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Artificial intelligence in higher education: a bibliometric analysis and topic modeling approach

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ABSTRACT

Artificial intelligence (AI) has brought unprecedented growth and productivity in every socioeconomic sector. AI adoption in education is transformational through reduced teacher workload, individualized learning, intelligent tutors, profiling and prediction, high-precision education, collaboration, and learner tracking. This paper highlights the trajectory of AI research in higher education (HE) through bibliometric analysis and topic modeling approaches. We used the PRISMA guidelines to select 304 articles published in the Scopus database between 2012 and 2021. VOSviewer was used for visualization and text-mining to identify hotspots in the field. Latent Dirichlet Allocation analysis reveals distinct topics in the dynamic relationship between AI and HE. Only 9.6% of AI research in HE was achieved in the first seven years, with the last three years contributing 90.4%. China, the United States, Russia and the United Kingdom dominated publications. Four themes emerged – data as the catalyst, the development of AI, the adoption of AI in HE and emerging trends and the future of AI in HE. Topic modeling on the abstracts revealed the 10 most frequent topics and the top 30 most salient terms. This research contributes to the literature by synthesizing AI adoption opportunities in HE, topic modeling and future research areas.

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Introduction

The world around us has been completely transformed by technology and information-based decision-making in the past few decades, leading to the rise of the knowledge economy. One of the biggest drivers of change is artificial intelligence (AI), which has affected our way of life, work, communication, and education (Zemel et al. 2013). AI is a field of computer science and engineering that simulates and mimics a human's intelligent behavior by applying theories, models, and applications to improve the decision-making (Naqvi 2020). The widespread adoption of mobile,

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wireless, and Internet technologies helps organizations collect and store large amounts of data to aid decision-making. AI automates tasks commonly carried out by humans, such as speech and image recognition, drone applications, stock trading, agriculture, engineering, and manufacturing (Maphosa 2023). AI integration in education enhances the learner's decision-making by accessing e-books, performing simulations, and virtual reality. The growth of AI technology and its applications in education have been increasing, with promising potential (Zhang and Aslan 2021). There has also been an increase in research on AI applications in higher education (HE) (Chatterjee and Bhattacharjee 2020; Popenici and Kerr 2017; Zawacki-Richter et al. 2019).

In the global economy, AI-driven technology is applied to accelerate development. It is now part of the national strategy of leading economies such as the United States, China, Korea, and Japan (Abbas et al. 2019). The USA and China are leading the one trillion investments in AI with $694 and $185 billion, respectively (Mou 2019). Billions of dollars are being poured into start-ups to implement an array of AI-driven technologies worldwide. The two significant economies also led investments in AI technologies in 2018, with the USA pouring in $9.7 billion while China spent $7.4 billion (Daws 2019). The impact of AI in education has been enormous; industry experts estimate a 43% growth by 2022 (Alexander et al. 2019). Zawacki-Richter et al. (2019) reported that learning institutions and governments show more interest in adopting AI in education.

The broad aims of AI are to create machines capable of reasoning and performing tasks requiring human intelligence, learning, making decisions and adapting to changes like people (Christie and de Graaff 2017). Educational data mining (EDM), learning analytics (LAs), and machine learning (ML) are the leading AI areas in education. Big data defines complex and large volumes of data depicting human behavior and requires non-traditional tools to process, and is captured by devices such as scanners, cellphones, cameras and social media sites (Riahi and Riahi 2018). Traditional data management techniques cannot process large heterogeneous data sets; hence, big data analytics is applied in acquiring, analyzing, and evaluating complex and large data sets (Lazer et al. 2014).

Developing countries must catch up in implementing and adopting AI-driven applications due to poor infrastructure, unavailability of technology, lack of policy, and data science skills. Harvesting and storing large amounts of data raises ethical questions. Research on AI-driven applications in education has grown in the past few decades. The traditional one-size-fits-all educational paradigm is slowly being replaced by introducing AI-enabled precision learning. This approach takes account of learner differences and prevailing learning environments, predicts student performance, and timely interventions to optimize the learning process (Tsai et al. 2020). Saravanakumar (2019) highlighted that AI facilitated individualized and precision learning that determines the most opportune time for learning based on the learner's characteristics.

Most of the research on AI in HE is done in developed countries as the field is still in its infancy stage in most developing countries. The effective adoption of AI by HE is the foundation for socioeconomic growth as AI-based technologies are deployed in industries and organizations. There has been steady growth in research covering AI in HE; therefore, this bibliometric analysis attempts to evaluate the status, trends and future research topics. This paper extends the initial work at a conference (Maphosa and Maphosa 2021). The conference work was a mini-review which provided an overview of AI research in HE. This bibliometric analysis uses more tools to evaluate the status, trends, top contributors and emerging hotspots.

This study conducted a bibliometric analysis and topic modeling of AI research in HE in the past decade (2012–2021). We examined publication and citation trends, the geographic distribution of articles, major subject areas, h-index analysis, and keyword analysis. The study answers the following questions:

(a) What has research in AI in HE been focused on from 2012 – to 2021?
(b) Which countries and publishers have contributed to the corpus?
(c) Which are the research hotspots in AI in HE?

