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The potential of artificial intelligence in vocational education research and development: A bibliometric study

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ABSTRACT

Artificial Intelligence (AI) is emerging as a revolutionary force that is changing how we interact and work and redefining the global education landscape, especially Vocational Education (VE). AI is an opportunity to develop learning research and good vocational Education. However, this opportunity has not been correctly utilized because not all educators can develop research and AI-based learning content well. This article reveals opportunities for current and future research development related to AI and vocational Education through bibliometric analysis. The database comes from Scopus, and 159 articles were analyzed from 2014 to 2023. Bibliometric analysis of documents, including author name, journal network, country, and keywords, is visualized using the VOSviewer program. The findings reveal three key insights: (1) research remains concentrated in vocational health, with limited exploration in other sectors such as engineering, tourism, and agriculture; (2) international collaboration is still weak, despite strong potential between countries with high and emerging publication rates; and (3) keyword clusters highlight Apprenticeship, Students, Artificial Intelligence, and Engineering Education as the main thematic areas. These insights form a roadmap for future research that emphasizes diversifying AI applications across vocational sectors, fostering cross-border collaboration, and developing innovative themes around curricula, personalized learning, and simulation-based training. Despite limitations related to database and language scope, this study offers strategic directions for advancing AI in VE research and strengthening its contributions to global vocational education development.

INTRODUCTION

In the era of the Industrial Revolution 4.0, the rapid growth of digital technologies not only transforms how people interact and work but also reshapes the global education landscape. Amid this transformation, artificial intelligence (AI) has emerged as a revolutionary force that has great potential to modernize, reform, overhaul, and improve the quality of education, especially in the context of vocational education (VE) (Kong et al., 2024). Vocational education, which emphasizes equipping learners with practical skills for workforce readiness, requires learning approaches that are adaptive, interactive, and aligned with evolving industry demands (Heck & Schouten, 2020; Squicciarini & Nachtigall, 2021).

AI provides innovative applications and solutions that enhance both the effectiveness and efficiency of teaching and learning (Xu, 2023). Examples include personalized learning pathways tailored to individual needs and abilities (Y. Cheng & Liang, 2023). AI-powered simulations and virtual reality for developing practical skills in realistic yet safe environments (Chiang, 2021) and

advanced data analytics that enable accurate identification of training needs while dynamically adjusting curricula to industry standards (Ni et al., 2022).

Despite the growing body of research on AI in education, studies focusing specifically on its application in vocational education remain limited. Existing literature tends to concentrate on general education or higher education contexts, leaving a gap in understanding how AI contributes to the unique requirements of vocational training, such as practical skill assessment, workplace readiness, and institutional efficiency. Moreover, there is a lack of bibliometric studies that map the intellectual structure, research clusters, and emerging trends of AI in vocational education. Furthermore, most bibliometric works provide only a snapshot of research trends, without tracing the longitudinal development of themes or identifying emerging hotspots that signal future directions (Galung et al., 2024).

To address this gap, the present study employs a bibliometric approach to analyze the existing body of literature on AI in vocational education (Donthu et al., 2021). This study aims to identify major trends, significant contributions, opportunities, and challenges in the field (Donthu et al., 2021). By highlighting how AI can contribute to adaptive curriculum design, interactive learning methods, and advanced skill evaluation through simulations and virtual reality, the research underscores AI's critical role in strengthening vocational education (Li & Leong, 2026; S. Wang et al., 2024). Ultimately, this study positions AI as a transformative force in creating inclusive, relevant, and future-ready vocational education systems (UNESCO, 2023).

In addition to its pedagogical contributions, the integration of artificial intelligence in vocational education also plays a strategic role in bridging the gap between education and industry (Semenkina et al., 2024). One of the persistent challenges in vocational systems is the mismatch between graduates' competencies and labor market needs (OECD, 2023). AI technologies, particularly those driven by big data and machine learning, enable real-time analysis of industry trends, skill demands, and workforce requirements, allowing vocational institutions to continuously update their curricula and maintain alignment with rapidly evolving industrial standards (Semenkina et al., 2024). As a result, AI not only enhances learning processes but also strengthens the relevance and responsiveness of vocational education systems to economic and technological changes.

Furthermore, AI contributes significantly to improving institutional management and decision-making in vocational education (S. Wang et al., 2024). Through intelligent systems, educational institutions can optimize resource allocation, monitor student performance at scale, and predict potential dropout risks (Dewi et al., 2023; Viberg et al., 2020). Learning analytics generated by AI systems provide educators and administrators with actionable insights, enabling early interventions and more targeted support strategies (Knight et al., 2023). In this regard, AI functions not only as a teaching tool but also as a management instrument that supports data-driven governance and quality assurance in vocational education institutions (UNESCO, 2023).

Another important dimension is the role of AI in supporting lifelong learning and reskilling, which are increasingly essential in the context of Industry 4.0 and beyond (Leopold et al., 2025). The rapid obsolescence of skills requires workers to continuously update their competencies throughout their careers (OECD, 2023). AI-powered platforms facilitate flexible, personalized, and on-demand learning opportunities that can be accessed beyond formal education settings (S. Wang et al., 2024). This is particularly relevant for vocational education, where continuous skill development is critical for maintaining employability (Semenkina et al., 2024). Therefore, AI contributes to expanding the scope of vocational education from initial training to continuous professional development.

