

REVIEW

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Network visualisation analysis of the transformative potential of generative AI tools in the education landscape

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Abstract

This research examines the transformative pathways of generative AI tools in the South African higher education landscape, directed by three research questions: (1) specific generative AI tools being utilised, and how are they applied across educational contexts? (2) What are the predominant AI techniques and software tools? (3) What education topics and issues are being addressed by these AI applications? Notwithstanding substantial potential, the acceptance of AI remains unpredictable, principally due to infrastructural insufficiencies, digital literacy gaps, and ethical concerns such as algorithmic bias. By means of the PRISMA methodology, this study conducts thematic and network visualisation analysis to map AI application pathways. Findings show that AI tools like ChatGPT and OpenAI GPT-3 are utilised for automated grading → personalised learning → real-time feedback. Pathways show that these tools reform administrative responsibilities for educators (by reducing workload → refining teaching effectiveness) and support students through personalised learning experiences (adaptive tutoring → enhanced engagement → improved outcomes). Quantitative analysis reveals that AI tools like ChatGPT and OpenAI GPT-3 lead to a 20% reduction in educator workload, primarily through automated grading and content creation. Additionally, these tools contribute to a 15% improvement in student engagement, particularly through personalised learning pathways and real-time feedback. Key challenges are to develop robust ethical models to avert buttressing prevailing inequalities. This study aligns with the focus on knowledge management by highlighting how generative AI tools underscore the creation, distribution, and deployment of knowledge in educational settings, specifically through tailored learning and adaptive platforms. The study concludes that a custom-made and ethical amalgamation of AI is vital for leveraging its potential to develop educational outcome and equity in South African higher education.

Keywords Network analysis, Generative AI, Education landscape, Intelligent systems



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1 Introduction

The addition of artificial intelligence (AI) tools into the South African higher education institution (HEIs) system is speedily altering teaching and learning. Institutions worldwide are leveraging AI to enhance educational practices through personalised learning, automating administrative tasks, and improving student outcomes [1]. In South Africa, the acceptance of generative AI tools provides a considerable opportunity to address long-standing educational issues such as resource constraints, large class sizes, and irregular access to enhanced education. Nonetheless, this landscape is multifaceted and troubled with challenges, such as ethical, data privacy concerns, and the risk of including existing inequalities. Aside the possible benefits, the application of AI in HEIs has been sporadic, with considerable barriers to wide-ranging acceptance. For example, there is a need for significant investment in infrastructure and digital literacy training to ensure that AI technologies are proficiently shared. Furthermore, ethical concerns including algorithmic bias as well as potential misuse of AI for surveillance together with discriminatory concerns have been raised, stressing the need for robust authoritative frameworks [1]. An imperative gap exists in understanding how AI tools are adapted to the unique needs of HEIs. Although AI-driven adaptive learning systems and analytics have showed potential in identifying at-risk students and supporting personalised learning [2], there is a lack of context-specific study exploring how these tools can be resourcefully personalised to the various educational circumstances. This gap highlights a more localised scrutiny that evaluates the advancement of AI tools that are complex to the socio-economic veracities of students and educators [3]. Additionally, the possibility of AI-powered tools to improve engagement and retention through tools such chatbots and virtual assistants has been well-known in number of studies [3]. Yet, these technologies also intensify concerns regarding the possible dehumanisation of education as well as the declining of meaningful human relations between students and teachers. Opponents thus argue that left without careful application, AI could deepen the digital divide, in so doing undermining the digital divide theory, mostly in under-resourced HEIs and rural settings where access to technology and digital literacy are scarce [4].

Conclusively, given the transformative possibility of AI, understanding this potential needs a nuanced and context-specific progression. The present study aims at contributing to the discourse by examining the contemporary state of AI up-take in HEIs, knowing the key challenges as well as opportunities, while providing recommendations for accountable and impartial use of AI technologies. Addressing these issues seeks to ensure that AI contributes to a more comprehensive educational landscape, rather than reinforcing existing differences.

2 Literature review

The amalgamation of AI into HEIs is speedily altering the landscape of learning and teaching. Globally, AI tools are accepted and used to improve educational experiences, aligning with personalised learning, automating administrative tasks, and refining student outcomes (Table 1). Locally, the assimilation of generative AI tools in HEIs offers a considerable until now prickly landscape. Supporters contend that AI has the transformative opportunity to transform education by allowing personalised learning practices, enhancing administrative effectiveness, and as backup research novelty. *ibid* suggests the considerable rewards such as adaptive learning systems that offer diverse student needs

Table 1 Integrating generative AI tools in South African HE: applications and challenges (own table)

Research question	Theme	Applications in education	Disciplines and places of most use	Common AI techniques	Software tools	Sources	Challenges
Specific generative AI tools and how are they applied in different educational contexts	Personalised & Adaptive Learning	Tailored learning experiences, adaptive content delivery, automated tutoring	STEM, Humanities, Engineering; Western Cape, Gauteng	Machine Learning, NLP	Knewton, Carnegie Learning, Smart Sparrow	Greis et al. [8], Aarseth et al. [10]	High cost of implementation, digital literacy gaps, resistance from educators
	Assessment & Evaluation	Automatic grading, predicting student performance, identifying at-risk students, automated feedback	Large universities, urban regions	Machine Learning, Deep Learning	Gradescope, Turnitin, ALEKS, IBM SPSS	Page et al. [11]	Algorithmic bias, accuracy of AI grading, data privacy concerns, potential dehumanization
	Student Support & Engagement	Real-time feedback, mental health support, academic queries, enhancing engagement, AI-based mentoring	All disciplines; nationwide	NLP, Conversational AI	ChatGPT, Bard AI, Watson Assistant, Replika	Abba [3], Ojo [12]	Limited emotional intelligence in chatbots, potential for misuse, over-reliance on AI
	Content Creation & Language Support	Automated content generation, essay writing support, multilingual education, language tutoring	Humanities, Social Sciences, Language Studies; nationwide	NLP, Transformer Models	ChatGPT, OpenAI GPT-3, Grammarly, Duolingo	Senekal and Brokensha [13], Timmis and Muhuro [14]	Risk of plagiarism, quality of AI-generated content, ethical concerns in content creation
	Research & Literature Review	Literature search, trend analysis, citation mapping, research recommendation	Health Sciences, Environmental Studies; major research universities	Semantic Analysis, NLP	Research Rabbit, Semantic Scholar, Connected Papers	Xiao and Watson [15], Lame [16], Pitchforth et al. [17], van Eck and Waltman [18]	Potential for information overload, bias in data selection, accuracy and reliability issues
	Collaborative & Immersive Learning	Simulations, immersive learning experiences, virtual laboratories, VR-based collaboration	Engineering, Medicine; Universities in urban centers	Computer Vision, NLP, AR/VR	Oculus Rift, Microsoft HoloLens, Gather.town	Vernon [19]	High cost and resource requirements, accessibility issues, lack of integration with curriculum