Literature Review

Artificial Intelligence Applications and Technologies

AI-directed learning applies techniques such as fuzzy logic, decision trees, neural networks, Bayesian networks, and hidden Markova models to support electronic learning (e-learning) and various forms of education and training (Colchester et al. 2017). The constructivist learning paradigm supports learner-centered and learner-driven learning, where learners actively construct new knowledge while the teacher provides a guiding role (Maphosa and Maphosa 2021). AI-based learning models learning around the constructivist paradigm. Lu et al. (2018) acknowledged that neural networks, deep learning, ML, speech and image recognition, and natural language processing simulate human intelligence and are classified as AI technologies. AI technologies employed in education include chatbots, expert systems, intelligent tutors, ML, personalized learning systems, visualization, and virtual learning environments (Zhang and Aslan 2021).

AI applications require large amounts of data for improved accuracy. The proliferation of mobile technologies, social media, and online learning systems generates large amounts of data to build AI systems (Chaudhry and Kazim 2021). Breakthroughs in information technologies, learning management systems and massive open online courses generate large amounts of data related to a student's records, learning activities, and performance outcomes (Daniel 2015). AI tools in education provide insight into how students learn, identify struggling students, and expand access to the education (Mou 2019).

Steele (2018) noted that AI improved decision-making and student performance in education. AI applications in education include predictive analytics, recommender systems (RS), intelligent tutoring systems, natural language processing and EDM. EDM is an emerging field whose goal is to enhance student learning performance by identifying patterns, analyzing student behavior and knowledge, and improving curriculum and planning processes (Zhang et al. 2021). Predictive analytics are also applied to detect learning patterns based on statistical analysis and can assist in identifying students at risk of not completing a course or failing and allow for early interventions (Akgun and Greenhow 2022).

AI-supported assessment algorithms are used in education to support scoring exams and assignments and automate manual tasks, freeing the teacher and reducing his workload, allowing focus on higher productivity tasks (Akgun and Greenhow 2022). Dialogue systems or conversational agents are used in education, also known as chatbots; this software interacts with a user on a particular topic using text or voice (Smutny and Schreiberova 2020). Laurillard (2013) notes that chatbots are being used as pedagogical agents, also known as intelligent tutoring systems. Chatbots in education have been welcome as they respond to the learner naturally and have been used in tasks such as assisting students with registration processes (Greenhow et al. 2020).

AI applications can assist teachers in adopting the most effective teaching methods that consider the individual student's context and automate manual tasks such as assessments, feedback, and grading systems.

Teachers are adopting AI teaching assistants to answer students' mundane questions in online discussion forums, leaving teachers to focus on higher-value work (Seo et al. 2021). Precision education (PE) is an educational philosophy and behavior-based approach relying on extensive data analysis, which classifies the characteristics of the learners to identify weaknesses and strengths in line with the constructivist learning paradigm (Ellis 2019). PE aims to use historical data to identify at-risk students and design interventions promptly (Luan et al. 2020).

In HE, big data is collected through digital tools and platforms and analyzed to make informed decisions based on a student's needs and learning patterns (Daniel 2019). Big data supports personalized learning (PL), where data on human behavior can be analyzed to identify learning needs and help teachers prepare lesson plans for individual learners (Klašnja-Milicevic, Ivanovic, and Budimac 2017). Intelligent learning systems can create PL using the learner's learning style, emotional state, and social background information in line with the constructivist learning paradigm (Xu 2021). To solve some education-related problems, EDM explores large data sets generated from educational environments (Maphosa and Maphosa 2020).

AI-driven facial recognition systems capture and monitor the learner's facial expressions to provide insights into the student's behavior and assist the teacher in developing learner-centered methodologies that enhance student engagement (Akgun and Greenhow 2022). RS improves learning outcomes by offering personalized exercises and assignments (Thai-Nghe et al. 2011). Course RS can determine how students choose to enroll on a particular course and be used to assist students in making informed choices (Elbadrawy and Karypis 2016). RS for elective courses has more than 90% accuracy rates, indicating their effectiveness (Maphosa, Doorsamy, and Paul 2020).

LAs refer to collecting, analyzing and reporting student data to optimize the learning environment (Lang et al. 2017). LAs are applied to big data technologies to accurately predict student performance (Huang et al. 2020). LAs analyze large amounts of data to gain insights into the learner's context to optimize the learning environment (Aldowah, Al-Samarraie, and Fauzy 2019). Using historical data, LAs support early interventions that help to identify students at risk of failing and dropping out. ML builds a knowledge base by identifying patterns, making predictions, and discovering new knowledge. In deep learning, students absorb and apply their knowledge by analogy to develop advanced thinking skills (Azer, Guerrero, and Walsh 2013).

Machine Learning

ML is a subset of AI that builds intelligent systems capable of learning independently without explicit programming (Jordan and Mitchell 2015). With access to a large data pool, ML can give insights, make predictions, offer solutions and achieve accurate results. This aids decision-making, improving services and productivity (Gobert et al. 2012). ML systems are being deployed in education to support PL by using automated systems such as facial recognition, predictive analytics and chatbots; these systems liberate teachers from monotonous tasks and free them to focus on observing, discussing, and facilitating collaborative learning (Roll and Wylie 2016). Regan and Jesse (2019) contend that ML models and algorithms can monitor learner activities, foresee learning patterns and performance, and prescribe areas where the teacher's intervention and assistance are required.

ML applications in education include student modeling, learning behavior modeling, early warning systems, dropout detection, and evaluation (Lu 2019). Developing pedagogies that target individual learners is critical in constructivist inclusive education; intelligent education systems that employ AI tools can collect personal data that reveals individual students' learning needs and patterns (Mislevy et al. 2020). AI has also been applied in special education, and it can improve the capability of special people's organs, augment their physical or intellectual deficiencies and promote PL (Xu 2021). Individual learners, such as those with disabilities, require adaptive educational tools that accommodate the learner's characteristics, such as the pace of learning and learner characteristics, by deploying flexible constructivist-based learning systems (Zawacki-Richter et al. 2019).