However, despite its potential benefits, the implementation of AI in vocational education also raises several critical challenges and ethical considerations. Issues such as data privacy, algorithmic bias, digital inequality, and the readiness of educators to adopt AI technologies remain significant barriers (Kasneci et al., 2023). Many vocational educators lack sufficient training and digital competencies to effectively integrate AI into their teaching practices (Al Darayseh, 2023; Su et al., 2023). Additionally, unequal access to technological infrastructure may exacerbate existing educational disparities, particularly in developing countries. These challenges highlight the need for comprehensive policies, professional development programs, and ethical frameworks to ensure responsible and equitable implementation of AI in vocational education (UNESCO, 2021).

Finally, the complexity and multidimensional nature of AI in vocational education underscore the importance of adopting a holistic research perspective. Future studies should not only focus on technological innovation but also consider pedagogical, social, economic, and ethical dimensions. A comprehensive understanding of AI in vocational education requires interdisciplinary approaches that integrate insights from education, computer science, labor economics, and policy studies. By doing so, research can better inform evidence-based practices and policies that maximize the benefits of AI while minimizing its risks. This further reinforces the relevance of bibliometric analysis as a method to systematically map the development, structure, and future directions of research in this evolving field.

METHOD

This study employs bibliometric analysis to map and characterize the global scientific publication landscape on AI in vocational education. This approach was chosen because it provides a robust framework for measuring productivity, identifying trends, and analyzing the cognitive structure of a research field in a transparent and measurable manner. The research process was divided into three main stages to ensure data reproducibility and reliability. In the first stage, data were collected using the Scopus database, which was selected for its extensive coverage and reputation as a reliable source for bibliometric analysis. The period analyzed was 2014 to 2023, reflecting the period of increasing global attention to the implementation and impact of AI. Particular search queries were formulated to ensure high relevance of the data corpus:

TITLE-ABS-KEY ("artificial intelligence" "vocational education") AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (SRCTYPE , "j"))

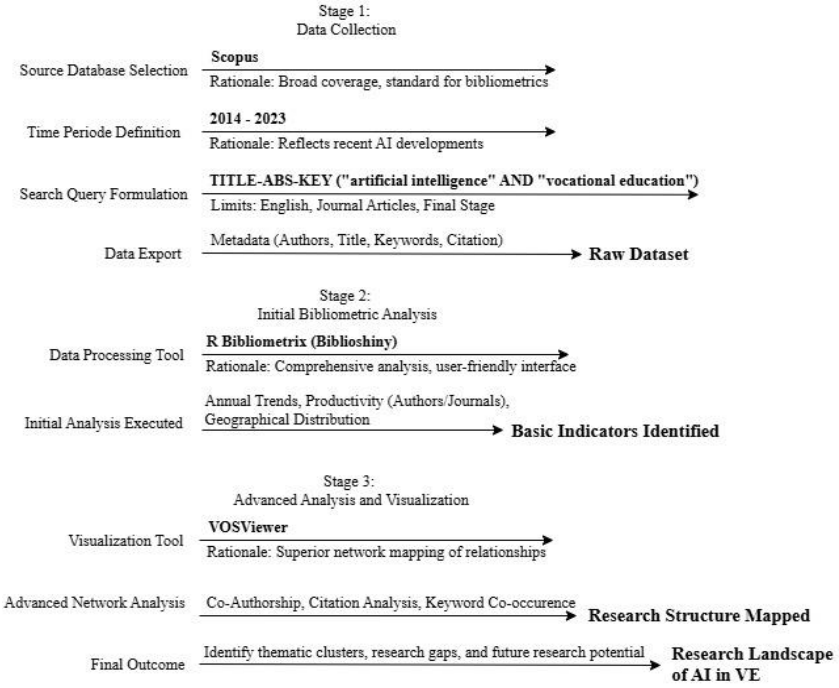


Figure 1. Steps of the Research Method

This query explicitly limits the results to journal articles (SRCTYPE, "j") published in English that have reached the final publication stage, a step taken to ensure data quality and consistency by focusing on research results that have undergone rigorous peer review. The collected data (metadata) is then exported from Scopus for further analysis.

In the second stage, the raw data were processed using the Biblioshiny interface to R/Bioconductor's Bibliometrix package. This tool was chosen for its comprehensive capabilities in processing and analyzing large volumes of bibliometric data and facilitating fundamental analyses such as annual publication trends, identification of the most productive authors and journals, and the geographical distribution of publications. This initial analysis provides the basis for mapping key productivity and impact indicators in AI and VE research.

The final stage involves more in-depth network analysis and visualization to reveal collaborative and thematic structures in this field. VOSViewer is used for visualization. This tool was chosen for its ability to generate informative network maps that help identify research clusters and relationships among elements. The advanced analyses performed include co-authorship analysis to map the collaboration networks of authors and institutions; citation analysis to identify seminal and influential works; and keyword co-occurrence analysis. The results of this keyword analysis are crucial, as they inform the identification of emerging themes and the determination of potential future research directions (emerging research frontiers) at the intersection of AI and VE. In summary, the research method is shown in Figure 1.