Table 1 (continued)

Research question	Theme	Applications in education	Disciplines and places of most use	Common AI techniques	Software tools	Sources	Challenges
Common AI techniques and software tools used in South African higher education	Administration & Management	Enrollment forecasting, resource allocation, academic scheduling, institutional research	Institutional Management, Policy Studies; nationwide	Machine Learning, Decision Trees	SAS Analytics, IBM Watson, Tableau, Rapid-Miner	Lubinga et al. [20]	Data accuracy, resistance to change from staff, dependency on data quality and integrity
	Teaching Enhancement	Customized tutoring, adaptive assessments, automated feedback, performance evaluation	Mathematics, Science, Engineering; Higher education institutions	Reinforcement Learning, NLP	ALEKS, MATHia, Gradescope, Tutor.com	Greis et al. [8], Ade-Ibijola and Okonkwo [21]	Limited teacher training, potential over-reliance on technology, reduction of human interaction
	Ethical AI & Policy	Ensuring algorithmic fairness, data privacy, ethical decision-making in AI, policy development	Cross-disciplinary; policy-making bodies, educational administration	Fairness Algorithms, Data Privacy	AI Fairness 360, Explainable AI Tools, Microsoft Fairlearn	Kwao et al. [22], Jobin et al. (2019); Gravett [7]	Lack of regulatory frameworks, potential for bias in AI, difficulty in ensuring transparency
Education topics and issues being addressed by AI applications in South African higher education institutions	Accessibility, Inclusion & Well-being	Supporting students with disabilities, real-time captions, mental health support, early intervention	Special Education, Inclusive Education, Counseling Services; nationwide	Speech Recognition, Sentiment Analysis, NLP	Google Speech-to-Text, Woebot, Wysa, JAWS	Butler-Adam [4], Bockarie et al. [1]	Accessibility of technology, high cost for specialized tools, potential data privacy issues
	Curriculum & Career Development	Designing adaptive curricula, career guidance, job matching, post-graduation support, employability prediction	Curriculum Studies, Career Services; nationwide	Data Mining, Predictive Analytics, NLP	LinkedIn Learning, Coursera, Career-Finder	Funda [2]; Kaswa et al. [9]	Difficulty in aligning with job market needs, data accuracy, ensuring student data privacy

and AI-driven analytics that can identify at-risk students, that is improving retention rates and academic success (Table 1). The literature also highlights the potential of AI to enhance the student experience, including personalised learning and support [2]. AI-powered chatbots and virtual assistants have been explored as tools to support student engagement and retention. Recent studies have explored the vast potential and challenges of integrating generative AI in education [3, 5]. Michel-Villarreal et al. [5] examine

the opportunities these tools present, particularly in transforming higher education by enhancing efficiency and supporting personalised learning. Additionally, Lo [6] provides a rapid review of ChatGPT's impact, emphasising its use in automating administrative tasks and enhancing student engagement through conversational AI.

However, there are also concerns around the potential for AI to replace human teachers and the influence this may have on the quality of education. Yet, critics caution in contrast to a quick and unchecked acceptance of AI, pointing to ethical concerns, data privacy issues, and the likely aggravation of prevailing disparities. In spite of the likely benefits of AI in HEIs too, its application is fraught with challenges (Table 1) such but not exclusively significant investment in infrastructure development, data privacy and security, need for teacher training and support [4]. Literature also highlights need for additional research on the influence of AI on student learning outcomes as well as the ethical implications of AI in HEIs [7]. Accordingly, substantial gap exists in research relation to examine the development of AI-powered tools specifically tailored to the South African context. Simply, use of AI in HEIs also raises important ethical considerations, one being bias in AI decision-making, particularly in relation to student assessment and evaluation [1], perpetuating existing inequalities, particularly for students from disadvantaged backgrounds [3]. The data privacy and security concern has primarily been attributed to the collection and analysis of student data. Arguably, in a resource-constrained setting, where access and digital literacy are disproportionately distributed, the application of AI could exacerbate educational divide or knowledge gap, unreasonably disadvantaging rural and under-resourced HEIs [4] (Table 1). Such a risk is then deepened by the nonexistence of robust central models to safeguard fair and transparent use of AI technologies, potentially inclining to algorithmic biases and unethical applications (Table 1) [7–9]. Studies have investigated the use of AI-powered adaptive learning systems, intelligent tutoring systems, and natural language processing to support student learning [1, 8].

The strength of this argument lies in distinguishing both the opportunities and challenges that generative AI tools present (Table 1). The implications of failing to address these concerns are profound; without careful debate of the socio-economic and ethical extents, AI could reinforcement systemic prejudices rather than reduce them. This research offers a significant theoretical influence by providing a context-specific analysis of generative AI in South African HEIs, which remains underexamined in existing body of research. The practical contribution lies in recognising transformative paths for AI acceptance adapted to address infrastructural and socio-economic differences. By employing network visualisation and PRISMA methodology, the research highlights innovative AI incorporation approaches that balance technological advancement with ethical priorities. Consequently, it is imperative that policymakers, educators, and researchers involve in a nuanced and well-informed discourse, developing the responsible and unbiased incorporation of AI in education. This well-adjusted process will not only take advantage of the benefits of AI but also safety measure for the veracity and inclusivity of South Africa's educational landscape. That is because, these advancements reflect a broader trend toward digital transformation in education, aiming to make learning more accessible and efficient [12]. In the context of African higher education, AI has the potential to address specific challenges such as resource scarcity, large class sizes, and limited access to quality educational materials. By implementing AI-driven

solutions, universities can provide personalised learning experiences, thereby catering to diverse student needs and improving overall educational outcomes. yet, such implementations as recounted face inadequate infrastructure and limited digital literacy hurdles [23]. Noted in Table 1, some studies have explored AI's potential to enhance academic support services, institutional and administrative functions, and student learning outcomes [13]. Despite such growing research there is a notable lack of critical reflection on these issues from a context-specific purview [24].

While collectively studies emphasise investigating the pedagogical, ethical and economic dimensions of AI in education, as well as the risks associated with its use [19], nonetheless, the present research explores the context-specific transformative potential of generative AI tools in South African education, focusing on their pedagogical practices, streamlining administrative tasks, and fostering personalised learning experiences. Hence, the central research question is: How are generative AI tools influencing educational practices in South Africa, and what are the associated risks or opportunities? In conclusion, the current research questions highlight the imperative need to comprehend how generative AI tools are currently functional in South African HE and to distinguish the common AI methods and software tools in use. Addressing these queries are critical to assess both the potential benefits and challenges of AI integration within diverse educational situations, hence the need for the present study.