ML techniques enable topic modeling to uncover latent relationships in extensive data (Blei 2012). Topic modeling algorithms help to reveal hidden thematic structures in extensive textual collections (Blei et al. 2003; Sievert and Shirley 2014). Latent Dirichlet allocation (LDA) is an ML algorithm that uses probabilistic topic modeling to discover underlying themes in the corpus by generating keywords (Zupic and Čater 2015). One advantage of LDA in topic modeling is that it extracts patterns without apriori assumptions. LDA allow researchers to input the algorithm to discover the hidden structure of topics within articles. LDA differs from factor and content analysis because it does not form new words or concepts but represents topics in the corpus using existing keywords (Moro et al. 2015).

Challenges to Artificial Intelligence Adoption

AI applications for HE may pose a few ethical challenges. Khosravi et al. (2022) note that AI tools and technologies outpacing their adoption's social and even legal aspects, leading to public mistrust. Appropriate security measures are required to protect student data, such as personal information and educational profiles, from commercial exploitation (Pardo and Siemens 2014). Currently, limited guidelines or frameworks, policies, and regulations address the issues related to using AI tools in education (Holmes et al. 2018). Ethical questions are raised when teachers use face recognition systems to monitor student behavior and participation in classroom activities (Zawacki-Richter et al. 2019). The use of explainable AI can mitigate the concerns of fairness, accountability, transparency and ethics in the use of AI. Explainable AI attempts to develop AI systems that can explain their inner workings to end-users, fostering transparency, interpretability, and trust (Maphosa, 2023).

Methodology

Data Collection

We used the Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) to comprehensively summarize previous studies published. The PRISMA guidelines include three phases: identification, screening, and inclusion (Page et al. 2021). Figure 1 shows the article selection process. Article searching and data collection were performed in April 2022 from the Scopus database. Scopus is a comprehensive and widely used repository for bibliometric analysis. The initial search string involved

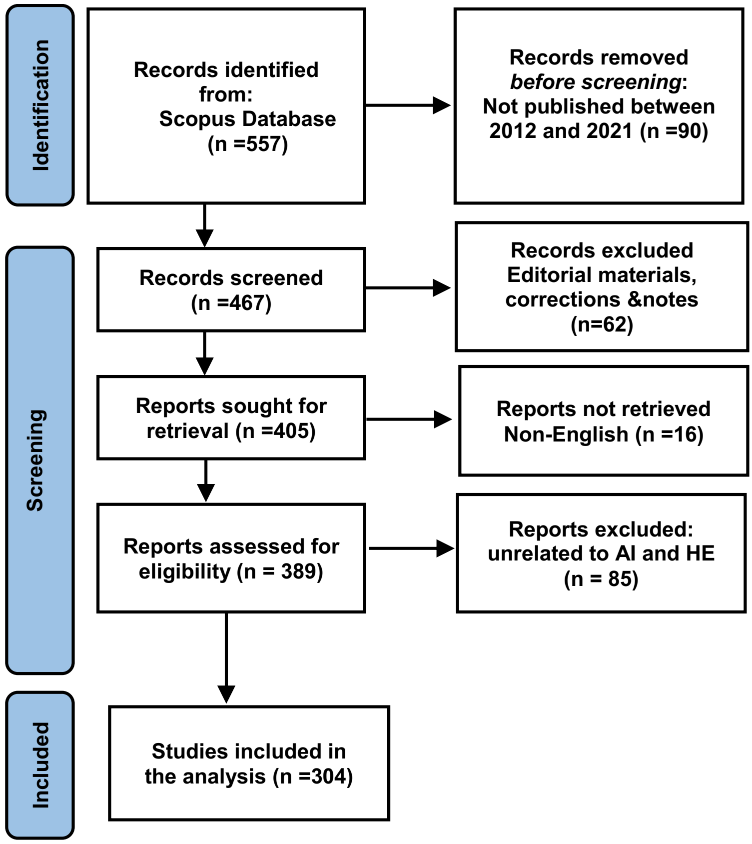

Figure 1. PRISMA flowchart (adapted from Page et al. 2021).

selecting articles focused on AI and HE. We then restricted our search to titles and abstracts containing "artificial intelligence" and "higher education." We selected 557 articles.

The results were filtered to include articles published from 2012 to 2021 – leaving 467 articles. We then refined the articles by type to include conference proceedings, journal articles, book chapters, books, and review articles. This led to the exclusion of 62 articles, leaving 405 articles. Articles not written in English were excluded, and this left 389 articles. The remaining 389 articles and the abstracts were exported to MS Excel for analysis. Publications not related to HE were removed, leaving 304 articles that were analyzed. The article selection process is shown in Figure 1. We downloaded data on 304 articles from the Scopus database in CSV Excel format. The abstracts, keywords, citations, and bibliographic information were exported to VOSviewer, a free bibliometric tool with visualization and text-mining abilities. VOSviewer provides network visualizations and density maps (van Eck and Waltman 2010). The LDA algorithm was run on Python 3 using Jupyter Notebook. Quantitative methods were used to analyze the data and explain the publications' emerging themes.

Data Pre-Processing

We pre-processed the data for analysis using the LDA algorithm. The 304 abstracts from the selected publications were tokenized into units of words. Special characters such as punctuation marks, stopwords, and verbs were removed from the data before analysis. The LDA algorithm was used to identify the 10 most dominant topics and the top 30 most salient terms.