RESULTS AND DISCUSSION

Data searches using the Scopus database identified up to 159 documents from 2014 to 2023 on AI in VE. The analysis results are presented in the following Table 1. Table 1 presents the number of 159 primary documents, with 94 sources from journals, books, and other sources. The document's annual growth rate is 23.03%, indicating that research on AI in VE continues to grow in demand. The average age of the document is 3.16 years for ten years. This means that the average article production is still relatively young and the most produced in the last three years. Most document types are conference papers (89), followed by journal articles (42) and conference reviews (15). The rest came from books, book chapters, editorials, errata, letters, retractions, and reviews.

Table 1. Main Information

Main Information	Result
Timespan	2014:2023
Sources (Journals, Books, etc)	94
Documents	159
Annual Growth Rate %	23.03
Document Average Age	3.16

According to Rafiq et al. (2024), research is often published at conferences for five reasons, namely: (1) conference papers have a better reputation, (2) have a more significant influence and are easily accessible, (3) are displayed at conferences so that many people see them, (4) good quality because not all papers are accepted at conferences, and (5) conferences are held more often than journals. This is the main reason why the number of documents derived from conference papers is higher. Furthermore, based on the data above, additional analyses were conducted for three aspects: co-authorship, citation, and keyword co-occurrence.

Co-Authorship Analysis

The relationship between two or more authors in developing a study is a benchmark for how far the research is conducted. Authors can establish research collaborations to achieve common research goals. This can be done on a broad scale, such as across authors from different fields of study, affiliations, countries, or continents. This pattern is consistent with bibliometric findings in educational technology research, which show that early-stage or niche topics often rely on domestic networks before expanding internationally (Durak et al., 2024).

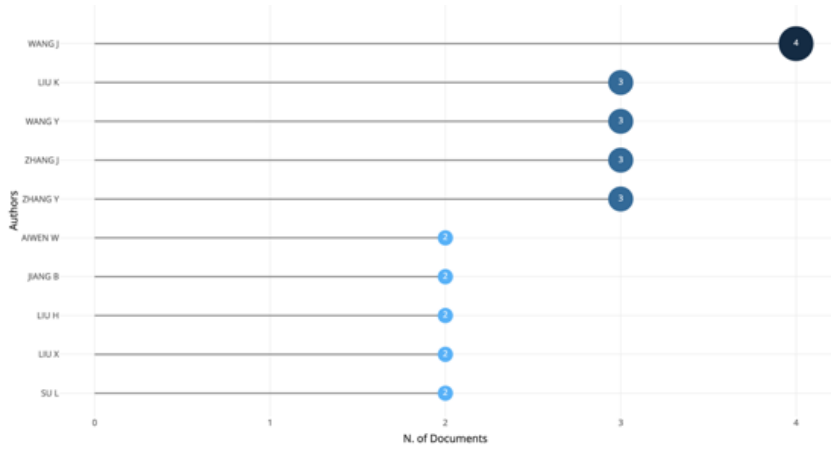
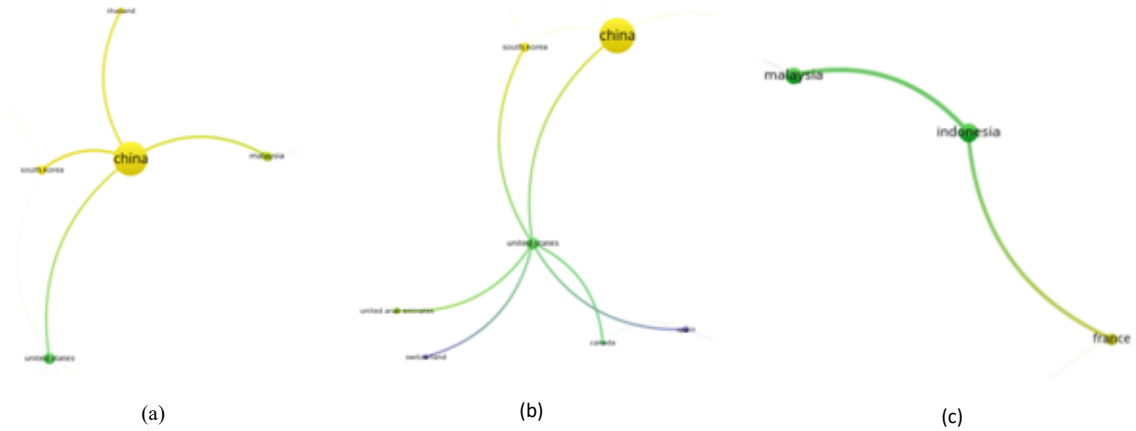


Figure 2. Top Authors by Number of Documents

Figure 3 shows a list of the top 10 authors based on the number of articles written. Wang J is the author with the most articles on this topic, with four articles. Incidentally, Liu K, Wang Y, and Zhang Y each wrote three articles. Then there are Aiwen W, Jiang B, Liu H, Liu X, and SU L, each of whom wrote two articles. The analysis results indicate that most collaborations among authors remain within a single country or within the same organization. Usually, this occurs because the research remains focused on local problems. In greater detail, Figures 2 and Figure 3 illustrate the relationship between countries' AI and VE productivity.