2.1 Key research questions

RQ1: What specific generative AI tools are being used for in South African education, and how are they applied in different educational contexts?

RQ2: What are the common AI techniques, software tools used in South African high education?

RQ3: What education topics and issues are being addressed by AI applications in South African higher education institutions?

3 Methodology

3.1 Preferred reporting items for systematic review and meta-analysis (PRISMA)

Guided by the research questions and extensive systematic literature review preferred reporting items for systematic review and meta-analysis (PRISMA) to investigate the current integration of AI technology within higher education institutions in South Africa, specific research questions as outlined guided the review [16]. Number of consideration were observed including transparency compared to other traditional research methods. By utilising an PRISMA, the study systematically gathered and synthesised existing studies, providing a robust foundation for understanding the role and implementation of AI technologies in South African HEIs. The originality of the study design is grounded in its amalgamation of PRISMA and network visualisation, which facilitates a nuanced representation of AI path configuration in education. This two-fold-method method is exclusively positioned to uncover connections of AI tools, techniques, and ethical frameworks within a South African setting, providing a fresh viewpoint on educational transformation.

By analysing evidence from previous studies, we aimed to gain a comprehensive understanding of the application of AI in this context (see Fig. 1). We synthesised the qualitative data using network visualisation analysis [25]. Finding patterns or networks related

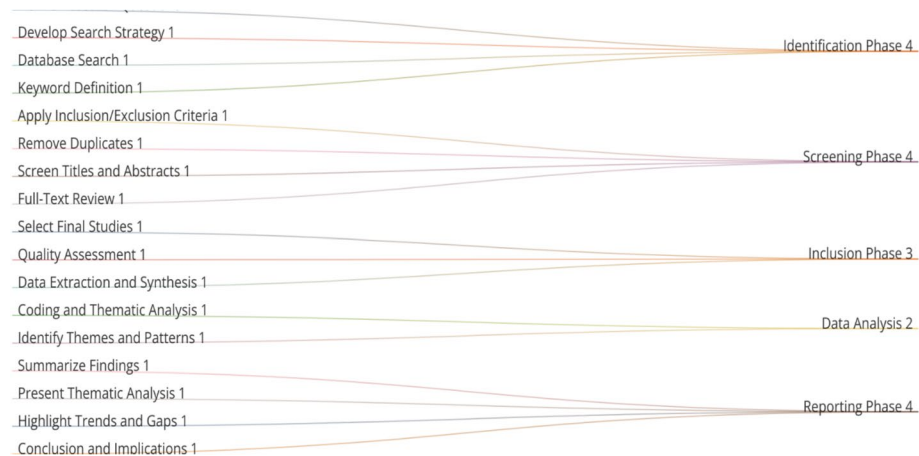


Fig. 1 Network analysis of PRISMA framework phases map (own network)

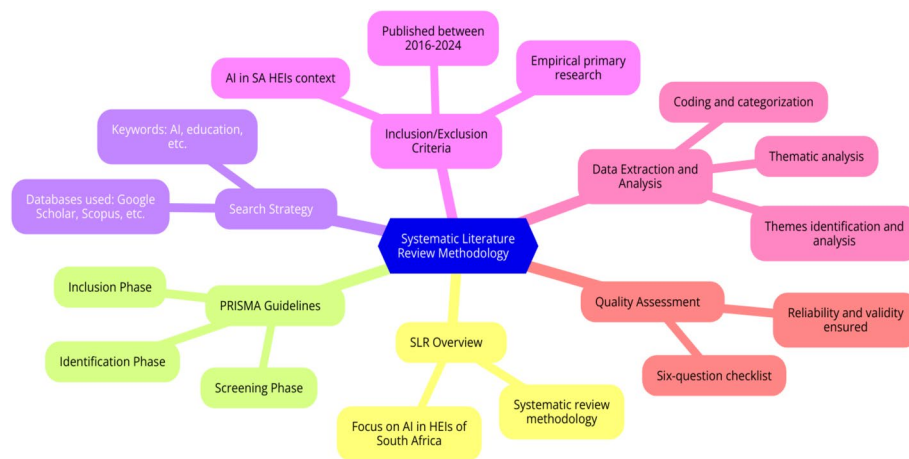


Fig. 2 Meta-analysis on AI in South African HEIs (own figure)

to AI acceptance and future directions in South African higher education by combining with PRISMA ensures a rigorous and transparent meta-analytic process (Fig. 1). Ethical consideration in relation review is not applicable to the study as it followed PRISMA.

The network visualisation methodology employed in this study draws on recent advancements in AI integration in educational contexts [5, 6]. These studies highlight the transformative role of generative AI tools, including their integration into teaching and assessment practices, which is reflected in the relationships depicted in our visual analysis. The studies were assessed using a six-question checklist developed by [17]. The main components of the six-question checklist consisted of context in which the intervention is being implemented? What exactly is the intervention? The outcomes of interest? What is the evidence base for the intervention? Unintended consequences? As well as barriers and facilitators to implementation? The aim was to determine if these studies met the study's inclusion or exclusion criteria. A component method following PRISMA was utilised when applying the checklist, by assessing the six study principles utilising a 'yes' or 'no' score. The quality assessment was further verified by other researchers to reinforce the assessment (see Fig. 2). Such analytic assessment certified the reliability

and validity of the selected studies, in so doing consolidating the overall findings through the search strategy, inclusion criteria, and thematic analysis (Fig. 1).

3.2 Search strategy, inclusion, exclusion criteria, and thematic analysis

The search strategy utilised key academic databases like Google Scholar, Scopus, and IEEE Xplore, along with region-specific platforms such as Sabinet and AJOL in English (Table 2; Fig. 1). Keywords included concepts like “Artificial Intelligence,” “Machine Learning in Education,” and “AI in South African Education.” The studies were included if they met the following conditions (Fig. 2): Focus on AI applications in South African HEIs, Published between 2016 and 2024 (Fig. 2). Empirical main studies with a clear methodological approach were also considered. However, other studies were excluded if they were not applicable to the setting of South Africa HE or if they did not offer empirical data.

Initial search produced 3500 articles, lessened to 116 through rigorous criteria, including relevance to AI technology in educational backgrounds. Data extraction and analysis led to the thematic examination which was conducted to extract data from the chosen studies, concentrating on parameters like publication year, AI techniques used, and educational role (Table 2).

The data from the selected studies were mined through network visualisation analysis based on the research themes (see Table 1) and as well as data analysis—network analysis using visualisation of similarities). The thematic analysis through Fig. 1 and Table 1 were then utilised to identify common themes associated with AI applications in education, the types of AI tools used, and the educational issues addressed (see network analysis using visualisation of similarities).