Data Analysis

The embedded analytic functions for citation, subject, and h-index analysis provided by the Scopus database support the direct export of data into VOSviewer and Excel. VOSviewer is used to develop network visualizations and density maps (van Eck and Waltman 2010). We analyzed the data using quantitative methods to establish key and emerging themes from the publications.

Results

The document types and the number of articles retrieved are shown in Table 1. Conference proceedings account for over half of all articles analyzed, followed by journal articles accounting for 35.9%. The fact that conference proceedings papers dominate can be attributed to the increasing interest in AI in HE and the growing number of conferences organized in the field.

Publications and Citation Trends

The publications and citation trends are shown in Figure 2. As can be seen, less than 10 articles were published each year between 2012 and 2017, with a steady increase in publications from 2019 to 2021. There were no citations between 2012 and 2014. 2015 and 2016 had less than 10 citations per year. 2017 and 2018 had 20 and 50 articles, respectively. The last three years saw astronomical growth in citations, with 2019 having 215, 2020 having 911, and 2021 having 3086. Interest in AI research in HE has grown, with 2019, 2020, and 2021 contributing 88% of all articles. In the past three years, citations have also been astronomical (>98%) of all citations, with 2021 having about 72%.

Most Productive Countries

Researchers from 69 countries authored the 304 articles analyzed, with four articles having their authors undefined. China dominates with 67 articles, followed by the United States with 25 articles, Russia with 21, and the

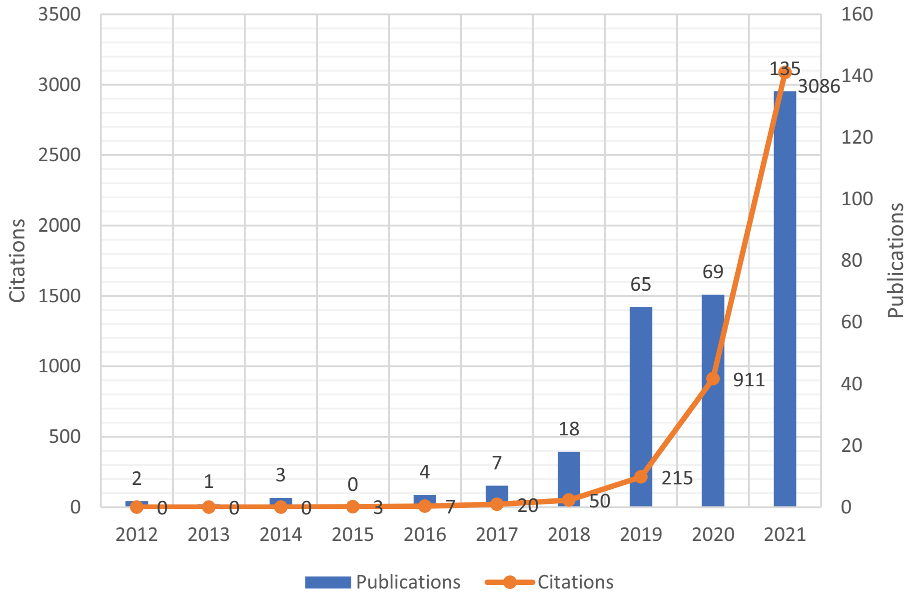

Figure 2. Publication and citation trends.

Table 1. Analysis by document Type.

Document Type	Count	Percentage of 304
Conference Proceedings	169	55.6
Journal Articles	109	35.9
Book Chapters	12	3.9
Book	7	2.3
Review Articles	7	2.3

United Kingdom with 20. Table 2 shows publications by country. The geographical distribution of articles shows that interest in research in this field is spread evenly in the global north and south, although the global north dominates. There is a notable difference in the number of articles being written, with countries from the global north producing more than their counterparts from the global south.

Analysis of Articles by Source

One hundred and sixty journals and conference proceedings published the 304 articles analyzed. Of these, 118 (74%) published one article, and 15 (12.5%) had two publications. Seven sources each published three articles. Table 3 shows the 12 sources that published the most papers. The top 11 sources contributed 70 (45%) of the articles, as seen in Table 3. The ACM International Conference Proceeding Series

Table 2. Geographical location of studies.

Rank	Country	Articles	Rank	Country	Articles
1	China	67	36	Thailand	3
2	USA	25	37	Viet Nam	3
3	Russian	21	38	Argentina	2
4	UK	20	39	Chile	2
5	India	17	40	Egypt	2
6	Spain	16	41	Finland	2
7	Australia	13	42	France	2
8	Germany	10	43	Italy	2
9	Malaysia	9	44	Jamaica	2
10	Portugal	8	45	Japan	2
11	Romania	8	46	Latvia	2
12	Saudi Arabia	8	47	Lebanon	2
13	Colombia	7	48	Malta	2
14	Hong Kong	7	49	Pakistan	2
15	Morocco	7	50	Peru	2
16	South Africa	7	51	Singapore	2
17	Turkey	7	52	Sri Lanka	2
18	Indonesia	6	53	Bahrain	1
19	Ireland	6	54	Bangladesh	1
20	Taiwan	6	55	Belgium	1
21	Oman	5	56	Croatia	1
22	Sweden	5	57	Denmark	1
23	UAE	5	58	Estonia	1
24	Brazil	5	59	Ghana	1
25	Canada	4	60	Hungary	1
26	Iraq	4	61	Iran	1
27	Kazakhstan	4	62	Mauritius	1
28	Mexico	4	63	Namibia	1
29	Poland	4	64	Nigeria	1
30	South Korea	4	65	Senegal	1
31	Cyprus	3	66	Slovakia	1
32	Ecuador	3	67	Tunisia	1
33	Greece	3	68	Ukraine	1
34	Netherlands	3	69	Zimbabwe	1
35	Serbia	3			

Table 3. Top 12 publishers.

