGPT in November 2022 by OpenAI marked a major inflection point in its history (Peters et al., 2024). We are now in the era of Generative AI (GenAI), which is gradually moving the world towards the realization of the philosophical ideals of AGI. GenAI is an enhanced deep learning model that takes raw data as input and learns to generate probable outputs (when prompted) that are similar to, but not the same as the original input (Martineau, 2023). Beyond their application in Natural Language Processing (NLP), GenAI has now been massively extended to other data modalities such as images, speech, music, video, etc.

GenAI models built on Transformers' architecture have dominated the AI space since the release of ChatGPT in November 2022. Following on this, year 2023 witnessed a deluge of several Large Language Models (LLM) adapted or specifically trained for different tasks that were hitherto considered unattainable for machines. These models include Pretrained Transformers (GPT-3, GPT-3.5, GPT-4 etc.), Bidirectional Encoder Representations from Transformers (BERT), Text-to-Text Transfer Transformer (T5), Bidirectional and Auto-Regressive Transformers (BART), Pathways Language Model (PaLM), Language Model for Dialogue Applications (LaMDA), Large Language Model Meta AI (LLaMA). In fact, Bubeck et al. (2023) posited that GPT-4 could be considered an early version of an AGI system. Although still undergoing continuous development, it supports multi- modal inputs, which embeds stronger capability towards AGI (Zhao et al., 2026; OpenAI, 2023).

Fourth Industrial Revolution (4IR or Industry 4.0) compliant education is an educational approach that is designed for preparing learners for the various challenges and opportunities presented by the emergence of AI and other 4IR technologies. The core characteristics of 4IR are the widespread adoption of its enabling technologies such as robotics, Internet of Things (IoT), big data analytics, Virtual and Augmented Reality (VR/AR), blockchain, drone/autonomous vehicle and principally the revolutionary advances in AI. This has culminated in the birth of Society 4.0, with significant societal changes in areas such as economy, industry, education and job market. Given the recent disruptions in AI, 4IR compliant education aims to equip learners to cope and thrive in a world order that is now heavily influenced by the earlier listed 4IR technologies and the ongoing advances AI models (Hossain, 2023; Melville et al., 2023).

Researchers are actively exploring how AI and the other 4IR technologies are transforming traditional education towards the realization of AI/4IR enabled education tagged Education 4.0 (Chaka, 2023; Bonfield et al., 2020). Some of the potentials in this regard especially for South Africa, a country with about twelve official languages and significant resource disparities are:

i) Creation of personalized learning materials specifically tailored to a learner's individual need
ii) Production of engaging learning contents for better comprehension of complex concepts
iii) Enhanced effectiveness of teachers through automation of tasks such as paper grading, prompt feedbacks to learners and creation of lesson plans
iv) Development of learning aids for learners with disabilities
v) Automated translation of educational resources across official languages, and host of others

Thus, the aim of this research is to explore how to leverage AI and its transformative effects for driving 4IR compliant education (i.e., Education 4.0) in South Africa through Scoping study. Research Questions (RQs) for Scoping studies are usually broad in nature because they seek to provide both breadth and depth of coverage. Based on recommendations by Levac et al. (2010), the RQs that guide the scope of enquiry should be properly articulated to include the concept, target population and an effective search strategy. Thus, the following are the two Research Questions (RQs) to be answered in order to achieve the research aim of this scoping study.

RQ1: What is the extent to which South African academic curricula cater for 4IR compliant education?

RQ2: How can AI be effectively integrated into the South African education curriculum to prepare students for the 4IR?

Related Work

Chen et al. (2024) conducted a scoping review to determine the current state of AI in entrepreneurship education to discover possible research gaps in the adoption of some pedagogical designs and intelligent technologies applied in the domain. Several studies focusing on the adoption of AI in entrepreneurship education were harvested and analyzed using various data items such as research questions, research quality, definition of intelligent technology, research method, education purpose, sample size and publication. The authors found that big data and machine learning algorithms were introduced into entrepreneurship education. Machine learning was also discovered to reduce educators' challenges while also improving the accuracy of assessment. Entrepreneurial analytics is credited with the potential of analysing entrepreneurial tasks and projects with lower costs and high effectiveness. Big data analytics utilise multimodal data to improve the effectiveness of entrepreneurship education and detect entrepreneurial opportunities. Despite these benefits, the authors posited that AI in entrepreneurship education requires additional sophisticated pedagogical designs in diagnosis, prediction, intervention, prevention and recommendation, combined with specific entrepreneurial learning content and entrepreneurial procedure, obeying entrepreneurial pedagogy.

In another study, Murphy et al. (2021) while acknowledging the potential of AI in improving health equity within and between countries, investigated the ethical implications of AI deployment in the health sector to reduce any inherent harms especially for the most vulnerable. The authors adopted a scoping review methodology to identify what ethical issues have been identified in relation to AI in healthcare especially from a global perspective. Concepts such as health, ethics, artificial intelligence and other related terms were used as search items in eight electronic databases for suitable articles. Descriptive and thematic analysis were thereafter performed from the records obtained after proper screening. Results obtained indicated that only 103 out of 12,722 articles retrieved met inclusion criteria and focused on the ethics of AI in healthcare, especially on diagnostics, carer robots and precision medicine but none on ethics of AI in public and population health. Though a few ethical concerns relating to trust, privacy, accountability, bias and responsibility were highlighted by the authors, they failed to discuss the ethics of AI in global health especially in low-and-middle-income countries.

In a scoping review conducted by Chaka (2020), educational systems were noted to be responding to the rapidly changing technologies and workforce demand triggered by the 4IR. High quality articles were examined in the scoping review to identify initial teacher training activities and challenges particularly focusing on 21st century skills and technology integration within the context of the 4IR. Results obtained indicate that teacher training institute needs alignment and synergy throughout the organization to ensure effective response to changing needs and contexts. New opportunities are thrown up to develop preservice teachers' 21st century skills to meet the development in the changing 4IR technologies. Although the role of teacher training institutes and teacher educators may be affected with these technologies as they also put pressure on the institute and teacher educators to maintain the required skills.

Furthermore, Awodiji and Naicker (2023) examined how 4IR and AI has altered career and institutional development and assessed the continuous professional development needs of school leaders to prepare them for the 4IR skills. The authors adopted the human capital development theory and a survey as well as random and snowballing approaches to select 284 school leaders. Findings revealed that school leaders demonstrate moderate proficiency in basic information technology applications, different continuous professional development are required for school leaders in primary and secondary education regarding information management and evaluation. Thus, school leaders are required to receive training on 4IR attributes including basic information technology applications and cutting-edge technologies.