(a) (b) (c)

Figure 3. Country Network

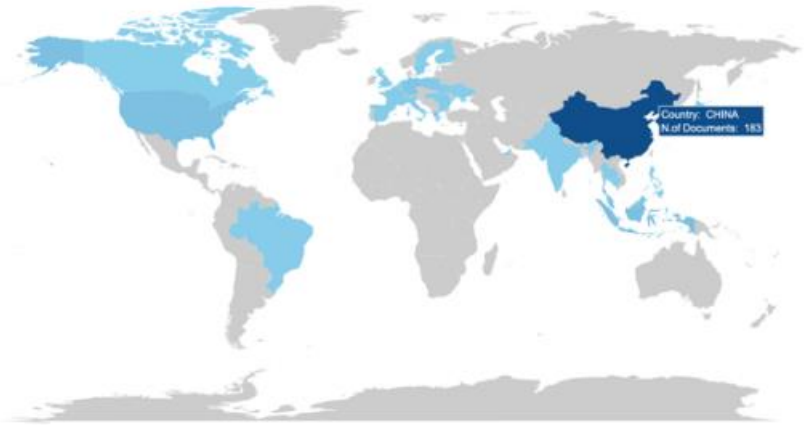


Figure 4. Country Scientific Production

The distribution of countries is pretty uneven. In Figure 3, a country network analysis is presented. China forms the largest bubble, indicating the country's dominance in AI in VE. In Figure 3(a), cluster 1 depicts China collaborating with South Korea, Malaysia, the United States, and Thailand. Cluster 2 in Figure 3(b) is the collaborative relationship between the United States and the United Arab Emirates, Switzerland, Canada, Spain, China, and South Korea. For cluster 3 in Figure 3(c), Indonesia collaborates with Malaysia and France. Figure 4 presents an overview of the author's country-of-origin distribution map. As noted earlier, China has a strong dominance in research on this topic. More clearly, China is the country that has published the most about AI in VE. This finding is compelling given the total number of documents; the country appears 183 times, followed by Indonesia 20 times, the USA 19 times, Germany 11 times, and Malaysia 10 times. The other countries shown on the map have publication frequencies below 10, indicating strong dominance by only a few key countries in research on VE and AI.

The results show a strong dominance of China. This finding aligns with previous scientometric studies in educational technology and artificial intelligence that similarly highlight China's increasing research productivity and investment in AI-related fields (Çakıt & Dağdeviren, 2022; Peng et al., 2021). The concentration of publications in only a few countries, such as China, the USA, and Indonesia, reflects structural inequalities in global research. As noted by Glänzel and Schubert (2004), research collaboration often mirrors geopolitical and economic capacity, with high-income countries taking the lead while developing countries have limited visibility.

The findings contribute to the understanding of knowledge networks in emerging fields like AI in VE. Co-authorship analysis not only maps productivity but also highlights structural gaps that require bridging. In practice, the study underscores the importance for policymakers and institutions in less-represented countries of actively engaging in international research networks. Strengthening global partnerships can help ensure that the development of AI in vocational education addresses not only the needs of dominant economies but also the diverse challenges of developing contexts.

Citation Analysis

Citation analysis is conducted to identify which documents receive the most citations. Most globally cited documents are publications that are cited most frequently by researchers worldwide. This analysis involves identifying the documents with the highest citation counts in the global scientific literature. These documents have a significant impact and are considered important works in a particular field of research or topic. Table 2 presents data on the most globally cited documents.

Table 2 shows that one of the most-cited articles in the period 2014-2023 is Kalpathy-Cramer J.'s work, "Evaluating performance of biomedical image retrieval systems-An overview of the medical image retrieval task at ImageCLEF 2004-2013," with 119 citations (Kalpathy-Cramer et al., 2015). The second is Bush C.L.'s work, entitled "Toward the Definition of Personalized Nutrition: A Proposal by The American Nutrition Association," which has 103 citations (Bush et al., 2020). Furthermore, the third position was occupied by Avis J.'s work entitled "Socio-Technical Imaginary of the Fourth Industrial Revolution and Its Implications for Vocational Education and Training: A Literature Review" with 85 citations (Avis, 2018).

The fourth to tenth orders are as follows: Ahn C with 48 citations, Jiang L. with 33 citations, Kortesniemi M with 32 citations, Dziurka M with 28 citations, Hassan R.H with 14 citations, Jiang B. with 13 citations, and finally Sarbadhikari S.N with 13 citations (Ahn, 2023; Dziurka et al., 2022; Hassan et al., 2021; Jiang, 2022; Sarbadhikari & Pradhan, 2020). However, the most significant trend is not Kalpathy-Cramer J's work but Ahn C's work on "ChatGPT," published in 2023. In the past year, the article has received 48 citations (approximately half as many as other articles published since 2014), with the highest annual average of 24 citations. These results indicate that AI is a current topic, with very significant citation counts.