Rank	Publisher	Count
1	ACM International Conference Proceeding Series	18
2	Advances in Intelligent Systems and Computing	13
3	Journal of Physics Conference Series	12
4	Lecture Notes in Computer Science, including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	10
5	International Journal of Emerging Technologies in Learning	6
6	Communications in Computer and Information Science	4
7	Frontiers in Psychology	4
8	IFIP Advances in Information and Communication Technology	4
9	Journal of Multiple-Valued Logic and Soft Computing	4
10	Lecture Notes in Networks and Systems	4
11	Procedia Computer Science	4
12	Proceedings 2021 International Conference on Computers Information Processing and Advanced Education Cipae 2021	4

contributed 5.9% of the articles, followed by Advances in Intelligent Systems and Computing with 4.3% and the Journal of Physics Conference Series with 3.9%.

Word Cloud

A word cloud was used to display high-frequency terms in text data visually. At a glimpse, the word cloud can help understand emerging ideas from text data. The 304 articles were analyzed based on term frequencies, with individual results shown using word clouds and tables. Figure 3 shows the word cloud for the high-frequency terms captured in the abstracts of the articles, which use a larger font size for the most frequent terms. As shown, the high-frequency terms include: “higher education,” “artificial intelligence,” “system,” “student,” “teaching,” “learning,” and “research” frequently occur.

Topic Modelling

Topic modeling is an ML technique that automatically identifies topics in a given corpus based on the relevance of the words within the topic. Topic modeling also assists in ranking the words within a specific topic (Sievert and Shirley 2014). The relevance (r) of each word to the topic is calculated using the equation (1):

$$relevance\,(word\,w|topic\,t) = \lambda \times p(w|t) + (1-\lambda) \times p(w|t) \div p(w)$$

The equation above shows that λ is the weight parameter (where 0 ≤ λ ≤1), w is the word, and t is the topic. The parameter controls the correlation between w and λ. The higher the word frequency, the more pertinent they are to the subject, especially if it is close to 1. The specific word is more pertinent to the subject if it is nearer 0. The Gensim library is used for topic modeling using the LDA algorithm. Table 4 shows the 10 topics, each associated with their 10 most frequent words, providing an overview of the key

Figure 3. Word cloud for AI application in HE.

Table 4. Ten Most frequent words per topic.

Topic Number	Ten most frequent words
0	education, university, learning, artificial, higher, intelligence, engineering, technology, students, systems
1	university, education, learning, intelligence, information, artificial, higher, technology, system, data
2	university, learning, education, artificial intelligence, students, higher, research, data, teaching
3	education, university, learning, higher, intelligence, artificial, technology, engineering, information, paper
4	university, education, intelligence, artificial, higher, learning, educational, technology, students, research
5	education, artificial, intelligence, learning, higher, university, technology, students, research, engineering
6	education, intelligence, university, artificial, technology, teaching, higher, research, students, training
7	learning, education, university, data, intelligence, artificial, students, teaching, technology, higher
8	education, university, higher, artificial, intelligence, management, learning, technologies, technology, research
9	education, university, learning, technology, higher, artificial, intelligence, information, students, engineering

themes explored in the study. Figure 4 visually represents the results of topic modeling analysis using LDA to explore the application of artificial intelligence AI in HE. The pattern shows that artificial intelligence has significantly impacted HE, where new AI-driven technologies are applied in the education system, with engineering disciplines leading this change. These observations are similar to Hinojo-Lucena et al. (2019), and Zawacki-Richter et al. (2019), who established that artificial intelligence, higher education, learning, teaching, technology, and students were the most common keywords in artificial intelligence research in higher education.

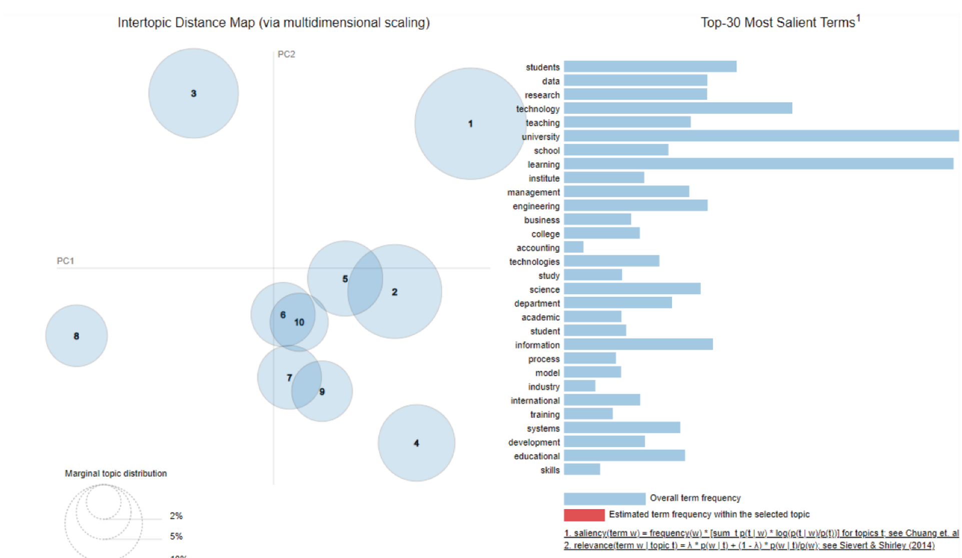

Figure 4. Topic modelling analysis for AI application in HE using LDA.