In Gordon et al. (2024), AI was noted to be rapidly transforming healthcare and a quest for exploring how it is changing teaching, learning and educational practice in medical education was pursued by mapping relevant literature on AI applications in medical education, identified their main findings and inherent gaps for future studies. In their rapid scoping review, the authors applied Arksey and O'Malley (2005) framework (as similarly applied in the study at hand) while complying with the guidelines of STORIES and BEME by comprehensively searching major databases including PubMed/MEDLINE, EMBASE and MedEDPublish. Multiple author pairs were used to chart data, which was further synthesized into various thematic maps and charts to ensure a wider representation of the landscape. Results obtained indicated studies covering various AI application areas in medical education including AI for teaching, assessment, admissions and clinical reasoning. Artificial intelligence divergent roles were also highlighted such as augmenting traditional educational methods to introducing creative innovative practices as well as the need for ethical regulations of AI application in medical education in order to address potential risks. The FACETS framework was consequently proposed to enhance future high utility reporting of AI application in medical education.

Vinuesa et al. (2020) identified the potential contributions of Artificial Intelligence (AI) in achieving the Sustainable Development Goals (SDGs), driven by an increasing interest in the application of 4IR technologies. The authors observed that several multilateral organizations have backed initiatives to raise awareness about the significance of incorporating AI into sustainable development projects to enhance the quality of life for citizens through educational enhancements. Their analysis primarily focused on aspects of lifelong learning and inclusive, equitable quality education as they relate to sustainable development, where AI can be applied. Through a comprehensive review of existing academic literature, the findings indicated various benefits of AI in education, including improved accessibility to technologies, increased employment opportunities and education at varying levels, contributing to greater equity among global citizens. Furthermore, AI and 4IR technologies have the potential to be integrated into future global enterprises, enabling the tracking, monitoring and enhancement of services related to global education. However, the study also highlighted significant challenges associated with the implementation of AI, such as infrastructure, security, ethics and the risk of job displacement for the repetitive and low-skilled workforce, which is predominantly susceptible to the waves of automation driven by AI and other 4IR technologies.

Goodell et al. (2021) had a holistic retrospection review of AI and machine learning technologies in financial scholarship. Co-citation and bibliometric analyses were used to infer thematic structure of AI and machine learning in finance for 16-year period (1986-2021). Nine and eight co-citation and bibliometric coupling specific finance clusters respectively relating to AI and machine learning were identified as well as three critical groups of finance scholarships including portfolio construction, valuation and investor behaviors, financial fraud, distress and sentiment inference, forecasting and planning. The thematic clusters that were identified include financial distress and corporate failure, text mining and sentiment analysis, algorithmic and high-frequency trading, investor behaviour and trade classification, forecasting and predictive analysis, scheduling, pricing and valuation as well as financial fraud. Some of the influential topics identified under these various clusters include financial management, backpropagation, transaction cost analysis, incomplete markets, genetic algorithm, parameter estimation, numerical algorithm, stock prediction, option pricing, investment, insurance, operational risks, micro credit, behavioural finance, big data, etc. Research trends and directions regarding AI and machine learning in finance research was presented thus providing an assessment and application in finance research.

The foregoing works explored the inter-play of AI and 4IR technologies across different sectors leveraging scoping, thematic, bibliometric and retrospective evidence synthesis methods. The study at hand however takes a deeper dive through scoping study to unearth how AI and other 4IR technologies could be leveraged to drive education 4.0 within the South African context.

Materials and Methods

In order to rigorously scope the literature, we adopted the methods outlined by Levac et al. (2010), which extended the original methodology for scoping review that was innovatively developed by Arksey and O'Malley (2005). We also adopted the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) in Tricco et al. (2018) for presenting the procedure and findings of this study. The details of the methods and tools as systematically harmonized for this work are hereafter presented. The search concepts for this study are Artificial Intelligence and the Fourth Industrial Revolution Impacts on Education.

There are different studies that have been published both in academic and grey literature on the interplay and impacts of AI and 4IR on Education 4.0 (Bonfield et al. 2020). But for this study, our search focus was on academic literature.

Protocol and Eligibility Criteria

The protocol for the design and conduct of this study was developed by the two co-principal investigators (ST and EA). The inclusion criteria for literature are succinctly presented in Table 1. The research team members arrived at the selected criteria in Table 1 after rigorous deliberations, refinement and consensus building through physical meetings, each one lasting for approximately 60 minutes.

Information Sources

For the peer-reviewed academic literature in this work, two electronic bibliographic databases were searched for content spanning a period of 20 years from 2004 to 2024 (Murphy et al., 2021). This timeframe was selected to capture the technological innovations (such as Web 2.0), which laid a robust foundation for the emergence of Industry 4.0 in 2011 (Lasi et al., 2014; Xu et al., 2018). The chosen timeframe provides a comprehensive longitudinal view on the evolution of digital education technologies and strategies, which led to the birth of Education 4.0 paradigm (Hussin, 2018).

As shown in Table 2, the databases include Scopus and Web of Science (WoS).

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Search and Selection of Sources of Evidence

For the search strategy, the search phrase (i.e., Artificial Intelligence and the Fourth Industrial Revolution Impacts on Education) were translated to each of the academic databases using their respective search input boxes. The search terms used for the academic databases include title, abstract, keyword, year range, subject and appropriate combinations of the three boolean operators (AND, OR, NOT). Filters that were related to the search phrase of Artificial Intelligence and the Fourth Industrial Revolution impacts on Education were appositely applied to ensure only core articles were curated for further analysis. PRISMA-ScR recommends using a study Flow Diagram to describe the screening and study selection process as shown in Figure 1.

As illustrated in the Figure, we performed two major iterations (i.e., search/filtering, screening/eligibility assessment) to arrive at relevant articles for final inclusion.

Table 1: Inclusion and exclusion criteria for academic literature

Inclusion Criteria	Exclusion Criteria
Articles reported on the core search concepts (i.e. *Artificial Intelligence and the Fourth Industrial Revolution Impacts on Education*).	Articles reported on other concepts outside of *Artificial Intelligence and the Fourth Industrial Revolution Impacts on Education.*
Articles are written in English.	Articles unavailable in English.
Articles are published between 2004 to 2024 (the last 20 years).	Articles published before 2004.
Articles are in peer-reviewed outlets.	Non-peer-reviewed articles.
Articles in outlet that are indexed/archived in any of the pre-selected bibliographic databases (i.e., *Scopus* and *WoS*).	Articles not indexed/archived in the preselected bibliographic databases.
Articles mentioning AI OR 4IR AND education. (Table 3 contains details of sub-string combinations).	Articles mentioning AI and 4IR without mentioning education are omitted.
High quality articles with no bias and high reliability	Low quality articles with bias and low reliability.