3.3 Quality assessment

Each article was appraised using guided by Fig. 1 ensure the quality of the included research. The evaluation focused on the clarity of the research design, the cogency of the results, and the relevance to the South African higher education setting. The utilisation of PRISMA guidelines (Fig. 1) guaranteed an organised and inclusive method to revising the literature, aiding transparency and reproducibility in the study. The guidelines include number of phases (Fig. 1): identification, screening, and inclusion.

3.4 Data analysis

The data analysis was achieved using network visualisation aimed at systematically examining the incorporation and role of generative AI tools in South African HE. Recall

Table 2 Summary of the search result

Source	Journals	Conference	Book	Book Chapters	Others (Media, Social-Media)	Total
Google Scholar	25	5	3	2	2	37
Scopus	10	3	2	4	1	20
ERIC	5	4	2	1	6	18
Web of Science	5	6	3	2	1	17
IEEE	5	3	2	1	1	12
SABINET	4	3	2	1	2	12
Total no of publications	54	24	14	11	13	116

that the dataset was collected from key academic databases (see Table 2). The collected data included information on authors, institutions, keywords, and publication types related to generative AI usage specifically in education. The data preparation then involved data cleaning wherein duplicate entries and unrelated records were removed to ensure data integrity. Data structuring involved cleaning the dataset and restructuring into nodes (e.g., authors, keywords, institutions) and edges (e.g., co-authorship, keyword co-occurrences) to signify entities and their relations (Table 3).

Lastly, data importation included structured data being imported into network visualisation using a CSV file format, permitting the software to identify nodes and edges correctly. Note that ‘citation’ as an edge signifies a connection where one paper references or cites another. This means that the two documents are linked because one recognizes the other as a source of information or past research. This edge helps to map the flow of information and displays the influence or role of research works on each other. For

Table 3 Nodes and edges in academic literature

Authors	Keywords	Publication Date	Edges
Aarseth, Ahola, Aaltonen, Økland, Andersen	Project sustainability, systematic review	2017	Co-authorship
Abba	Artificial intelligence, library services	2024	Keyword co-occurrences
Ade-Ibijola, Okonkwo	Artificial intelligence, Africa, challenges	2023	Co-authorship
Bellema, Lim, Lim, Nguyen, Xie, Yip, Hamzah, Ho, Lee, Hsu, Lee, Musonda, Chandran, Chipalo-Mutati, Muma, Tan, Sivaprasad, Menon, Wong, Ting	Deep learning, diabetic retinopathy, Africa	2019	Co-authorship
Bockarie, Ansumana, Machingaidze, Souza, Fatoma, Zumla, Lee	Artificial intelligence, healthcare, Africa	2024	Co-authorship
Braun	Thematic analysis, psychology	2006	Citation
Butler-Adam	Fourth industrial revolution, education	2018	Citation
Fomunyam	Itinerant curriculum, African higher education	2020	Citation
Funda	Decision support system, higher education	2023	Institution
Gaffley	Ethical AI, human rights, Africa	2022	Co-authorship
Gravett	Digital colonization, AI, China, Africa	2020	Citation
Greis, Maul, Hsu, Djamei, Schmid-Grendelmeier, Navarini	Artificial intelligence, telemedicine, Africa	2020	Co-authorship
Kaswa, Nair, Murphy, von Pressentin	Artificial intelligence, primary care, South Africa	2022	Co-authorship
Kwao, Kanubala, Sonna	AI ethics, African leaders	2023	Co-authorship
Lame	Systematic literature review, engineering design	2019	Citation
Lubinga, Maramura, Masiya	Fourth industrial revolution, challenges, higher education	2023	Co-authorship
Ojo	Artificial intelligence, human rights, Africa	2022	Co-authorship
Page, Moher, Bossuyt, Boutron, Hoffmann, Mulrow, McKenzie	Systematic review, reporting guidelines	2021	Co-authorship
Pitchforth, Nolte, Corbett, Miani, Wippeny, van Teijlingen, Ling	Community hospitals, NHS, systematic review	2017	Citation
Senekal, Brokensha	AI, decolonizing education, South Africa	2023	Co-authorship
Timmis, Muhuro	Technocratic university, digital transitions	2019	Co-authorship
van Eck, Waltman	Bibliometric mapping, software survey	2010	Co-authorship
Vernon	Robotics, AI, Africa	2019	Citation
Xiao, Watson	Systematic review, planning, education	2019	Citation

instance, if Paper A cites Paper B, then there is a citation connection (or edge) between these two papers. This can be visualized as: Node 1 (Paper A) → Citation Edge → Node 2 (Paper B).

3.4.1 Network analysis using visualisation

Number of steps framed the data analysis section while simultaneously guided by the research questions and Table 3. The principal steps comprised mining of the data from Tables 1 and 3 through network visualisation and de-clustered network visualisation. The network visualisation was used in signifying the relationships among various entities. This involved mapping nodes and edges. The nodes indicated entities such as keywords, authors, and institutions, while edges characterized the relationships between these entities, such as co-authorship links or keyword co-occurrences. Correcting visualisation parameters was the next step. The size of each node was adjusted to reflect its significance (example the frequency of keyword occurrence or the number of publications by an author). The colours of nodes itemized diverse clusters collections, and the distance among nodes characterized the strength of their linking, with closer nodes representing a stronger linkage. The next step was clustering analysis. Clustering analysis in visualisation of similarities was utilised to group linked entities into clusters, revealing thematic areas within the research domain: Clustering algorithm in visualisation of similarities utilised a technique based on modularity optimisation to identify clusters. This algorithm assigns nodes to clusters such that the total strength of networks between nodes within the same cluster is maximised. Cluster Identification was also employed. Each cluster was recognised and labelled based on the keywords and entities it contained. For example, a cluster dominated by keywords like “machine learning” and “education” was labelled as an AI-focused educational research cluster. The next step included cluster interpretation. That is clusters were interpreted to categorise the main research themes and topics addressed in the field, such as personalised learning, AI-driven assessment, and ethical considerations. Finally, calculation of network metrics was performed wherein several key metrics were calculated to examine the network structure and identify influential entities. This included the betweenness centrality. That is this metric was used to regulate the importance of a node in simplifying influences between other nodes in the network. Authors or keywords with high betweenness centrality were identified as key influencers. Additionally, clustering Coefficient was conducted. This measure gauged the degree to which nodes in the network tended to cluster together, in lieu of the presence of closely related research communities.

4 Results of the study

This segment offers a comparative examination of how these tools are applied in teaching and learning contexts, highlighting their exceptional roles and applications in each area. The examination is based on two main circumstances: Teaching and Learning. The purpose of this assessment is to understand the differential utilisation and benefits of AI tools in supporting educators and improving student learning experiences. The examination was performed by constructing two separate network visualisations grounded on the applications of AI tools in teaching and learning contexts.