Figure 4 shows a two-dimensional inter-topic distance map from the LDA model. A good topic model will have pretty big, non-overlapping circles scattered instead of grouped in one quadrant. A model with many topics often results in overlaps and little bubbles grouped in one chart area. We may create this two-dimensional representation by calculating the topic separation and using multidimensional scaling. The map's inter-topic distance is shown on the left panel, which shows the similarity among topics. As depicted, each topic is represented by a bubble, whose size displays the frequency of the topic. The distance between the topics shows the disparity or similarity between the topics. The left panel shows the top 30 most salient terms that appear most often in the articles analyzed. The top 30 most prominent terms are university, learning, students, data, research, technology, teaching, school, institute, management, engineering, business, college, accounting, technologies, study, science, department, academic, student, information, process, model, industry, international, training, systems, development, educational and skills. Therefore, bubbles close to each other show related topics, while those far apart represent different topics. Highly similar topics may overlap each other.

Figure 4 shows the 10 topics derived through LDA analysis, collectively offering a comprehensive view of the dynamic interplay between AI and HE. Topic 1 is the most prominent topic relating to HE's integration of AI for learning, underscoring HE's role in deploying advanced systems to create a dynamic and efficient educational environment. Topic 3 focuses on student-centric learning using AI. Topic 4 is on academic research and AI, highlighting AI's role in driving innovation within academic research. Topic 8 delves into data-centric educational approaches facilitated by AI. The analysis of the figure reveals that these topics are distinct from one another, occupying separate quadrants and exhibiting unique focuses.

Topic 2 explores data-driven educational advancements, encompassing themes like information management, decision-making, and AI-driven educational approaches. Topic 5 centers on innovative pedagogical practices in HE. The overlap in the bubbles within Figure 4 indicates a shared research focus, suggesting that data-driven educational advancements and innovative pedagogical approaches often intersect in scholarly exploration. The analysis of the bubbles shows that more research is being done on Topic 2 than on Topic 5. Topic 6 relates to using technology to promote student-centered learning and research, emphasizing how technology empowers students to engage in research and enhance their educational journeys. Topic 10 shares a similar focus, focusing on technology-enhanced learning and research within HE. The almost similar sizes of the bubbles suggest that the topics are attracting similar interest. The significant overlap in these topics, as indicated by the overlapping bubbles, underscores their shared exploration of how technology, AI, and research converge to drive ongoing improvements and innovations in the educational arena.

Topic 7 focuses on the transformation of teaching, research, and training in the AI era within higher education institutions, highlighting the profound influence of AI on both students and educators. Conversely, Topic 9 centers on the strategic management of AI within HE, enhancing multiple dimensions such as research, learning, and innovation. The substantial overlap observed in the bubbles suggests a clear intersection between these two topics, indicating a shared exploration of AI's multifaceted impact within HE.

These 10 topics provide a comprehensive view of the dynamic interplay between AI and HE. They unveil the multifaceted transformations in the educational landscape due to the pervasive influence of AI and technology. Beyond the central focus on AI and HE, the findings reveal that the most extensively researched areas include "university," "learning," "technology," "students," "student information," "engineering," "data," and "research." This synthesis underscores the profound impact of AI and technology on HE, reflecting the diverse facets researchers explore within this evolving domain.

H-Index Analysis

The h-index is used to evaluate the academic and scientific achievement of scholarly articles and authors (Bertoli-Barsotti and Lando 2017). It is a reliable and authentic measure of educational and scientific achievement (Bornmann and Daniel 2007). Most subscription-based databases automatically calculate the h-index for selected articles (Durieux and Gevenois 2010). The h-index for the 304 articles was obtained from the Scopus database analysis for this study. In a set of activities, an h-index indicates that h publications have been mentioned at least h times (Hirsch 2005). All articles were cited 3 086 times, with an h-index of 31. This means that 31 of the 304 articles have at least 31 citations.

Keyword Analysis

We used VOSviewer to perform keyword analysis. In particular, we used the author keywords from the 304 articles analyzed. VOSviewer generated 7 127 keywords. The minimum occurrence of each keyword was set to 15, leaving 135 keywords. For each of the 135 keywords, a relevance score was calculated. Based on this score, 81 (60%) of the most relevant keywords were selected. These keywords related to the search terms were removed, leaving 77 keywords.

Figure 5 depicts the keyword co-occurrence network map generated by VOSviewer. The distance between two nodes shows the associative strength between the nodes, with a shorter distance revealing a stronger relationship. The red cluster is the most significant cluster, with 27 keywords. It focuses on