Table 2. Most Globally Cited Documents

Authors	Year	Title	Total Citations	TC per Year	Normalized TC
Kalpathy-Cramer J.; de Herrera A.G.S.; Demner-Fushman D.; Antani S.; Bedrick S.; Müller H.	2015	Evaluating performance of biomedical image retrieval systems: An overview of the medical image retrieval task at ImageCLEF 2004-2013	119	11.90	3.93
Bush C.L.; Blumberg J.B.; El-Sohemy A.; Minich D.M.; Ordovás J.M.; Reed D.G.; Behm V.A.Y.	2020	Toward the Definition of Personalized Nutrition: A Proposal by The American Nutrition Association	103	20.60	16.26
Avis J.	2018	Socio-technical imaginary of the fourth industrial revolution and its implications for vocational Education and training: a literature review	85	12.14	3.97
Ahn C.	2023	Exploring ChatGPT for information of cardiopulmonary resuscitation	48	24.00	20.16
Jiang L.	2021	Virtual Reality Action Interactive Teaching Artificial Intelligence Education System	33	8.25	13.20
Kortesniemi M.; Tsapaki V.; Trianni A.; Russo P.; Maas A.; Källman H.-E.; Brambilla M.; Damilakis J.	2018	The European Federation of Organisations for Medical Physics (EFOMP) White Paper: Big data and deep learning in medical imaging and in relation to the medical physics profession	32	4.57	1.49
Dziurka M.; Machul M.; Ozdoba P.; Obuchowska A.; Kotowski M.; Grzegorczyk A.; Pydyś A.; Dobrowolska B.	2022	Clinical Training during the COVID-19 Pandemic: Experiences of Nursing Students and Implications for Education	28	9.33	9.63
Hassan R.H.; Hassan M.T.; Naseer S.; Khan Z.; Jeon M.	2021	ICT-Enabled TVET Education: A Systematic Literature Review	14	3.50	5.60
Jiang B.	2022	Research on The Application of Chinese Traditional Culture Teaching in Higher Vocational Education	13	4.33	4.47
Sarbadhikari S.N.; Pradhan K.B.	2020	The Need for Developing Technology-Enabled, Safe, and Ethical Workforce for Healthcare Delivery	13	2.60	2.05

Table 3 shows that China is the most frequently cited country, with 168 citations and an average of 2.3 citations per article. This reaffirms China's dominance in the topic of VE and AI. The large number of articles from China is the main reason why the country has the highest number of citations. Nonetheless, the United States (USA) ranks second with 109 citations and an average of 21.80 citations per article. The United Kingdom (UK) ranks third, with 96 citations and an average of 32 citations per article. Furthermore, Finland ranks fourth, with 32 citations per article, followed by Poland at 28.

Although China has the highest number of articles and citations, the average number of citations per article is relatively small compared with those of the other top five countries. The USA, the UK, Finland, and Poland have fewer articles but exhibit a relatively high average citation rate, indicating the impact and relevance of their published articles. Other countries, such as Indonesia, Korea, the Philippines, India, and France, also contribute despite having a lower number of citations. Broadly speaking, this data provides an overview of the distribution of research impact across countries within the scientific community. Overall, these data provide insight into the distribution and impact of scientific research across countries, suggesting that dominance in the number of publications is not necessarily directly proportional to the impact per article.

Table 3. Most Cited Country

Country	TC	Average Article Citations
China	168	2.30
USA	109	21.80
United Kingdom	96	32.00
Finland	32	32.00
Poland	28	28.00
Indonesia	23	4.60
Korea	15	7.50
Philippines	15	7.50
India	13	6.50
France	7	7.00

China has strategically integrated AI courses across various educational levels, including vocational Education, to enhance public awareness and the application of AI while nurturing AI talent (Song et al., 2022). This national-level strategy aligns with the importance China places on vocational and technical education and training (TVET) as a crucial pathway to boost labor productivity and drive economic development (Fan et al., 2024). China's focus on AI and vocational Education is driven by strategic national initiatives, the importance placed on vocational training for economic development, and the recognition of vocational education as a key component of the educational system. The country's efforts to integrate AI into education, particularly vocational Education, reflect a forward-looking approach to preparing individuals for the evolving demands of the workforce.

Keyword Co-Occurrence Analysis

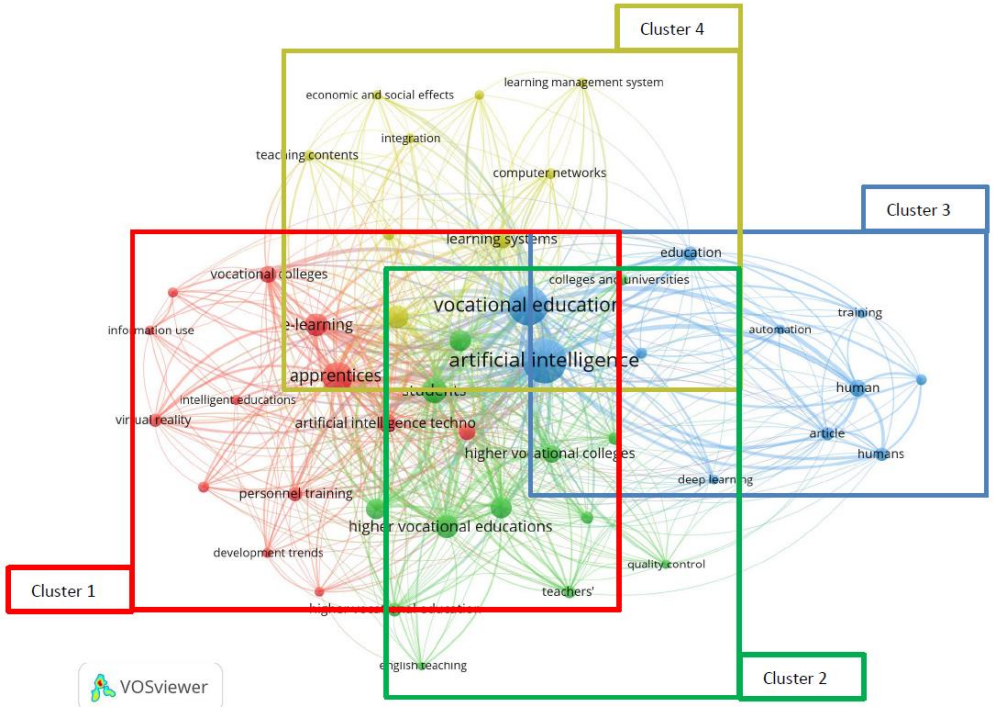


Figure 5. Visualization of Co-Occurrence Clusters Based on Author Keywords for AI and VE

Keyword co-occurrence describes the co-occurrence of two or more keywords in a document. These keywords are used to identify research trends that are often discussed together, to create visual maps showing how various concepts are related, and to determine themes that are the focus of attention within a discipline, based on the emergence of keywords. Figure 5 shows the keywords that most frequently appear in artificial intelligence (AI) research related to vocational education (VE).