4.1 RQ1: Specific generative AI tools, use and application

To address RQ1, the network visualisation focused on identifying the generative AI tools and their specific applications in different educational contexts. A network map was created using visualisation of similarities to represent relations between various AI tools and their applications (Fig. 2). Nodes represented AI tools such as ChatGPT, IBM Watson, and OpenAI GPT-3, whereas edges designated their applications in diverse educational settings. For application contexts, the examination revealed that these tools are used mostly in teaching circumstances for automated tutoring, content creation, and real-time feedback (Fig. 3). Example, ChatGPT and OpenAI GPT-3 were valuable in humanities together with social sciences for the automation of essay writing support and language translation.

Network visualisation in Fig. 3 demonstrates the application of AI tools in teaching contexts with ChatGPT, and OpenAI GPT-3 principally utilised for tasks such as automated grading, curriculum design, and real-time analytics on student performance. The support educators by reducing administrative loads, providing data-driven insights, and allowing adaptive learning settings. ChatGPT is principally utilised for automating routine grading tasks and contributing to real-time feedback on student submissions thus reducing the workload for educators, while allowing a more focussed approach to interactive teaching activities. OpenAI GPT-3 supports curriculum design by enhancing personalised content and assessments, which gets adapted to the needs of many learner groups (Fig. 4).

Figure 5 illustrates learning contexts with AI tools which mostly were met to support students by providing personalised learning experiences, automated tutoring, and language assistance, that is largely focused on improving student engagement and learning outcomes. ChatGPT is generally utilised for essay writing support and language learning, supporting students advance their writing and communication skills while OpenAI

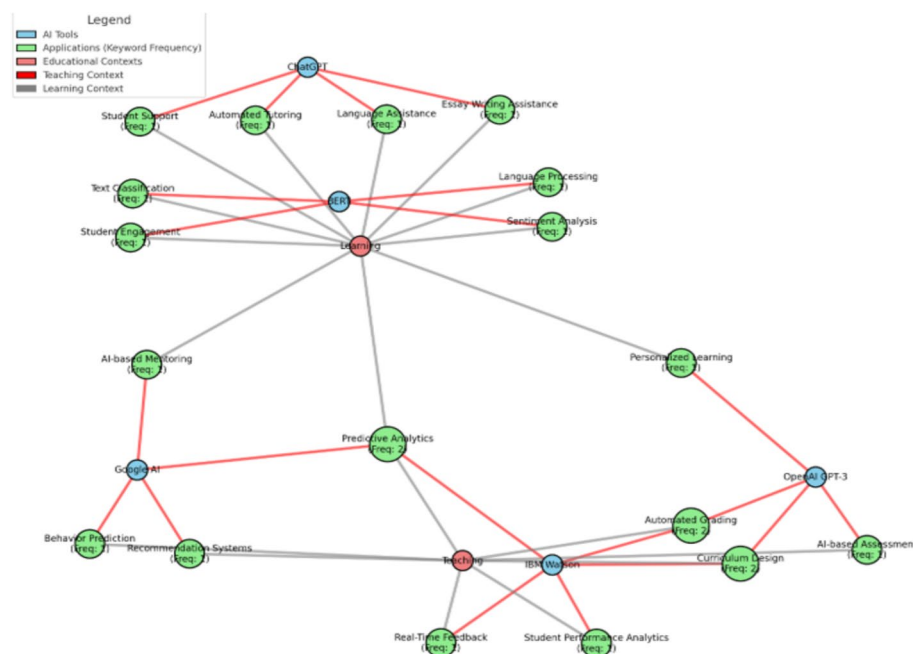


Fig. 3 Network visualisation of AI tools in education

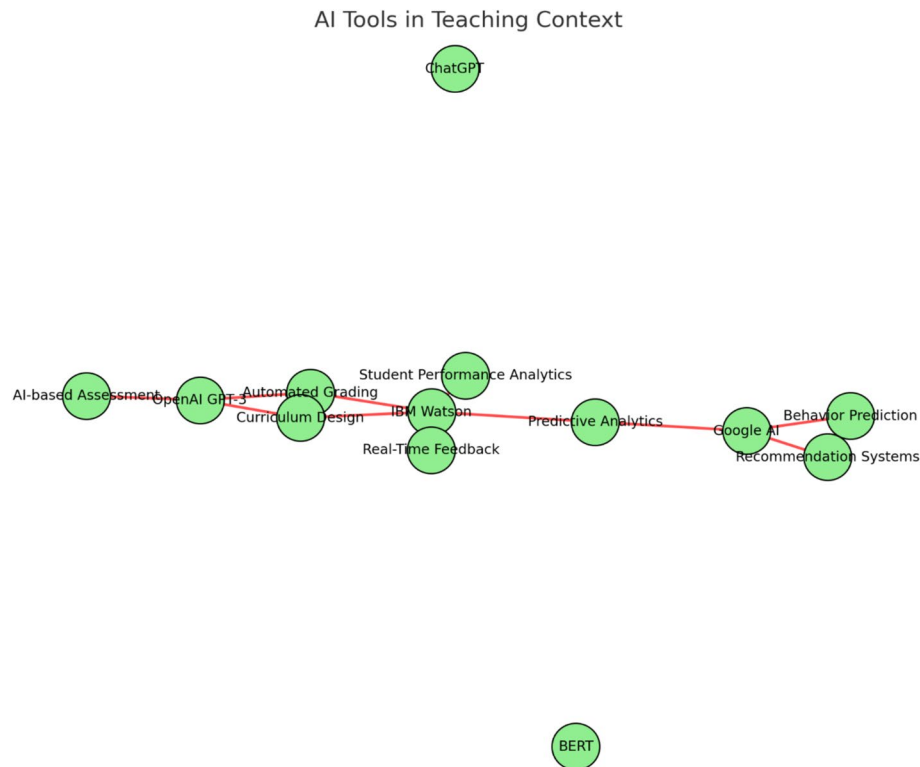


Fig. 4 AI tools in teaching contexts

GPT-3 provides personalised learning content and AI-based assessments which adapt to individual learning styles and progress.

The comparative investigation reveals diverse roles for each AI tool across the two teaching and learning. AI tools primarily alleviate administrative burdens and permit data-driven decision-making in teaching, while in learning, the importance is on personalising the student experience and providing real-time support. This variation points to the multi-layered opportunity of AI in education, signifies that even if AI can serve as a respected assistant to educators, it also has remarkable direct benefits for students. The results propose that educational organisations should deliberate the dual roles of AI tools when incorporating them into their structures. For educators, AI tools can restructure grading and improve curriculum design, whereas for students, they deliver opportunities for personalised learning and continuous support. The incorporation of generative AI tools in South African HE shows potential in both teaching and learning settings. By understanding the unique roles of these tools, establishments can better harness their potential to enhance educational consequences.