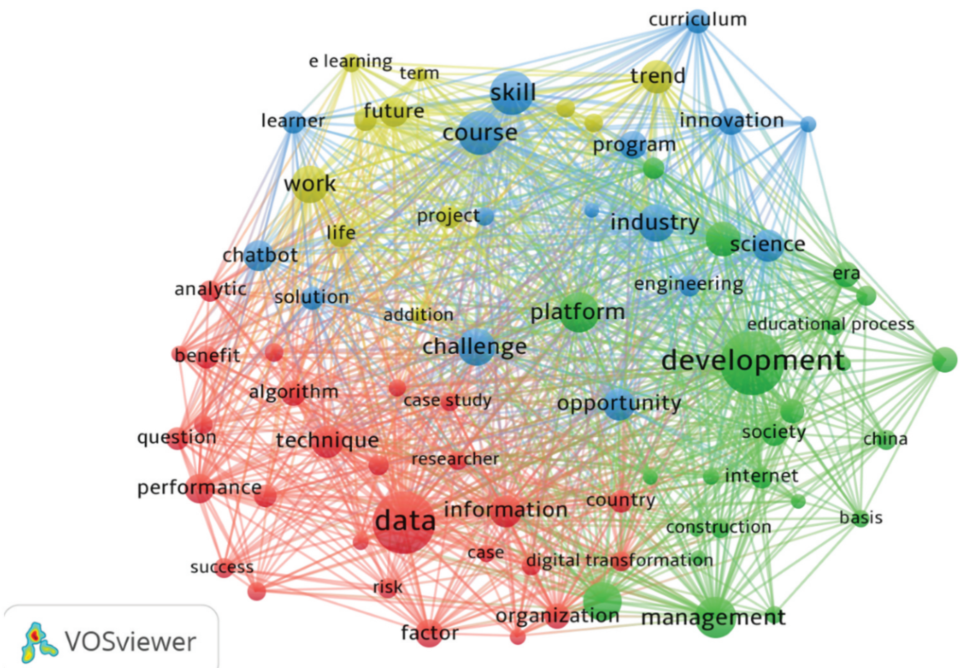

Figure 5. Keyword co-occurrence map of high-frequency terms in titles and abstracts.

data as the central theme. The data is operated upon using algorithms, analytics, and techniques to transform teaching and learning through the adoption of AI. The cluster also focuses on the uses of AI in academic performance monitoring, tracking student success, and making recommendations. The green cluster has 23 keywords and highlights research on developing AI-based applications in HE on various platforms and its use by management and teaching staff at HE institutions. The cluster shows the use of AI technology systems as driving forces in the growth of AI in HE. The blue cluster has 16 keywords and depicts the implementation of AI to support course and curriculum delivery. Thus, creating new skill development opportunities ensures that graduates are ready for the industry. The clusters also show research on opportunities and challenges the sector faces and innovations and solutions adopted for HE, such as chatbots, RS, and analytics. The last cluster, yellow, is the smallest, with 11 keywords. This cluster depicts the use of AI to prepare students for the future world of work. It also shows trends of AI in HE in e-learning and the classroom.

Figure 6 shows the research hotspots in the study field. These hotspots are clustered, showing a cluster of the researched topics. As can be seen, "data" and "development" 'course and skills" have been the research hotspots in the last decade. Analysis of the density visualization map shows that this field has matured, as it can be seen that research is conducted in clusters. A few keywords, such as platform, innovation, and opportunity, are not clustered with

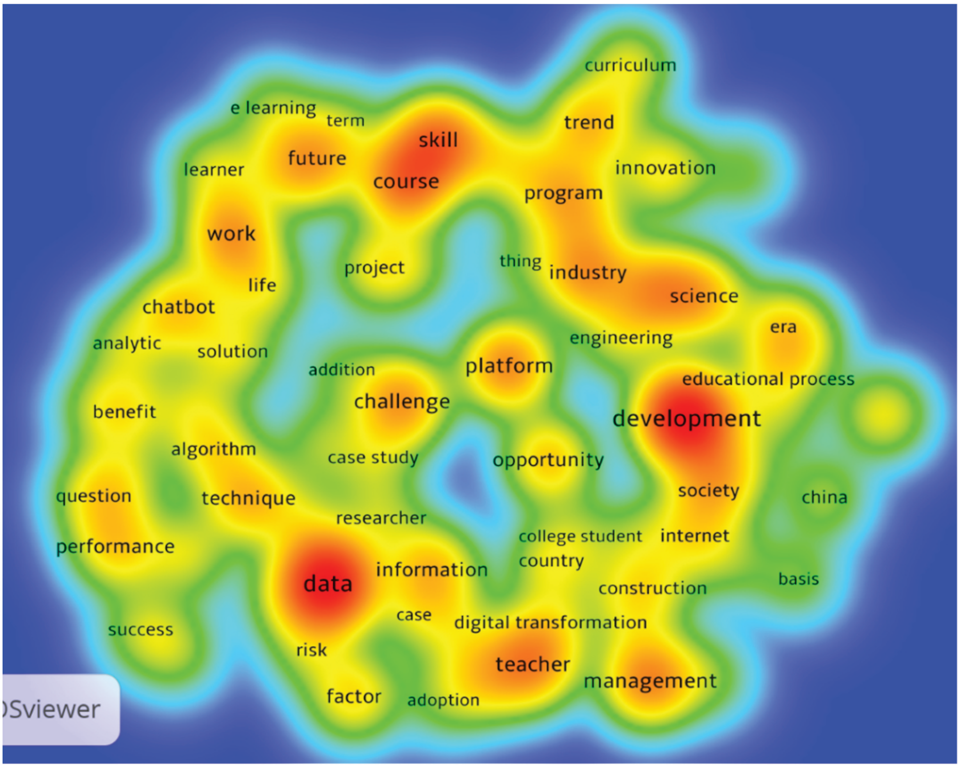

Figure 6. Keyword density map of high-frequency terms in titles and abstracts.

others. In addition to these fields, the map demonstrates that the study is expanding to previously undiscovered themes and areas, factors influencing the adoption of AI in HE, and the basis of implementing AI in HE.