Table 2: Bibliographic databases of academic literature

Bibliographic Data Sources	Link
Scopus	https://www.scopus.com/search/form.uri?display=basic#basic
Web of Science (WoS)	https://clarivate.com/products/scientific-and-academic https://clarivate.com/products/scientific-and-academic-research/research-discovery-and-workflow-solutions/webofscience-platform/research/research-discovery-and-workflow https://clarivate.com/products/scientific-and-academic-research/research-discovery-and-workflow-solutions/webofscience-platform/solutions/webofscience-platform/

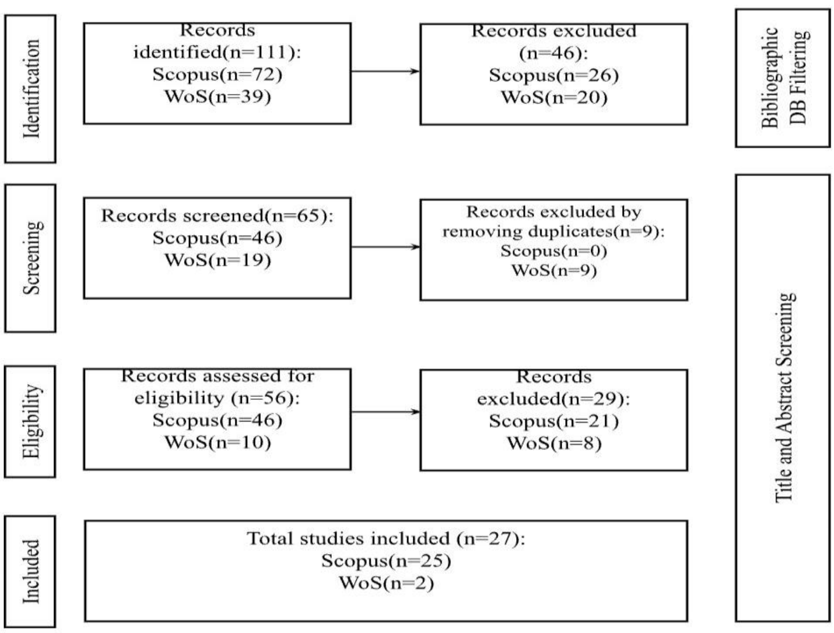

Fig. 1: PRISMA-ScR flow diagram for the scoping study data collection

The first iteration involves entering the search string in the text input box of the respective bibliographic databases using the string combinations presented in Table 3 and with full consideration for the inclusion/exclusion criteria presented in Table 1. To ensure reliability in the second iteration (i.e. screening), the process was conducted in two stages. Firstly, two reviewers (EA and AA) independently screened titles and abstracts against the inclusion criteria. Disagreements between these reviewers were discussed until there was a consensus. Secondly, full-text articles were reviewed independently by (EA and AA). In cases of uncertainty regarding eligibility, a third reviewer (ST or RS) was consulted for a final decision. The results of included/excluded records are succinctly presented in Section 4.

Data Charting Process and Data Items

The extracted data were downloaded from the two bibliometric data sources in comma-separated values (.csv) formats. However, for ease of charting, the downloaded data were converted to standard Microsoft Excel (.xlsx) formats and uploaded to Google Sheets, a cloud-based spreadsheet application. This is to afford easy collaboration for further iterative screening of articles by the research team members (EA, ST and AA). The Microsoft Excel files that contain the final set of selected articles for the two bibliographic databases (Scopus and WoS) were validated on local laptops in Microsoft Excel (Office 365) by (EA and AA). The second column of Table 4 contains the original data items from each of Scopus and WoS databases while the third column contains the harmonized data items that were retained for the included records.

Table 3: Search string for the scoping review

Artificial Intelligence		Fourth Industrial Revolution		Education
"artificial intelligence" OR "machine learning" OR "deep learning" OR "data science"	OR	"fourth industrial revolution" OR "4IR" OR "industry 4.0" OR "emerging technologies" OR "technological innovations"	AND	"learning" OR "teaching" OR "education" OR "higher education" OR "secondary education" OR "primary education" OR "pedagogies" OR "training" OR "skills development" OR "literacy" OR "curriculum" OR "education 4.0"

Table 4: Data items for the extracted data

Bibliographic Database	Original Data Items	Harmonised Data Items
Scopus	Authors, Author full names, Title, Year, Source Title, Volume, Issue, Art. No., Page Count, Cited by, Affiliations, Authors with Affiliations, Abstract, Author Keywords, Publisher, Document Type	
Web of Science	Authors, Authors Full Names, Article Title, Source Title, Document Type, Author Keywords, Abstract, Addresses, Affiliations, Funding Orgs, Times Cited, All Databases, Publisher, Publisher City, Publisher Address, eISSN, Journal Abbreviation, Publication Date, Publication Year, Volume, Issues, Number of Pages, Web of Science Index, Research Areas.	Authors, Title, Year, Source Title, Volume, Issue, Page Count, Cited by, Affiliations, Abstract, Author Keywords, Publisher, Document Type

Results and Discussion

Selection of Sources of Evidence

The search date, search term, filtering steps, number of accepted and rejected articles/records from the Scopus bibliographic database are shown in Table 5, while those of WoS database are shown in Table 6. The filtering terms are keywords, article publication stage, year range of publications, document type, language screening and subject area.

As earlier mentioned, the search/filtering, screening and eligibility assessment of records were carried out systematically in three iterations. As illustrated in Figure 1, Table 5 and Table 6, the total records identified at the end of

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the first iteration were (n = 111) (with Scopus = 72 and WoS = 39) while the total records excluded were (n = 46) (with Scopus = 26 and WoS = 20). At the end of the second iteration, the total records included were (n = 65) (with Scopus = 46 and WoS = 19) while the excluded records were (n = 9) (with Scopus = 0 and WoS = 9).

Table 5: Selection and filtering of evidence sources from Scopus

Search Date: 17/04/2024		
Search Engine/Bibliographic Database: Scopus		
Search Term: TITLE-ABS-KEY Artificial Intelligence and Fourth Industrial Revolution Impacts on Education		
Stages		Accept
Step 1	*Keywords:* Artificial Intelligence, Industry 4.0, Fourth Industrial Revolution, Engineering Education, Internet of Things, Education, Robotics, Machine Learning, 4IR, Education Computing, Education 4.0, Information Technology, Natural Language Processing, Employment, Learning Systems, Smart Classroom, Educational Technology, Educational Robots, Educational Innovation, Digital Education	72
Step 2	*Article Publication Stage:* Final, Articles in Press	62
Step 3	*Year Range of Publications:* 2004-2024(20 Years)	62
Step 4	*Document Type:* “Articles”, “Conference Papers”, “Book Chapter”, and “Review”	60
Step 5	*Language Screening:* Include documents in English only.	58
Step 6	*Subject Area:* Computer Science, Social Sciences, Engineering, Business, Management and Accounting, Decision Sciences, Economics, Econometrics and Finance, Mathematics, Health, Arts and Humanities	56
	Total Included	46