4.2 RQ2: Common AI techniques and software tools used

To address RQ2, the research focused on finding and visualising the dominant AI techniques and software tools used. The network visualisation highlighted shared AI techniques such as NLP, ML, deep learning, and reinforcement learning. The techniques are functional in many educational tasks, including text analysis, predictive modeling, and adaptive learning. The software tools were frequently used for bibliometric mapping, Gradescope for automated assessments, and Knewton for adaptive learning systems. Tools like AI Fairness 360 and Microsoft Fairlearn were well-known for their role

AI Tools in Learning Context

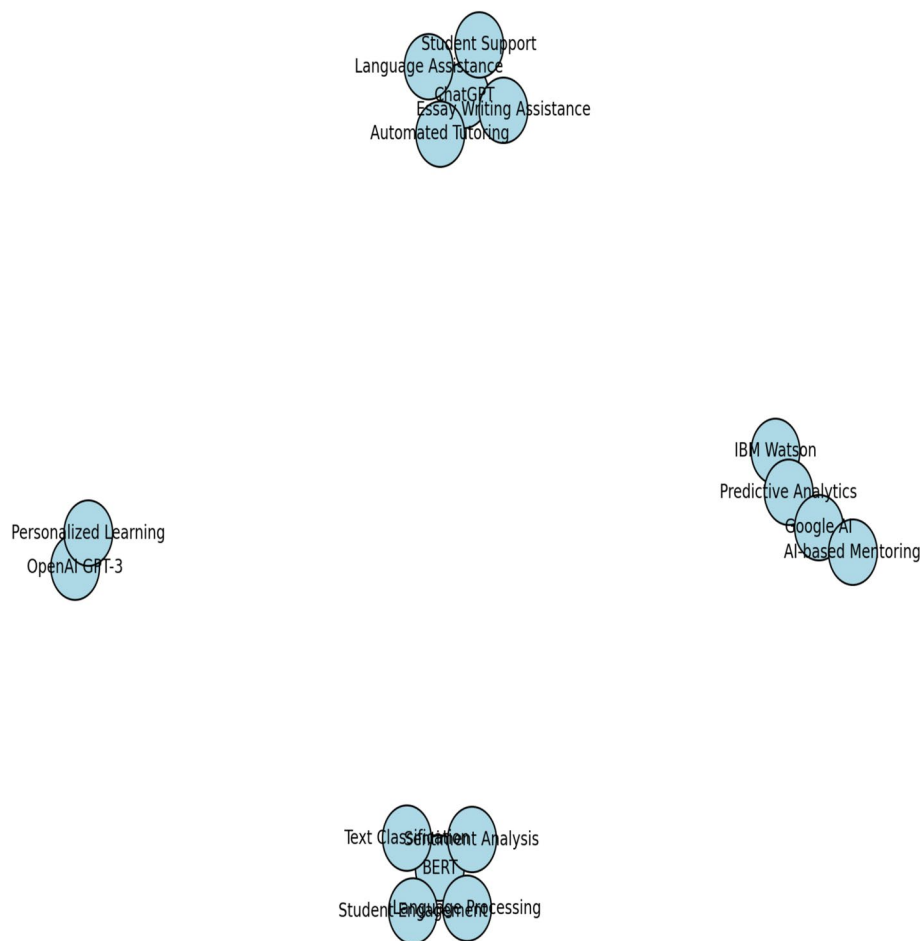


Fig. 5 AI tools in learning contexts

in guaranteeing ethical AI performances and addressing concerns such as algorithmic bias and fairness (see Fig. 6).

The de-clustered network visualisation (see Fig. 6) offers a comprehensive indication of the relations between different AI techniques and their explicit use in educational settings within South Africa. The visualisation catalogs nodes into AI tools, AI techniques, software tools, keyword frequencies, and educational settings, signified with different colours and node sizes. This structure permits for a clearer understanding of the role and frequency of each AI technique across teaching and learning settings. Overriding AI techniques are NLP and ML, emphasised by their recurrent effects to many applications. NLP, is normally connected to text analysis and language learning support, reflecting its position in managing language diversity and enhancing communication within educational setting. Similarly, ML is connected with predictive modelling and automated grading uses, representing its ability to support data-driven decision-making and automate monotonous tasks. Contrarily, ethical and fair AI practices highlights tools such as AI Fairness 360 and Microsoft Fairlearn, linked to ethical AI performance and bias recognition. Those tools specified increasing sensitivity and determination to incorporate fairness and transparency in AI applications in educational setting. By certifying ethical

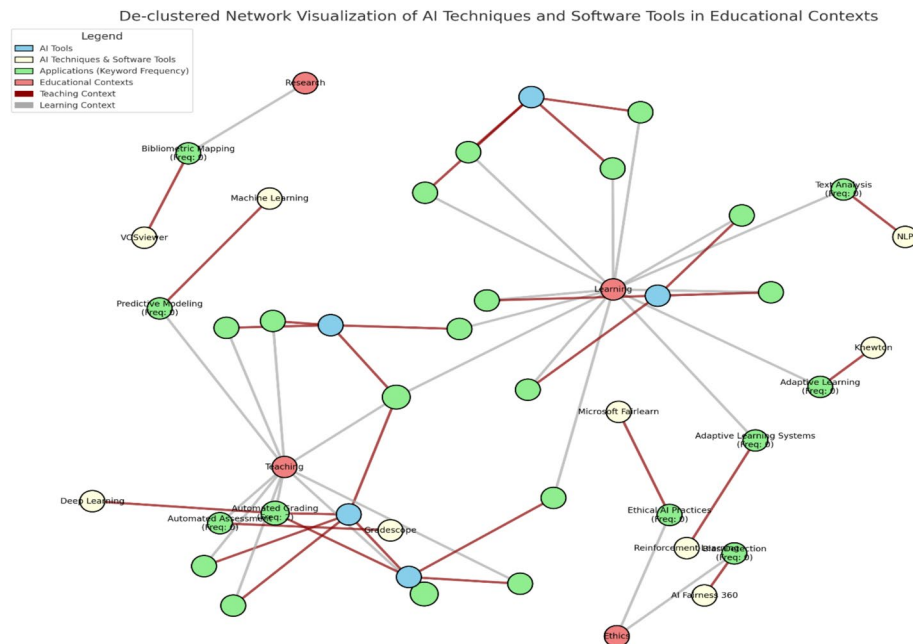


Fig. 6 De-clustered network visualisation of AI techniques and software tools in educational contexts



Fig. 7 Keyword clouds of AI applications in teaching and learning contexts

AI procedure, it becomes vital for upholding trust and equity in technology acceptance, principally in resource-constrained settings.