The first cluster is "apprenticeship," which is indicated in red. In cluster 1, the most frequently occurring keywords are artificial intelligence, big data, development trends, e-learning, and education reforms. Cluster 1 focuses on incorporating AI technology into the internship program. Keywords such as "artificial intelligence technology", "big data", and "e-learning" suggest that research in this cluster explores how AI can be used to improve internship programs, such as providing personalized instruction, tracking learner progress, and facilitating collaborative learning (Permana & Pradnyana, 2019; Santos & S. Junior, 2024; Wolf & Wolf, 2023). The keywords "development trend" and "education reforms" suggest that the study also examines how AI can be used to reform and update internship programs to be more relevant to current industry needs (Aggarwal & Aggarwal, 2021; Coelho & Primo, 2017).

The second cluster is shown in green, with "students" appearing most frequently. The five keywords that often appear are colleges and universities, curricula, education computing, employment, and English teaching. This cluster focuses on the influence of AI on students in VE. Keywords such as "colleges and universities", "curricula", and "education computing" suggest that research in this cluster explores how AI can be used to improve the student learning experience, such as providing personalized feedback, creating more engaging learning materials, and improving access to educational resources (Mackey et al., 2024; Vundela & Kathiravan Muthiah, 2024). The keywords "employment" and "English teaching" indicate that the study also examines how AI can be used to prepare students for the workforce, such as helping them develop their English skills and find a job (L.-M. Wang et al., 2014).

"Artificial intelligence" is the most frequently used word in the third cluster (indicated by blue). The most widely used keywords in this cluster are article, artificial intelligence, automation, and deep learning. This cluster focuses on the application of AI in vocational education. Keywords such as "article", "artificial intelligence", "automation", and "deep learning" suggest that research in this cluster explores a variety of ways AI can be used to improve VE, such as automating administrative tasks, providing personalized instructions, and developing new learning tools (Çapşek & Karacı, 2022; Ran & Han, 2023).

The yellow color indicates the cluster 4 area, in which "engineering education" is the most frequently used term. The five main words in this cluster are computer networkers, economic and social effects, engineering education, information management, and integration. This cluster focuses on the use of AI in engineering education. Keywords such as "computer networkers", "economic and social effect", "engineering education", "information management", and "integration" suggest that research in this cluster explores how AI can be used to improve engineering education, such as preparing students for jobs in the field of computer networks, studying the economic and social impacts of AI technology, and integrating AI into the engineering education curriculum.

Taken together, these clusters suggest two significant insights. First, research in AI and VE is both pedagogical and systemic, spanning from micro-level student experiences to macro-level reforms. Second, the distribution of clusters aligns with global trends reported in previous scientometric studies, which have found that AI research in education increasingly emphasizes personalization, employability, and sector-specific applications (Zawacki-Richter et al., 2019). These findings highlight the multidimensional role of AI in vocational education, shaping both learning processes and systemic reforms. In practice, they underscore the importance of developing interdisciplinary approaches that integrate technological, pedagogical, and socio-economic perspectives. This suggests that future research should not only deepen exploration of dominant themes, such as apprenticeships, but also strengthen underrepresented areas, such as the societal impacts of AI in VE.

Table 4 presents the ten most frequently used keywords in publications on digital media and vocational education at the international level. VOSviewer's analysis indicates that "Artificial Intelligence" occurs 90 times, underscoring the magnitude of concern regarding the application of AI in VE. These findings align with studies by Muttaqin et al. (2024) and Rosyadi et al. (2023), which show that AI serves not only as a technical tool but also as a catalyst for learning personalization, industrial simulation, and the enhancement of the effectiveness of vocational education systems. The keywords "vocational education" (81 times) and "apprentices" (45 times)

indicate a sustained focus on the linkage between theory and real-world practice, consistent with the trend toward technology-based vocational education reform (Aggarwal & Aggarwal, 2021).

Table 4. Top 10 Most Frequently Used Words

Words	Occurrences
artificial intelligence	90
vocational Education	81
apprentices	45
students	32
engineering education	28
higher vocational educations	28
e-learning	27
curricula	23
teaching	23
education computing	21

Furthermore, the occurrence of the word "students" (32 times) underscores the importance of the experience and student engagement dimensions, particularly through the integration of e-learning, adaptive curricula, and AI-based teaching methods (Dewantara et al., 2024; Mackey et al., 2024). Meanwhile, keywords such as "engineering education" and "higher vocational education" indicate a research concentration on the development of specific technical skills, while the emergence of "e-learning", "curricula", "teaching", and "education computing" affirms the role of digital technology as a driver of innovation in curriculum design and learning methods (Peeken et al., 2018). Overall, these results confirm that the latest research is not only focused on the technical use of AI, but also on how AI is integrated into vocational learning systems to improve the quality of education, workforce readiness, and the relevance of the curriculum to industry needs.

