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Article

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ARTIFICIAL INTELLIGENCE AND COMPETENCY-BASED EDUCATION: A BIBLIOMETRIC ANALYSIS

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Abstract

In the context of the educational transition toward a competency-based approach, this study aimed to identify trends, challenges, and emerging opportunities generated by the intersection of Artificial Intelligence (AI) and Competency-Based Education (CBE). The research was carried out using a bibliometric analysis of 1,028 articles included in the Web of Science database and based on reports provided by the biblioshiny application, the graphical interface of the bibliometrix R package. The results included a quantitative analysis of scientific production, collaborations, and cocitations, as well as the evolution and thematic map of the field. These revealed an annual increase of 8.43% in publications with acceleration after 2017 and global involvement, with the United States and China in leading positions. Thematic analyses have shown the field's evolution from technological foundations to an interdisciplinary approach, highlighting the influences of global events, such as COVID-19. The research confirmed the profound interaction between AI and CBE, demonstrating its potential, complexity, and the need for collaborative and interdisciplinary approaches. The bibliometric analysis performed can serve as a guide for future research directions and for identifying strategic directions in the implementation of AI in education.

Keywords: artificial intelligence (AI), competency-based education (CBE), bibliometric analysis, thematic map, Web of Science (WoS).

JEL Classification: I20, I21

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Introduction

In recent decades, education has undergone significant transformations, moving from a traditional model centred on memorisation and standardised assessments to a more flexible and personalised educational system. Competency-Based Education (CBE) is a contemporary approach that emphasises the development of practical skills, pertinent knowledge, and essential cognitive abilities vital for success in our current world (Johnstone and Soares, 2014). A key shift in this transition has been the integration of artificial intelligence (AI) into the educational process by providing advanced solutions and technologies that improve the efficiency, effectiveness, and relevance of the learning experience. AI refers to the capability of a machine to make decisions in a manner akin to human intelligence (Winkler-Schwartz et al., 2019). Indeed, artificial intelligence has emerged as a rapidly expanding field of research and application, leading to a true revolution in various sectors of modern society (Fosso Wamba et al., 2021). Within the educational realm, AI has become an instrumental tool with extraordinary potential to improve teaching and learning processes, transforming traditional methods into innovative and personalised approaches (Mhlanga, 2021).

This paper offers a bibliometric analysis that aims to investigate and highlight the benefits and challenges posed by AI applications in CBE. The motivation for this bibliometric scrutiny stems from a need to comprehend the evolution of research in the field, key themes and pivotal moments, identification of leading authors and primary contributions, research sources, collaborations, emerging research directions, and potential gaps or understudied areas.

Recently, various bibliometric analysis studies have been conducted on the relationship between artificial intelligence and education. However, these studies either have a general focus on the AI use in an educational setting (Baek and Doleck, 2020; Talan, 2021; Prahani et al., 2022) or concentrate on applying AI for specific educational levels or types, such as higher education (Hinojo-Lucena et al., 2019), e-learning (Jia et al., 2022), mathematics teaching-learning process (Hwang et al., 2020), or leadership education (Harto et al., 2022). A detailed bibliometric analysis, focused exclusively on AI's use within the CBE context, is still absent. In this context, the present study aims to answer the following research question: How has the specialised literature evolved, and what are the main research trends regarding the intersection of AI and CBE? The results of the analysis can contribute to developing both theoretical and practical domains. In this way, the authors can provide clarity on the current research landscape, identifying gaps and the predominant directions of investigation. From a theoretical perspective, the aim of bibliometric analysis is to highlight areas where researchers have primarily focused their efforts and to present the dynamic development of the theoretical landscape. However, from a practical applied point of view, the study aims to contribute to the advancement of knowledge and the improvement of educational processes, directly impacting the development of key competencies in students.

To explore the crucial role that AI plays within the context of competency-based education, this paper is structured into four distinct sections. The first part presents a brief yet comprehensive review of the literature on CBE and AI applications in education, identifying the main trends and challenges in the field, as well as how AI can facilitate the development of key abilities and competencies in education. The second part delves into the research methodology and the results of the bibliometric analysis, a method allowing us to trace the research evolution, and pinpoint significant influences and connections between

various topics and concepts related to AI and CBE. The third section is dedicated to discussions, where a detailed analysis of research findings and their implications in the context of previous studies and existing theories is conducted, also addressing the limitations of the study and prospective research directions. In the final part, conclusions are presented, emphasising the primary findings of the research and highlighting the contributions to the domain of education and artificial intelligence, alongside its theoretical and practical implications.

1. Review of the scientific literature

1.1. Competency-Based Education: A Holistic and Balanced Approach to Learning

Competency-Based Education (CBE) has emerged as a major topic of interest in educational research and pedagogical practice in recent times (Paek, Um, and Kim, 2021). A competent graduate is one who can apply what they have learnt, thereby operating independently in various real-world practical contexts (Yip and Smales, 2000). At present, CBE is still in the early stages of implementation in certain disciplines, while in others, such as medicine, it already has an extensive history and is supported by numerous studies validating its efficacy (Brammer and Goodrich, 2021).