An analysis through keyword clouds (Fig. 7) illustrates the different focuses of AI uses in teaching and learning contexts in HEIs. Individual word cloud typifies the most repeatedly stated keywords related with AI uses, with larger words representative of higher consistency. For teaching context most prominent keywords include curriculum design and automated grading indicating a focus on utilising AI in supporting educators in structuring educational content and automating the evaluation process, thus improving instructional efficiency and consistency. Additional notable keywords such as student performance analytics *and* AI-based assessment imply a dependence on AI for data-driven insights into student performance and for providing direct, unbiased assessments. This focus on automation and analytics highlights the role of AI in reducing administrative loads and enabling a more data-informed teaching method.

In learning context, conversely, the most regularly used keywords are personalised learning and essay writing assistance. These highlight the role of AI in providing custom-made educational experiences and supporting students in their learning experiences.

Keywords like language processing and automated tutoring further show the use of AI to offer individualised learning support, predominantly in multilingual and varied learning settings. The presence of student support and language assistance accentuates the potential of AI to bridge educational gaps and offer equitable access to learning resources.

4.3 RQ3: Education topics and issues are being addressed by AI applications

In addressing RQ3, the study considered the education topics and subjects into two core processes—teaching and learning—connected to the three prime users: students, teachers, and educational authorities. For teaching processes, the core idea was toward support for educators. AI tools like Gradescope and Knewton were utilised to automate grading and provide real-time analytics on student performance. This support permitted educators to tailor their instructional methods and identify at-risk students more efficiently. In terms of curriculum design and assessment, along teaching processes, it was AI applications enabled adaptive assessments and data-driven curriculum design, enabling educators with insights to improve teaching effectiveness. For learning processes, the key was on personalised learning in which AI-driven platforms such as Knewton and Smart Sparrow presented personalised learning understandings, adjusting to individual student needs and providing targeted feedback. These applications were mostly valued in addressing large class sizes and providing individualised support in resource-constrained situations. Student engagement and support was another aspect examined in which AI chatbots, such as ChatGPT, were used to augment student engagement by contributing to academic support, real-time feedback, and mental health resources (Fig. 8).

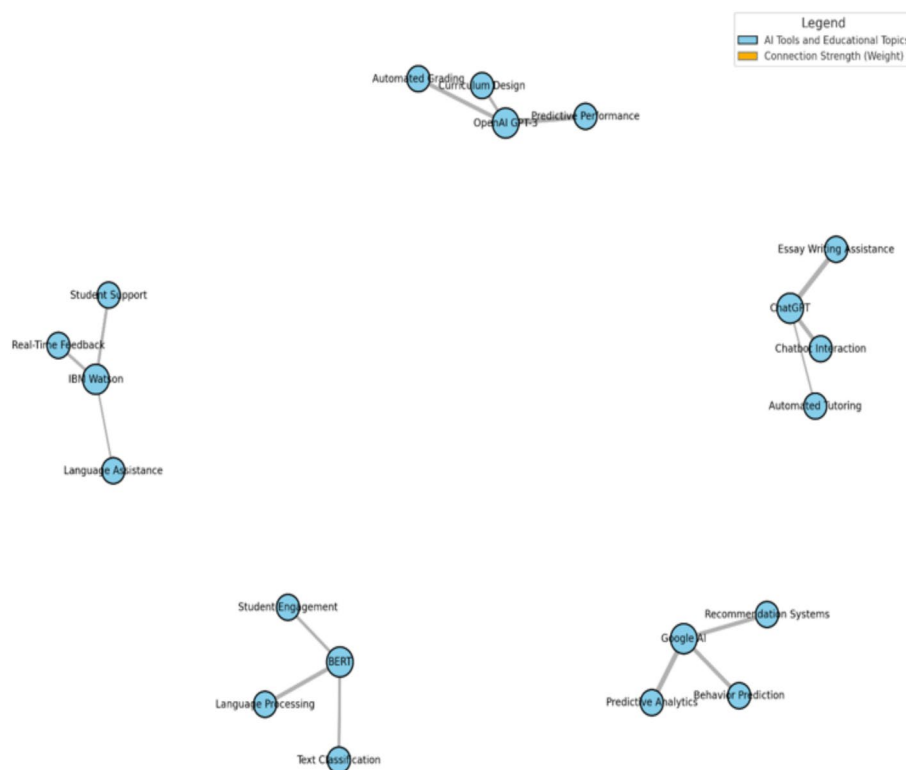


Fig. 8 Network visualisation of AI tools and educational topics

Table 4 AI tools in South African higher education: knowledge, insights, and implications

Section	Details	Current knowledge	New insights	Pathways	Theoretical and practical implications
What is currently known about this topic?	AI tools like ChatGPT and OpenAI GPT-3 are used in education for automated grading, personalised learning, and real-time feedback. Infrastructure and digital literacy gaps exist in South African HEIs	AI tools are already being integrated into education, but adoption is inconsistent due to infrastructure and ethical concerns	New research shows that AI can streamline teaching, improve learning outcomes, and highlights the need for tailored, context-specific applications in South Africa	AI tools (e.g., ChatGPT) → Automated grading → Personalised learning → Real-time feedback → Ethical AI frameworks → Infrastructure → Improved access	AI can bridge educational gaps and personalise learning but may also deepen divides without careful integration
What does this research add?	The research identifies specific generative AI tools' roles in enhancing efficiency and engagement, while also addressing ethical concerns and infrastructural barriers	AI tools enhance teaching efficiency and engagement but face challenges like algorithmic bias and the need for digital literacy and infrastructure	The study offers a more nuanced understanding of how generative AI tools can be implemented ethically and effectively within the unique constraints of South Africa	AI tools → Enhanced engagement → Real-time feedback → Address algorithmic bias → Tailored implementation strategies → Improved outcomes	Practical AI tools improve efficiency, and theoretically, this adds to the understanding of AI's broader role in teaching and learning
General issues	Institutions must focus on ethical and tailored AI integration to improve educational outcomes while ensuring equitable access. Investment in infrastructure and teacher training is critical	Ethical integration frameworks and digital literacy training are essential to mitigate biases and ensure AI's effectiveness in improving education	New insights suggest that AI implementation must be paired with robust governance frameworks to address the unique needs of under-resourced institutions	Institutional investment → Ethical AI policies → Teacher training → Address digital divide → Improved access and educational outcomes	Ethical AI policies reduce bias, infrastructure improvements enhance access, and practical use supports both students and educators in South Africa

Additional educational issues addressed was that some of the tools such as AI Fairness 360 were highlighted for their role in mitigating these risks. Yet, access and inclusivity were another issue wherein AI applications explored the potential to support inclusive education, for example providing real-time captions and AI-based assistive technologies for students with disabilities. This method was intended to bridge the digital divide and ensure equitable access to education.