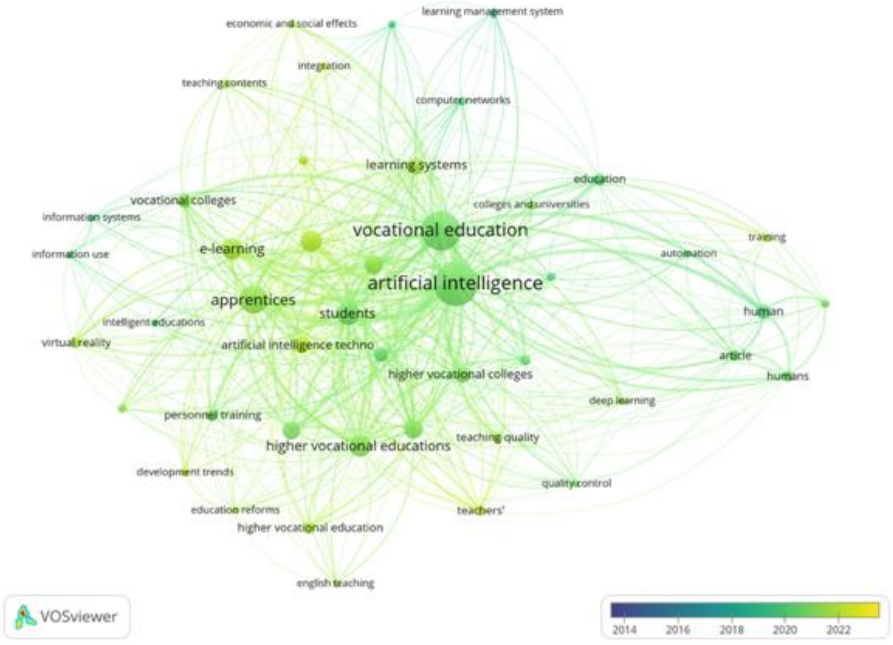


Figure 6. Keyword Co-Occurrence Network

The color analysis in this visualization provides insight into the temporal development of the topic under study. The dots and lines reflect the year of the relevant research publication, with blue indicating earlier publications (around 2014) and yellow indicating more recent publications (around

2022). The majority of dots and lines related to "artificial intelligence" and "vocational education" are green to yellow, indicating that these topics have become significant foci in recent years. This reflects the increased interest and attention to the integration of AI into VE, driven by technological advancements and the need for a more adaptive and innovative education system.

In addition, the relationships among keywords such as "learning systems", "virtual reality", "deep learning", and "automation" indicate the interconnections and integration of various educational technologies and artificial intelligence. This shows that the research not only focuses on the basic applications of AI in VE but also explores the use of other advanced technologies to improve the effectiveness and quality of education. Topics such as "teaching quality", "quality control", and "economic and social effects" indicate concern with the broader impacts of applying these technologies, including improved teaching quality and the resulting socioeconomic effects. This indicates that research in this area is not only technical but also considers practical aspects and real-world societal impacts.

The relationship indicates that AI is a complex, multidisciplinary field encompassing a wide range of topics and concepts. AI has the potential to revolutionize various sectors, including education, vocational education, industry, and government. However, AI also poses a range of ethical and social challenges that need to be considered. AI offers innovative solutions to improve the quality of Education. AI can help personalize learning by adapting learning materials and methods to each student's needs and learning style. This enables students to learn more effectively and efficiently and to reach their full potential. Additionally, AI can assist teachers in assessing and monitoring student progress by providing real-time and accurate feedback. Teachers can also use AI to identify students who need additional support and provide appropriate interventions.