CBE emphasises the development and evaluation of specific competencies rather than focussing solely on theoretical knowledge. The primary goal of CBE is to prepare learners to successfully tackle real-world challenges by focussing on developing skills and aptitudes applicable in various contexts (Johnstone and Soares, 2014). This educational approach is tailored and applicable (Brammer and Goodrich, 2021), fostering the growth of practical skills and competencies essential for individuals to achieve their personal and professional objectives.

Unlike traditional education, CBE does not adhere to a standard time framework for class attendance and homework. As a result, students often complete courses or even entire programmes in shorter time frames, which can reduce costs and make education more accessible (Lindsay, 2018; Mehall, 2019; Brammer and Goodrich, 2021). Learning takes place in modules and, given the student-centred approach, learners progress to the next topic or skill once they have sufficiently mastered the associated competencies (Evans, Landl and Thompson, 2020; Brammer and Goodrich, 2021). Research indicates that CBE can increase motivation and engagement in the learning process (Evans, Landl, and Thompson, 2020), and foster critical and analytical thinking skills (Chen, Zhang, and Li, 2022). These benefits suggest that the implementation of a competency-based approach in education can contribute significantly to improving the learning experience and the holistic development of students.

The CBE has played a pivotal role in the reform of global education systems. Reform advocates, policymakers, educators, and experts have defined “key competencies” for compulsory education in various ways (Anderson-Levitt and Gardinier, 2021). Numerous countries have adopted or piloted competency-based learning in their curricula, attempting to align education with the demands of the labour market and the requisites of modern society. The implementation of CBE is not without challenges; such an approach can be complex and requires significant resources for course design and the technology used (Burnette, 2016). Competency evaluations can occasionally be subjective and challenging

to administer objectively. For instance, Gielissen et al. (2022) highlight the issue of the proficiency attained by each learner (typically measured) and the pace of individual progress in learning, both being predictors of future success. A further challenge arises from the time-based structures of tertiary institutions (courses, semesters), and abandoning these is a hard-to-implement innovation (Gruppen et al., 2016). Lastly, it is necessary to emphasise that identifying relevant and necessary competencies in a rapidly changing society is a challenge in itself.

1.2. The Role of Artificial Intelligence in Competency-Based Education

Artificial intelligence (AI) is defined as a system's capability to correctly interpret external data, learn from these data, and use this knowledge to accomplish specific tasks and objectives through flexible adaptation (Kaplan and Haenlein, 2019). Consequently, these systems can think and act human-like, employing advanced algorithms and intricate mathematical models to achieve specific aims (Akgun and Greenhow, 2022). For example, ChatGPT represents an artificial intelligence model, specifically, a language generation model developed by OpenAI, employing machine learning techniques to produce text that closely resembles human language. The advent of ChatGPT marks a transformative shift in the landscape of education (Kasneci et al., 2023; Peters et al., 2023).

One of AI's remarkable facets in education is its ability to customise individual learning experiences (Chen, Chen, and Lin, 2020). By analysing students' behaviour and progress, AI systems can adjust the curriculum and teaching methodologies to align with individual learning paces and needs (Kuleto et al., 2021; Mhlanga, 2021). This leads to more effective and efficient learning, and students feel more motivated and engaged. Furthermore, Huang (2021) examined how artificial intelligence curriculum design is correlated with the cultivation of key competencies in students. This is particularly important, since academia should carefully assess its capabilities and make a concerted effort to provide the latest knowledge and skills to empower students to face the challenges of future realities (Ellahi, Khan and Shah, 2019).

Although sometimes criticised for being less empathetic, AI can recognise emotions, such as a student's frustration (Poria et al., 2019). In CBE, this capability can be pivotal, with recognition unlocking student potential. Adaptive learning systems generate precise student profiles and models based on their emotional states, knowledge levels, individual personality traits, and held competencies (Almohammadi et al., 2017). In addition, AI offers real-time assistance and continuous feedback. Virtual tutors and AI assistants can answer student questions, provide supplementary explanations, and give detailed feedback on academic progress (Hwang et al., 2020). This ensures that students have access to personalised support anytime, helping to consolidate knowledge and develop skills.

In addition to student benefits, AI also significantly impacts educators and academic institutions. Teachers can perform various administrative functions, such as grading student assignments through an automated process (Chen, Chen, and Lin, 2020), allowing them to focus more on direct educational activities, human interaction, innovative content creation, and fostering a collaborative learning environment (Akgun and Greenhow, 2022), while evaluations are conducted more efficiently. Additionally, AI assists researchers in analysing large data volumes, discerning trends and patterns, thus facilitating the development of new theories and addressing intricate challenges in various study areas (Kuleto et al., 2021).