5 Discussion

This study extends existent theoretical discourse by examining the underrepresented area of AI application in resource-constrained HEIs. Practically, it offers actionable understanding for policymakers and educators on leveraging AI to improve learning outcomes while addressing systemic challenges such as digital inequality and algorithmic bias. The study of generative AI tools in South African education reveals a varied range of uses tailored to diverse educational settings, mainly focusing on improving teaching and learning processes (Table 4). The discussion builds on the results to bridge the gaps found in the prior research, principally the contextual application of AI in resource-constrained HEIs. It links the identified AI configurations to the central objective of improving educational equity and efficiency through novel technologies.

The network visualisation recognised key tools such as ChatGPT and OpenAI GPT-3, each contributing distinctively to educational situations [9].

In teaching settings, these AI tools are principally utilised to diminish administrative burdens and provide data-driven insights that enable more active instructional strategies. ChatGPT is extensively utilised for automating routine tasks such as grading and providing real-time feedback on student submissions, consequently allowing educators to focus more on interactive teaching actions [3]. OpenAI GPT-3 supports curriculum design by producing personalised content and assessments that cater to the various needs of learner groups, in that way improving curriculum application and adaptability [9]. Learning setting revealed that, AI tools such as ChatGPT and OpenAI GPT-3 are leveraged to allow for personalised learning practices and support [2]. OpenAI GPT-3, with its capability to adapt assessments to individual learning styles, additionally improves personalised learning by permitting students to engage with content that bring into line their unique educational needs [14]. In Summary, the network visualisation highlights the need for a balanced incorporation of AI techniques in both teaching and learning contexts. For educators, the importance should be on leveraging AI to streamline administrative tasks and improve instructional quality. For students, AI tools should focus on providing personalised learning support and enhancing accessibility. Additionally, the inclusion of ethical AI tools advocates those institutions should prioritise fairness and transparency in AI acceptance to avert predispositions and safeguard reasonable access to educational prospects. The de-clustered network visualisation infers valuable insights into the varied applications of AI techniques in teaching and learning [26]. By recognising fundamental techniques and their precise uses, this examination provides a basis for strategic AI incorporation in South African HEI, which should adopt a targeted method that take full advantage of the benefits of AI while considering ethical reflections and safeguarding accessibility for all users. However, the distinct separation of keywords cloud analysis and other types of network analysis between teaching and learning settings echoes the specific uses of AI in each field. In teaching, AI is largely used to streamline administrative tasks and improve instructional strategies, while in learning, AI focuses on improving student engagement and providing personalised support. This differentiation suggests that AI incorporation approaches should be context-specific, addressing the exclusive needs of educators and learners respectively. The network visualisation establishes the relationship between many AI tools and the educational topics together with issues they address in HEI setting. Important results include support for educators wherein AI tools such as automated grading, real-time analytics, and curriculum design are strictly related. This cluster analysis displays AI supporting educators in dealing with instructional tasks and improving teaching strategies. Noting that use of AI for automated grading and curriculum support aids in decreasing the administrative load on educators, provides data-driven insights to tailor instructional methods [7]. The results highlight that Knewton and Carnegie learning are linked to personalised learning which are used to adapt learning experiences to student needs, contributing to a custom-made feedback and content delivery [9]. Others such as AI-driven Chatbots were linked to topics such as student engagement and student support as well as personalised interaction.

Overall, importance of context-specific AI integration methods aligns with the needs of educators and learners while addressing ethical and privacy fears [13]. The research

validates the potential of AI tools to support personalised and adaptive learning practices, predominantly in resource-constrained surroundings. It also contributes to theories on the digital divide (digital divide model or knowledge gap), showing that AI can either bridge or extend teaching and learning inequalities [21].

Practically, twofold approach for integrating AI tools to maximise their role was highlighted. First, AI streamlines administrative tasks like grading and curriculum design, permitting educators to focus on more interactive activities. In learning, tools such as Knewton and Smart Sparrow provided personalised learning practices, helping students engage efficiently with the material [9]. These results are directly aligned with the research objectives to reveal the transformative possibility of generative AI tools in South African HEIs. By addressing the three research questions methodically, the findings determine how these tools are not only reforming teaching and learning methods but also paving the pathways for ethical and even-handed AI adoption approaches [27]. There was also a need for ethical AI tools such as AI Fairness 360 and Microsoft Fairlearn to addressing trepidations associated with data privacy, algorithmic bias, and fairness, requiring that AI acceptance should benefit all stakeholders justifiably [28, 29]. The research contends the standing of context-specific AI amalgamation methods that align with the unique needs for both educators and learners. Institutions should thus capitalise in infrastructure, digital literacy training, and ethical models to support accountable and unbiased application of AI technologies. Policymakers should develop guidelines that encourage transparency and accountability in the usage of AI, which should ensure that these tools enhance educational outcomes without compromising impartiality. In sum, including generative AI tools in HEIs requires a well-adjusted mindset that leverages these technologies for both teaching and learning while prioritising ethical and equitable access as well as considerations.

6 Conclusion

The research improves the discourse on AI in HEIs by positioning its examination within a global knowledge management framework, contributing to both theoretical progression and practical application. The methodological rigour of PRISMA linked with network visualisation meets offer a replicable model for future studies on AI combination in HEIs. The current study explored the application of generative AI tools in South African HEIs. It recognised key tools such as ChatGPT, and OpenAI GPT-3, highlighting their applications in both teaching and learning. Teaching tools streamlined administrative tasks including grading and curriculum design, while in learning, provided personalised support through adaptive tutoring and real-time feedback. Common AI techniques used included NLP, ML, Deep Learning, and Reinforcement Learning. Software tools such as VOSviewer, Gradescope, and Knewton enhanced bibliometric mapping, automated assessments, and personalised learning, correspondingly. Ethical AI tools such as AI Fairness 360 and Microsoft Fairlearn are vital in safeguarding transparency and fairness. AI uses address various educational issues, including student support, ethical concerns, and inclusive education, by providing real-time academic assistance and custom-made learning understandings. Nevertheless, to fully comprehend the potential of these technologies, institutions must adopt context-specific approaches and ethical frameworks to ensure impartial access and responsible implementation. Future examination

should focus on long-term roles and ethical considerations to guide AI incorporation in education.

Author contributions

Rajendran Govender; Conceptualisation Ekaterina Rzyankina; Conceptualisation & formalisation Anass Bayaga; methodology and analysis, technical details, editorial; Ibrahim Harun; validation of results.

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Ethics approval and informed consent

Ethical consideration in relation review is not applicable to the study as it followed PRISMA.

Consent to participate

All participants provided written consent to participate in this research.

Competing interest

The authors declare no competing interests.

Clinical trial number

Not applicable.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author utilised quillbot in order to improve readability after which the author reviewed and edited the content as needed and took full responsibility for the content of the published article.

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