Discussion

The study shows that AI research in HE has centered around four themes – data as the catalyst of the digital transformation, the development of artificial intelligence, the implementation of artificial intelligence in higher education and the trends, work, and future of artificial intelligence in higher education. This study contributes literature on AI usage in HE, using bibliometric analysis and topic modeling techniques. The bibliometric analysis provides visual insight into AI in HE and contributes to emerging and ongoing research. Results show that computer science has emerged as the top field in the past few decades. Still, other subfields, such as medicine, engineering, natural language processing, education, and commerce, have emerged as top application areas. AI research is multidisciplinary, covering traditional fields such as computer science and engineering, physics, and astronomy. AI research in HE over the past 10 years is shown through the clusters. Our keyword mapping shows that the green cluster relates to processes, tools, skills, impact, and the resultant change. The yellow cluster relates to the use of AI to prepare students for the world of work. The blue cluster relates to implementation, experiment, ability, and interaction, while the red clusters depict the course, concept, factors, learner, and implication. The interest in AI in education is transforming teaching and learning and supporting students and teachers during pandemics where face-to-face learning is impossible. This has seen the rise in adopting adaptive learning technologies, virtual and augmented reality, analytics, data mining, PE, and data-driven education.

The top leading countries in AI research in education include China (22.04%), the USA (8.22%), Russia (6.9%), the UK (6.57), and India (5.56%). Results also show little research coming from Africa, with only South Africa (2.30%), Morocco (2.30%), Zimbabwe (0.30%), Nigeria (0.030%), and Ghana (0.030%). The results show that the country's economic progress is proportional to AI research, which has seen Africa contributing 5.5% of research in AI in HE. The uptake of AI research in HE needs to be improved, as from 2012 to 2018, publications contributed only 9.7%. An astonishing 90.4% of the articles covering the AI application in HE were published in the past three years. In 2021, 195 articles were published, constituting 54% of the publications under review. Citations also grew proportionately, with 90.4% of the citations coming in the last three years and the other seven years contributing 9.6%. The ACM International Conference Proceeding Series, Advances in Intelligent Systems and Computing, and the Journal of Physics Conference Series are top publications.

The heat map demonstrates that process and skill, context and factor, course and work, time and impact are emerging hotspots. One of the emerging trends in AI application in HE is predictive analytics, where institutions apply it to enhance performance and competitiveness (Bowdre 2020). The density map shows a theme on the development of educational processes. One such relates to AI tools helping identify complex learning situations and improving the learning outcomes within the institution (Bhardwaj 2019). Teacher bots are vital to addressing the challenges HE has faced, which led to the disruption of traditional face-to-face teaching. Institutions deploy robots to teach students and monitor classroom activities (Yu 2020). Another way AI is being used in higher education is indirectly, with exoskeletons and prosthetics powered by AI to ease the limitations of age and disability and increase access to education (De Lange 2015). Pervasive neurotechnology and advancements in neuroscience enable gathering data from the human brain to support learning (Williamson 2019). According to Bahadır (2016), RS and AI predictions may accurately estimate a student's likelihood of finishing or failing a course. Automated student recruitment will be the focus of future AI applications.

Although much attention was put into conducting the bibliometric analysis, it has some limitations. We selected the Scopus database and left other databases such as the Web of Science and Google Scholar; thus, our report may underestimate research index trends. Again, only English-based papers were selected, thus excluding some other research, leading to underestimating research. Other research materials, such as editorial comments, newspaper articles, and gray literature, have been excluded.

Conclusion

The current study aimed to provide a bibliometric analysis and topic modeling of the volume and research trends regarding the application of AI in HE from the Scopus database. This study extends our initial conference work, which provided an overview of AI research in HE, and this bibliometric delves deeper to cover status, trends, top contributors and emerging hotspots. AI is revolutionizing education through reduced teacher workload, individualized learning, intelligent tutors, profiling and prediction, high-precision education, collaboration, and learner tracking. AI assists educators in adopting effective teaching methods and identifying learning needs and patterns, thus improving learning outcomes and decision-making.

Using the PRISMA methodology, we initially selected 557 articles based on our search criteria. Publications unrelated to the use of AI in HE, commentary and editorial notes, and those that did not include the keywords and not in English were removed, leaving 304 articles for analysis. We used VOSviewer to perform keyword analysis to provide answers to our research questions. The LDA was used to develop a two-dimensional inter-topic distance map. The study provided analysis, reporting annual publications, countries, keyword analysis, and unearthing emerging research trends from 2012 to 2021. Results show a dramatic increase in publications in the past three years. In 2019–2021, they contributed 90.4% of the publications, highlighting the emerging importance of AI in education. The study noted the top productive countries, authors, institutions, journals, keywords, and emerging research themes. Developed countries lead the research contributions, with insignificant output coming from developing countries, with Africa contributing less than 5% of the research. China, the United States, the United Kingdom, Spain, Taiwan, and Russia are the leading nations in AI research in education. The most influential journals are the International Journal of Emerging Technologies in Learning, Computer Applications in Engineering Education, and the International Journal of Educational Technology in Higher Education.

The identified hotspots will receive global attention in the coming years due to the influence of AI on every aspect of human life, including education. Our study provides a global overview and a holistic picture of AI applications in HE. Our findings reveal that most publications focused on teaching and learning support with limited application on the administrative aspects of higher education. Future studies could focus on AI in admissions and administrative aspects, such as responding to student queries. The imbalance in research output between the

Global North and South needs attention. The fast-evolving adoption of AI in HE requires continuous investigation of the current state, trends, and emerging areas to influence research. Our research appeals to governments and organizations in developing countries to fund research in AI in education since students will be required to work in AI-based jobs. This research adds to the literature on AI research in education from Africa.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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