Table 6: Selection and filtering of evidence sources from Web of Science

Search Date: 29/04/2024			
Search Engine: Web of Science			
Search Terms: TITLE-ABS-KEY Artificial Intelligence and Fourth Industrial Revolution Impacts on Education			
Stages		Accept	Reject
Step 1	*Keywords:* Fourth Industrial Revolution, Industry 4.0, Digitalization, Education, Artificial Intelligence, Automation, IOT, Machine Learning	39	0
Step 2	*Article Publication Stage:* Final, Articles in Press, Early Access, Open Access	32	7
Step 3	*Year Range of Publications:* 2004-2024(20 Years)	32	0
Step 4	*Document Type:* “Articles”, “Book Chapter”, “Review”	26	6
Step 5	*Language Screening:* Include documents in English only.	25	1
Step 6	*Subject Area:* Education, Educational Research, Computer Science, Science Technology, Business Economics, Health Care Sciences Services, Information Science Library Science, Medical Informatics, Arts and Humanities, Engineering	21	11
	Total Included	10	

A total of 56 records were assessed for eligibility at the third iteration culminating in the exclusion of 29 records. Thus, the total records that fully met the inclusion criteria were 27 (Figure 1) among which records from Scopus were (n = 25, 92.59%) and those from WoS were (n = 2, 7.41%). The twenty-seven (27) articles were further taken for descriptive and thematic analysis as reported in the subsequent sections.

Characteristics of Sources of Evidence

Table 7 presents the core characteristics of the two bibliographic databases (i.e., Scopus and Web of Science) from where the sources of evidence/articles in this work were curated. The publications indexed in these two databases enjoy long-standing credibility and are acclaimed to be authoritative. This is due to thorough peer-review and strict adherence to standard academic publishing practices. Scopus was launched by Elsevier in 2004 and it is currently one of the largest abstract and citation databases of peer-reviewed literature. As of January 2024, the total number of journals = 42,402, publications = 94+ million, citations = 2.4+ billion, author profile = 19.6+ million and number of disciplines covered = 330. Web of Science was founded in 1964 at the Institute for Scientific Information (ISI) and it is currently managed by Clarivate Analytics. Based on latest statistics, the total number of journals in WoS = 24,908, publications = 92+ million, citations = 2.2+ billions, author users' profiles = 28 million and the number of disciplines = 254.

Synthesis of Results

The data synthesis in this work followed deductive thematic analysis, a top-down approach that is often anchored on a chosen theoretical framework (which is Arksey and O'Malley in this work) and specific research questions to ensure rigorous data charting (Fereday and Muir-Cochrane, 2006). Initial thematic codes were generated based on the two research questions. Two reviewers (EA and AA) independently read the full texts of included articles to identify recurring patterns. These patterns were then grouped into the four final themes: AI/4IR enabling technologies, educational levels, educational activities, and countries of first authors. Notably, the discrepancies in thematic coding were resolved through consensus meetings with a third reviewer (ST or RS).

Findings Based on Descriptive Analysis

Our literature search focused on 20 years, which ranges from 2004 to 2024, however, the years covered by the included publications fall between 2018 and 2024 (Figure 2).

Table 7: Core Characteristics of the sources of evidence

	Journals	Publications	Citations	Author Profiles	No of Disciplines/Research Categories
Scopus	42,402	94+ Million	2.4+ Billion	19.6+ Million	330
Web of Science	24,908	92+ Million	2.2+ Billion	28 Million	254

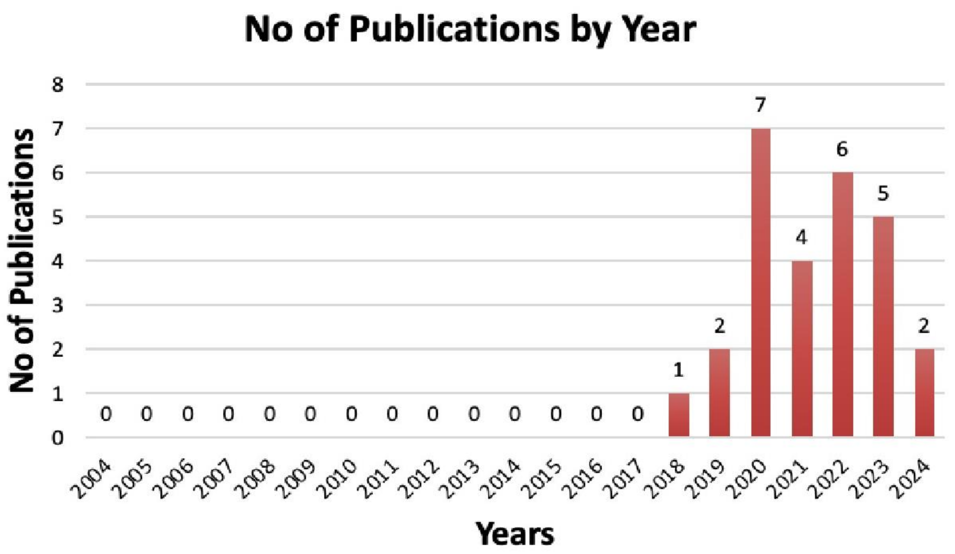

Fig. 2: Number of publications by year from 2004 to 2024

The highest number of publications (n = 7) was in 2020, followed by (n = 6) in 2022 and then (n = 5) in 2023. The small number of publications (n = 2) in 2024 could be attributed to the time the literature searches were conducted for the two databases, which was the first quarter of 2024 (i.e., 17/04/2024 for Scopus and 29/04/2024 for Web of Science). The surge in literature between 2018 and 2023 based on our search strings could be attributed to the recent spike of interest in AI starting with Deep Learning advances in 2012, which snowballed into the emergence of the GenAI-enabled ChatGPT in late 2022.

First authors of the included publications are located in 22 different countries with the study focusing on their respective country of affiliation. However, one of the publications, with the first author in the United States of America (USA) focused on the European Union for the study. Notably, the highest number of publications (n = 3) had primary authors located in South Africa (n = 3) while Russia, South Korea and Spain have the same number of publications (n = 2). All the other countries (Figure 3) with primary authors have one publication each (Figures 3 and 4). These results clearly indicate the mild but leading role being played by South African research stakeholders towards leveraging on the advances of AI and other 4IR enabling technologies for Education 4.0.