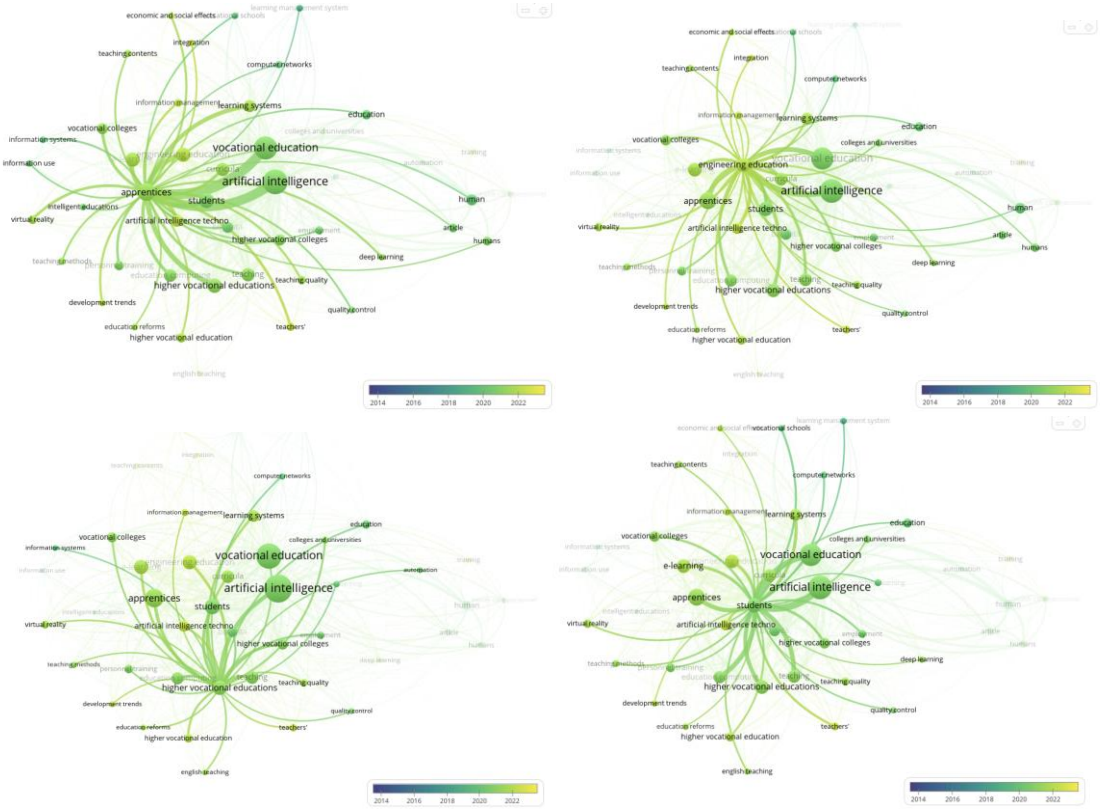


Figure 7. Highlight Keyword in (a) Apprentices, (b) Engineering education, (c) Higher Vocational Education, (d) Students

AI can be used to automate tasks, improve efficiency, and generate new products and services. AI offers numerous revolutionary benefits. Its ability to automate tasks brings unparalleled

efficiency, frees humans from repetitive work, and allows them to focus on more creative and strategic things. Moreover, AI opens up opportunities to create products and services that were previously unimaginable. From intelligent virtual assistants to self-driving cars, AI continues to push the boundaries of innovation and improve the quality of human life. However, it is important to remember that AI is not without its risks. The unethical and irresponsible application of AI can have negative consequences. Therefore, the development and use of AI must be undertaken with utmost caution and with due consideration for its ethical and social implications.

The analysis of keyword relationships presented in Figure 6 highlights several critical themes that shape the discourse on Artificial Intelligence (AI) within vocational education (VE). The strong prominence of the keyword "apprentices" demonstrates the centrality of internship-based learning in recent scholarship. Its connections with terms such as "e-learning," "higher vocational education," and "artificial intelligence" suggest that apprenticeships are no longer viewed as traditional workplace practices but are increasingly enhanced by digital technologies. This finding aligns with the broader trend of digitalization in work-based learning, where AI and virtual reality are integrated to create more adaptive, immersive, and industry-relevant training models (Yang et al., 2023). Thus, while internships remain a core component of VE, their transformation through AI points toward a paradigm shift in how practical training is conceptualized and delivered.

Similarly, the keyword "engineering education" reflects the expanding role of AI-driven pedagogical innovation in technical fields. Its strong ties with "virtual reality" and "teaching methods" indicate that AI not only enriches the engineering learning environment but also provides scalable solutions for simulation-based training, reducing cost and risk while improving engagement. This resonates with studies emphasizing the integration of immersive technologies to prepare learners for increasingly complex industrial ecosystems (Çapşek & Karacı, 2022; Ran & Han, 2023).

The appearance of "higher vocational education" further emphasizes the institutional dimension of AI adoption. Its association with "learning systems," "education reforms," and "teaching quality" illustrates how AI is framed as a strategic response to quality enhancement and curriculum modernization. This finding echoes X. Cheng and Tang (2023), who observed a rapid acceleration of AI integration in vocational colleges as part of systemic reform agendas. Importantly, this suggests that AI is not merely an instructional tool but a policy-driven priority embedded within broader education modernization strategies.

Finally, the prominence of the keyword "students" reinforces the learner-centered nature of AI research in VE. Its frequent association with "deep learning," "curricula," and "employment" indicates a dual emphasis: enhancing student learning experiences and strengthening employability outcomes. This reflects the consistent argument in the literature that AI-driven personalization and adaptive learning systems can both improve academic performance and bridge the gap between education and labor market needs (Shi & Wan, 2024). At the same time, the link between students and terms such as "mental well-being" highlights emerging concerns about the ethical and psychological dimensions of AI in education, suggesting that while AI promises efficiency, its human impact must also remain a research priority.

CONCLUSION

This study provides a comprehensive bibliometric overview of global research on artificial intelligence (AI) in vocational education (VE) from 2014 to 2023. Although the field is still emerging, publication trends have increased significantly in recent years. The findings reveal an uneven research landscape characterized by the dominance of vocational health topics, limited international collaboration, and concentration around several key themes, such as apprenticeship, students, artificial intelligence, and engineering education. These findings highlight opportunities to expand AI research into underrepresented vocational sectors and strengthen cross-border research partnerships. Furthermore, the study offers a strategic roadmap for future AI-VE research by identifying promising directions for thematic development, collaboration, and innovation. Researchers may explore AI integration in apprenticeship programs, personalized learning, and practical simulations across various vocational fields. Despite its contributions, the study is limited by its reliance on a single database (Scopus) and English-language journal articles. Future studies

are encouraged to adopt multi-database approaches, include diverse publication types, and conduct qualitative analyses to gain a deeper understanding of AI implementation in vocational education.

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