Figures 4 and 5 presents the targeted education levels by authors per region and country derived from Figure 3. The three publications that were authored in South Africa addressed higher education. Two of the other countries with two publications (i.e., Russia and South Korea) also targeted higher education whereas Spain targeted primary and secondary education levels. The one publication from Nigeria addressed the three levels of education (i.e., primary, secondary, and higher education levels). Similarly, the study that focused on the EU targeted the three levels of education. The one publication from China also focused on primary and secondary education levels, but we conjecture that getting only one publication from China could be attributed to our language inclusion criteria, which is English. All other countries with one publication each also focused on higher education. Furthermore, the distribution of publications across different education levels are presented in Figure 6. Higher education has the highest number of publications (n = 21) as the sole focus. There are two (2) publications each with sole focus on secondary education, combination of secondary and primary education as well as combination of higher, secondary, and primary education levels (n = 2).

The foregoing clearly unearths the fact that current efforts on the inclusion of AI and other enabling 4IR technologies are predominantly targeted at higher education. It is actually not a surprise that more efforts are directed at higher education across countries and especially in South Africa. The higher education system is often established and funded to serve as the engine room of national innovation and creativity. However, in our opinion, efforts should also be made by researchers in South Africa to embark on studies with focus on the applications of AI and other 4IR enabling technologies at both primary and secondary levels. Government should also make it a priority to provide necessary fundings that will power such research endeavors. Notably, the burgeoning opportunities of Industry 4.0 can only be leveraged by the adolescent/youth populations that are equipped with Education 4.0 fundamental knowledge and skills.

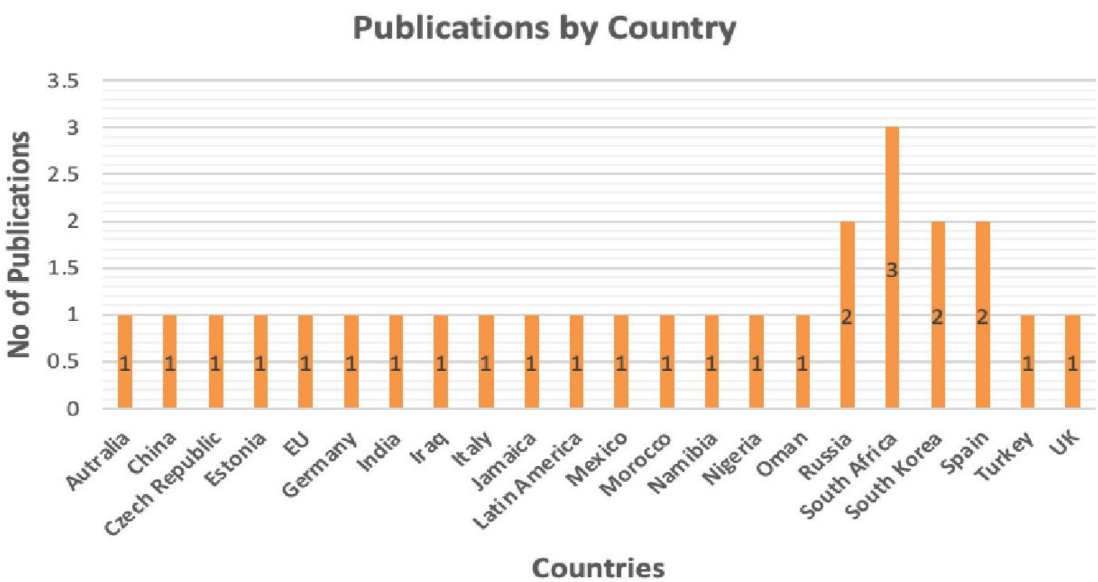

Fig. 3: Number of publications on applications of AI/4IR by country

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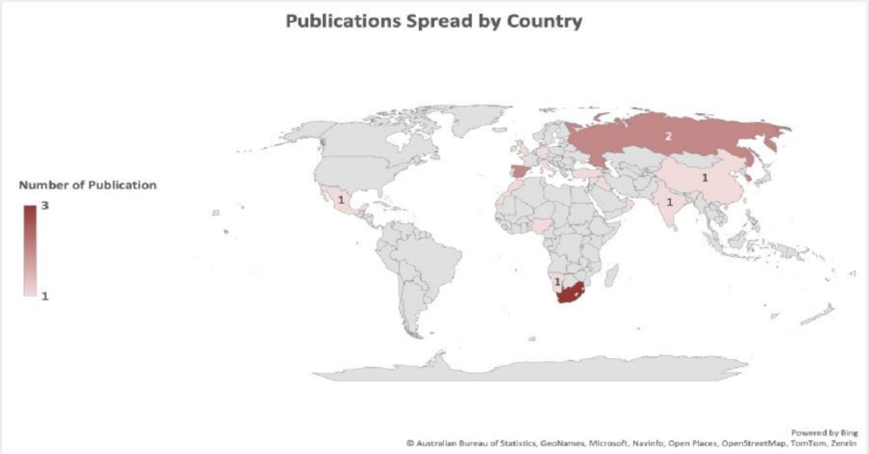

Fig. 4: Number of publications spread of AI/4IR technologies' applications by region

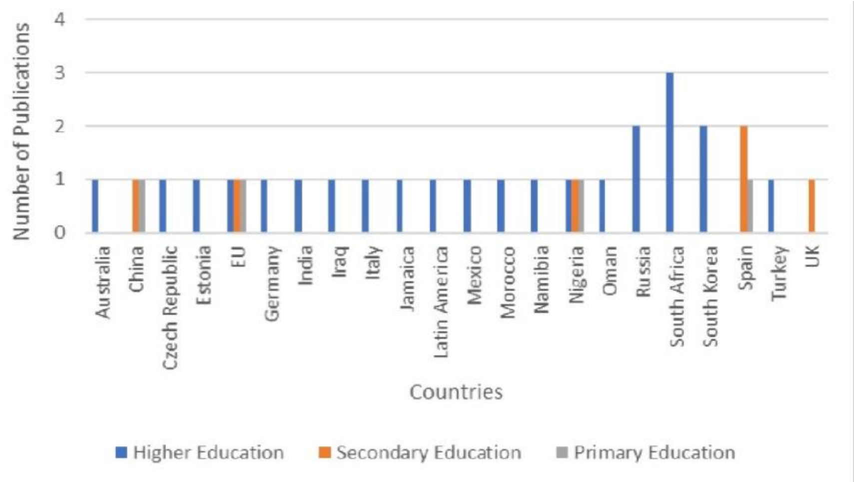

Fig. 5: Number of publications on applications of AI/4IR technologies by country and education level

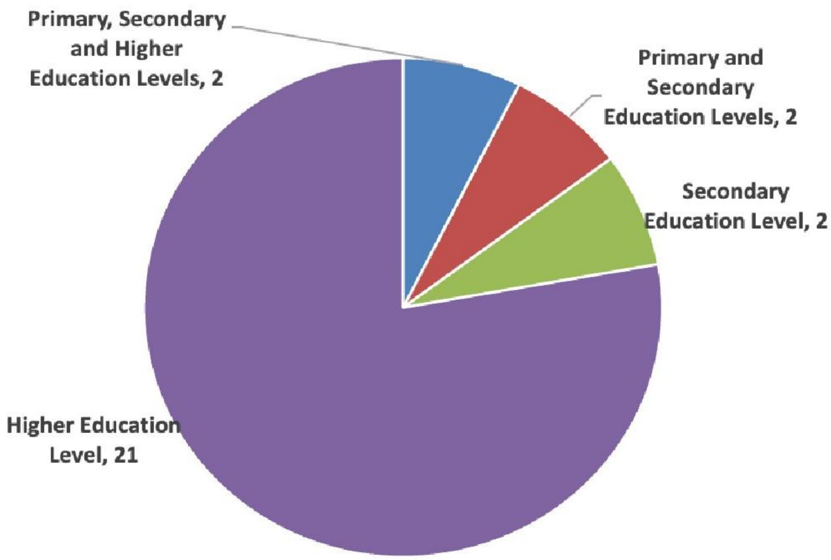

Fig. 6: Number of publications on applications of AI/4IR technologies by education levels

Further descriptive analysis explores the seven (7) individual educational activities that were addressed by the included publications as shown in Figure 7. The highest number of publications (n = 19) mentioned Learning with respect to the applications of AI and other 4IR enabled technologies in education. This is followed by teaching with thirteen (13) publications. Each of research and curriculum has seven (7) publications, management has five (5), policy has two (2) while only one (1) publication addressed infrastructure, with focus on smart classroom. Further elaborations on the combinations of educational activities that were addressed by each of the twenty-seven (27) included publications are graphically presented in Figure 8.

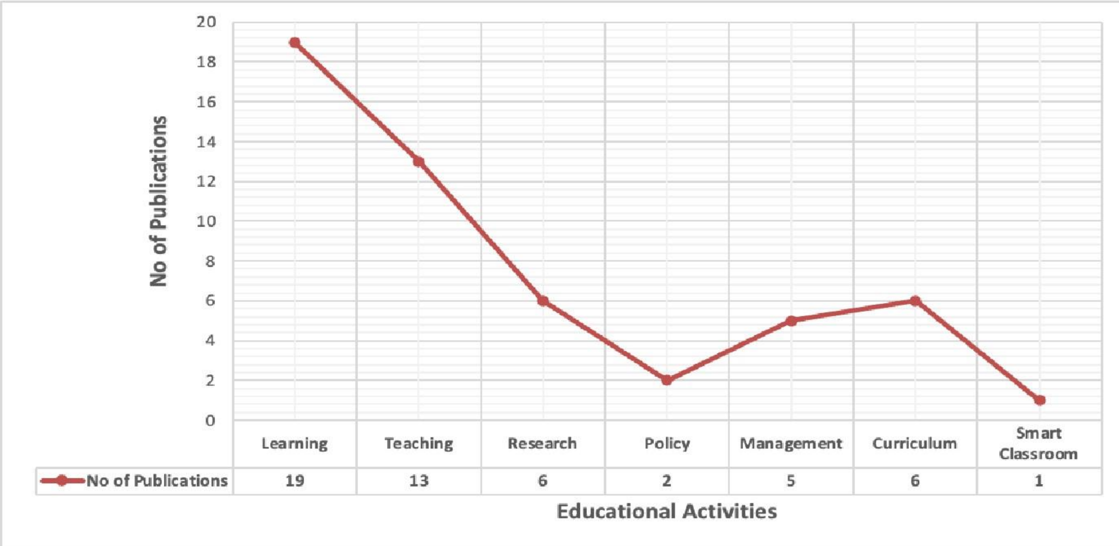

Fig. 7: Number of publications on applications of AI/4IR technologies by each education activity

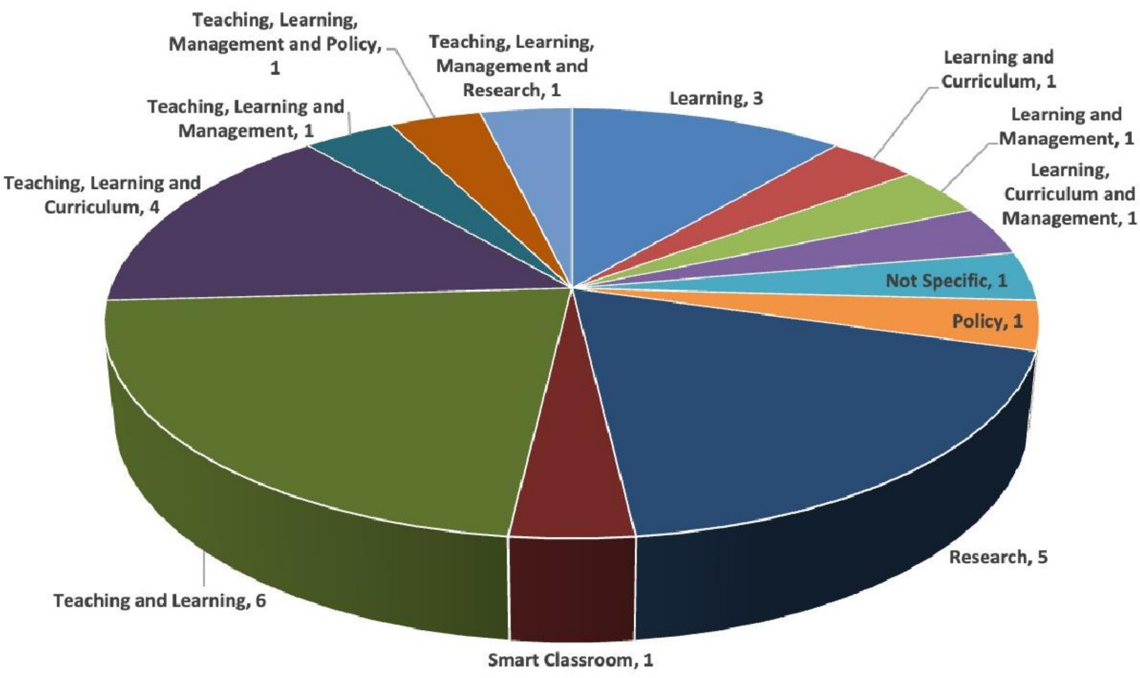

Fig. 8: Number of publications on applications of AI/4IR technologies by education activities

The actual AI and 4IR enabling technologies as well as the respective number of publications focusing on each of them are shown in Figure 9. The highest number of publications (n = 25) are on Artificial Intelligence (AI) out of which three (3) publications are on ChatBots (such as ChatGPT) and four (4) publications are on Machine Learning (ML). This is followed by robotics (n = 12) then IoT with (n = 9) while big data and blockchain have the same number of publications (n = 5). 3D printing/additive manufacturing has four (4) publications, Virtual Reality/Augmented Reality (VR/AR) as well as cloud computing has three (3) publications each, while biotechnology as well as drone/autonomous technologies has one (1) publication each. This clearly illustrates that AI has become the major enabler of Industry 4.0 among the various 4IR enabling technologies. Robotics as a branch of AI having the second highest number of publications further reinforces this standpoint empirically.

Findings Based on Thematic Analysis

The thematic analysis was carried out to provide answers to RQ1 and RQ2 as reported in the subsequent sub-sections.

What is the extent to which South African academic curricula cater for 4IR compliant education? (RQ1)

Three studies that met the inclusion criteria (Chaka, 2022; 2023; Hoosain et al., 2020) have their first authors located in South Africa as mentioned in the previous section. Chaka (2022; 2023), who published two of the three papers, is affiliated to the Department of English Studies, University of South Africa, Pretoria, South Africa. The author argued that most previous studies about 4IR in higher education focused on single 4IR technologies in isolation (Chaka, 2023). Thus, he attempted to contribute to closing this gap through systematic literature review of 26 selected journal articles covering a period of six (6) years from 2013 to 2019. The applications, prospects and challenges of AI, robotics and blockchain at selected Higher Education Institutions (HEIs) were explored. There were three key findings reported in this study that support the relevance of AI, robotics and blockchain in higher education. These include:

i) The dominant AI technologies for learning are chatbots, which provide personalized, scalable, and affordable learning
ii) Applications of robotics possess meta-teaching and meta-learning orientation by applying robotics in some higher education courses to evaluate how or whether teaching or learning occurred
iii) Some applications of blockchain include digital grading, credentialing and certification, real time contracting as well as time stamping of learning

The foregoing provides insight into the fact that the three AI/4IR enabling technologies in the analyzed studies focused majorly on learning and teaching. This agrees with the descriptive analysis earlier presented in this paper.

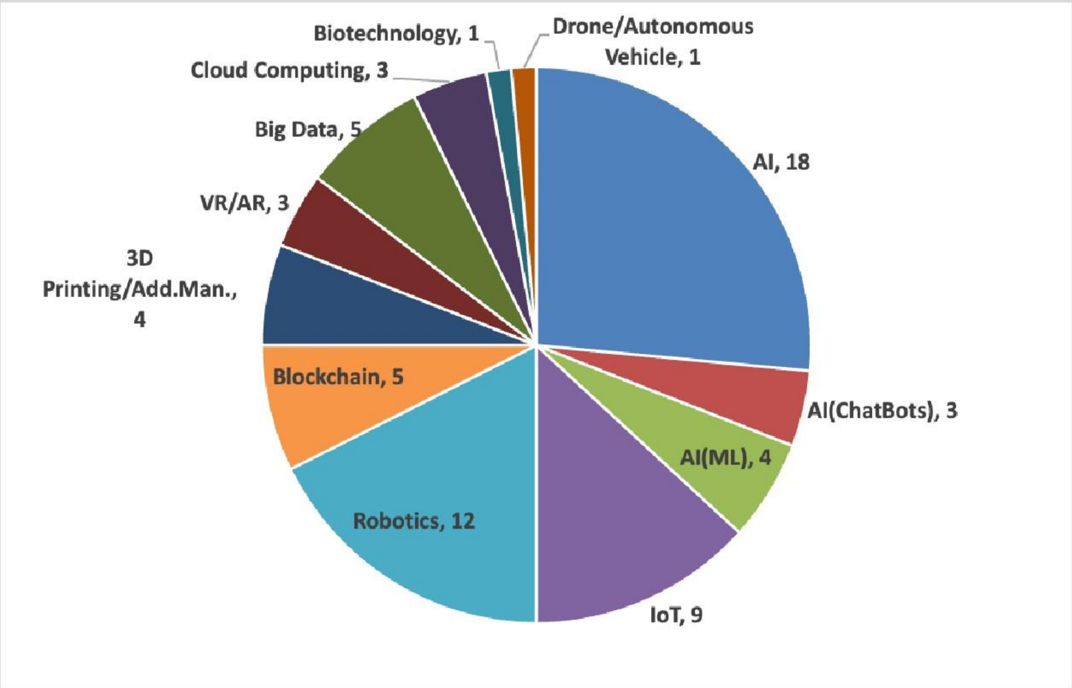

Fig. 9: Number of publications with focus on applications of different AI/4IR technologies

Nevertheless, we took a deeper dive into this study to unearth the study sites of the analyzed publications. This is to properly answer RQ1 in terms of the extent to which South Africa academic curriculum caters for 4IR compliant education. The author reported that the notable Universities for their usage of AI technologies are predominantly from the United States of America (USA) (5 universities) and Poland (2 universities) with one university each from the United Kingdom (UK), Pakistan, Japan, Australia, Brazil, India, and Taiwan (Chaka, 2023). Findings by this author also revealed that six (6) of the Universities at which educational robotics were explored for higher education are sited in the USA, with one (1) each from Uganda, Australia, Germany, Italy, Sweden, and South Korea (Chaka, 2023). However, the topmost challenge with educational robots is that in many of these institutions, faculty members are not yet equipped to use robotics and curricula are not yet updated to accommodate educational robots as teaching assistants/aids.

Chaka (2023) further employed ChatGPT as a use case tool to extract and repurpose different stylised-facts on the prospects and challenges of AI and automation as instances of 4IR technologies.

The third South African based paper (Hoosain et al., 2020) has affiliation to the Department of Electrical and Electronic Engineering, University of Johannesburg, South Africa. The authors explored how 4IR technologies and the concept of circular economy are used in different sectors such as education, ICT, built environment, healthcare as well as mining and manufacturing to understand and resolve the 17 United Nations' Sustainable Development Goals (UN-SDGs). The study reported that an Institute for Intelligent Systems (IIS) was established at the University of Johannesburg (UJ) in 2016. This was aimed at achieving Industry 4.0 initiatives within the university (Institute for Intelligent Systems, 2025) towards achieving the SDG #4 goal of quality education. It was also reported in the article that UJ established a Makerspace in November 2017, which was equipped with a 3D printing and scanning area as well as robotics and other digital tools. Students and lecturers utilize the space and tools for educational purposes. According to the author, Engineering teams at the UJ used the facilities in the laboratory to design and develop portable 3D printed mechanical ventilators to treat multiple patients during the COVID-19 pandemic (Venter, 2020).

Anchoring on the foregoing three publications from South African, the following can be inferred with respect to Research Question 1:

i) Notable universities on the usage of AI technologies and educational robots are predominantly from the United States of America (USA). However, a researcher from University of South Africa leveraged ChatGPT for research data collection in a stylised-fact analysis of opportunities and challenges of AI/4IR enabled technologies
ii) Based on this scoping study, there is currently no academic publication on the upgrade of curricula for 4IR compliant education across primary, secondary, and higher education levels in South Africa. This gap in 4IR compliant curriculum needs to be closed with urgency, however, this will require pragmatic efforts on the part of all education stakeholders in South Africa

How can AI be effectively integrated into the South African education curriculum to prepare students for 4IR? (RQ2).

One of the findings reported in subsection 4.3.2.1 established the lack of academic evidence on the upgrade of curricula across all education levels in South Africa for 4IR compliant education. We therefore ventured to explore instances of 4IR compliant curricula upgrade efforts from other countries. Propitiously, six of the studies that met the inclusion criteria in this scoping study mentioned curriculum as one of the educational activities with foci across primary, secondary, and higher education levels (Ilori and Ajagunna, 2020; Chun, 2021; Howson et al., 2022; Kuddus, 2022; Shenkoya and Kim, 2023; Benriyene et al., 2024). Further analysis into Chun (2021) research was aimed at extracting potential lessons for South Africa by determining how 4IR technologies (AI and 3D printing) have been integrated into curricula in China. Chun (2021) presented a prototype curriculum and teaching methodologies centered on Computer-Aided Design (CAD) tools and 3D printing concepts, designed for practical implementation in public education. Thus, given the current advances in Generative AI, we herein propose an extension to this prototype curriculum for AI-enabled 3D printing topics, that could be adopted in South Africa contextually across relevant educational grades. This proposed curriculum/topics adaptation is presented in Figure 10. It is grounded in constructionist pedagogy, which posits that learning is most effective when learners are actively engaged in constructing tangible objects in the real world (Papert and Harel, 1991; Blikstein, 2013). Thus, implementing this in South African context would require three phased approaches as hereafter described vis-a-vis the components of Figure 10.

Curriculum Integration: The seven topics indicated in the Figure can sit within the Technology subjects across Grades 7-9 in the Curriculum and Assessment Policy Statements (CAPS) (Department of Basic Education [DBE], 2021). This will enhance the "Graphics and Communication" strand by replacing manual drawing with Computer Aided Design (CAD) software and 4IR-enabled rapid prototyping.

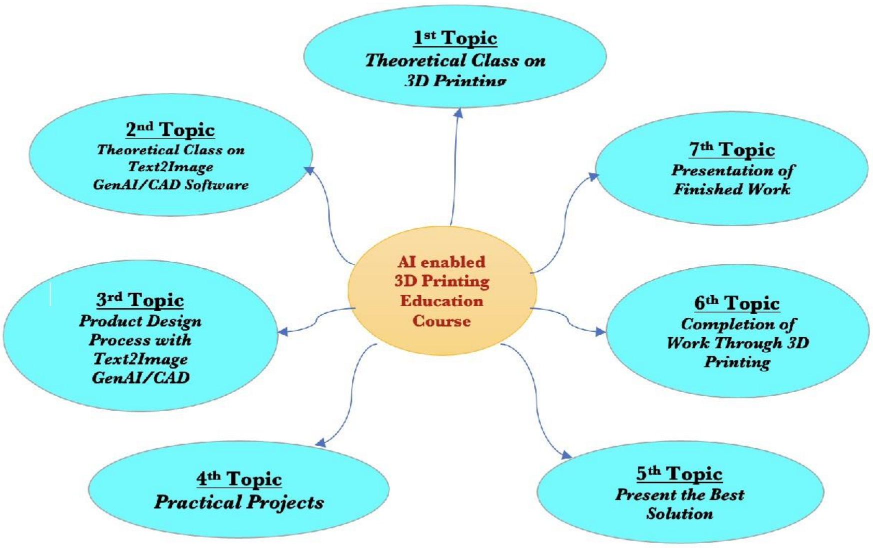

Fig. 10: Extended prototype curriculum for AI-enabled 3D printing education topics (Extended from Chun, 2021)

Upskilling of Teachers: Educators in selected schools at each province in South Africa should be capacitated in both AI-assisted design and AI-enabled CAD software. This should involve teaching them to use AI prompts to generate initial 3D models, which the students can refine towards effective implementation of the 1st, 2nd, 3rd topics.

Upgrade of Infrastructure: Makerspaces with entry-level 3D printers and GenAI-capable workstations should be set up in the selected schools for piloting purposes. This is critical to successfully implement the 4th, 5th, 6th and 7th topics.

Limitation of the Study

This scoping review is subject to limitations firstly regarding its search strategy, which was restricted to Scopus and Web of Science. Although these are reputable sources for high-impact academic literature, other relevant studies indexed solely in education-specific databases like Education Resources Information Center (ERIC) or technical databases like IEEE Xplore may have been inadvertently omitted. Secondly, exclusion of grey literature in this scoping review implies that information from sources such as policy documents, white papers and unpublished these are not captured. This direction was intentionally taken to ensure methodological rigour, verifiability, reliability and reproducibility of the synthesized evidence. Thirdly, the exclusion of non-English studies in this review is because English is the primary medium of instructions in the South African education system. This apparently excludes relevant comparative studies from non-English speaking regions that have explored the integration of AI and 4IR technologies for Education 4.0. Lastly, the AI-enabled curriculum extension proposal for the South Africa education system is still a theoretical proposition, which is grounded in constructionist pedagogy. Thus, it requires future empirical validation to assess its feasibility in practical classroom settings.

Conclusion

In this study, we have systematically scoped the academic literature to explore how the advances in AI and other 4IR enabling technologies can be leveraged for Education 4.0 in South Africa. Both descriptive and thematic analyses of the literature have clearly opened up the bold efforts that have hitherto been made by education stakeholders in the country. The gap with respect to the non-existence of 4IR compliant curricula across the three education levels in South Africa has also been brought to the fore. As a preliminary effort to address this gap, we have presented an extension of a 3D printing technology curriculum/topics from China by fusing relevant GenAI concepts, which can be contextually adapted across educational grades (i.e., Grades 7-9) in the country. Our next step involves further exploration of academic and grey literature as well as stakeholders' engagement in focus group discussions to elaborate more on this subject for a sustainable Education 4.0 in South Africa.

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Authors Contributions

Emmanuel Adetiba: Ideation, design, implementation, writing, editing and approval of manuscript for submission, funding acquisition.

Surendra Thakur: Ideation, approval of manuscript for submission, funding acquisition.

Abdultaofeek Abayomi: Implementation, writing of manuscript.

Wellington B. Zondi and Yaseen Khan and Rasmi Singh: Editing of manuscript.

Mogandren Govender: Administrative support for funding acquisition.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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