All these aspects emphasise the significant potential of artificial intelligence to transform education and research.

Beyond all these advantages, there are a series of risks and challenges associated with AI-based education. Although AI systems may be more cost effective in the long run than well-paid human resources, their selection by university managers is not necessarily a good choice, as it compromises the personalisation of education (Kaplan and Haenlein, 2019). Ethical concerns, such as data protection and ensuring a secure and fair environment for all students, are ongoing debates (Nguyen et al., 2022). Using AI in education typically involves collecting and analysing extensive personal data, ranging from facial recognition (Borenstein and Howard, 2021) to monitoring systems with detailed information about students' and educators' actions and preferences (Akgun and Greenhow, 2022). AI, being human-created, can inherently possess biases that may disadvantage certain students (Baker and Hawn, 2022). Other potential issues include an overreliance on technology and the possible replacement of teachers with robots (Kanungo et al., 2022). While fostering growth in labour productivity, AI technologies contribute to partial job displacement (Lazaroiu and Rogalska, 2023). Lastly, even though AI boasts accessibility, not all students have access to AI technology (Holmes et al., 2022), potentially widening the gap between the haves and have-nots. However, with ethical and responsible management, AI has the potential to bring about significant enhancements in the educational process and student learning experiences around the world.

2. Research methodology

The bibliometric study aimed to identify and analyse the evolution of the specialised literature addressing the intersection between artificial intelligence (AI) and education, with a particular focus on competencies, skills, and efficiency. Specifically, we aim to achieve the following objectives:

- Identify the main research trends in the literature addressing the relationship between AI and CBE in terms of the most influential authors, publications, institutions involved, and collaboration networks;
- Analyse the evolution of the specialised literature on AI and CBE in terms of both the number of publications per year and the topics addressed.

The chosen research method is bibliometric analysis because it allows the synthesis of a large amount of information and the identification of essential research characteristics (Aria and Cuccurullo, 2017).

The research process followed the steps below according to the PRISMA approach:

Data Collection: A systematic search was conducted in the Web of Science (WoS) database by Topic, using the following keywords: (“artificial intelligence”) AND (“education*”) AND (“competenc*” OR “skill*” OR “proficienc*” OR “capabilit*” OR “abilit*”). The selection of keywords was based on a careful analysis of articles addressing aspects of AI and CBE, which necessitated the use of synonyms for the term “competences” alongside the primary keyword. Other words, such as “robot”, “machine learning”, “chatGPT”, etc., were not included because testing showed that they either led to finding works covered by the term “artificial intelligence” or to papers deviating from the research subject.

The search was carried out in June 2023 and produced $n=1,853$ results, to which a series of exclusion and inclusion criteria were applied. The exclusion criterion was the year 2023 to obtain a complete and comparable selection across years, resulting in a total of $n=1,606$ articles. The inclusion criteria applied were document type (article or review article or early access) ($n=1076$) and English language ($n=1,028$). For the year 2023, although excluded from the analysis, 40 works were retained, represented by those included in the database since 2022 (early access articles). The database comprising 1,028 articles was reviewed and corrected for import errors or missing records. Furthermore, all articles were analysed to confirm their eligibility with respect to the treated subject.

Data Preprocessing: After the data was collected, the search results were imported into the bibliometrix R-package. This package allows for comprehensive bibliometric analyses compared to other major software tools (Aria and Cuccurullo, 2017).

Data Analysis: *Biblioshiny*, a graphical interface for *bibliometrix*, was used to analyse the data extracted from WoS.

Interpretation and Data Visualisation: The analysis results were interpreted and visualised using various tables, graphs, and diagrams generated by *biblioshiny*. These helped the study identify trends and synthesise information in an easy-to-understand manner.

Before starting the research, various research databases were evaluated to determine the most appropriate data source for the study. Ultimately, exclusive use of the Web of Science (WoS) database was chosen for the following reasons (Azañedo et al., 2022): its broad coverage of research literature from various fields of study, including science, technology, social sciences, and humanities; its high-quality standards ensured the credibility and solid foundation of the analysed studies; advanced search and filtering features, which allowed precise topic-based searches and the application of specific filters, such as document type, language, and year range; compatibility with *biblioshiny*, the tool utilised for bibliometric analysis.

3. Results and discussion

Table 1 centrally presents the records retained for bibliometric analysis. The collected data covers a 32-year period (1991-2022), with 1.028 documents found in 573 different sources. The annual growth rate of publications is 8.43%, indicating a continuous increase in interest in the intersection of AI and education. The documents were written by 3.693 different authors, with 192 of them contributing to single-authored docs. This shows a large diversity of contributions and may indicate an interdisciplinary nature of the field. Of the collected documents, 195 are single-authored documents, and, on average, each document has 3.88 coauthors. 23.54% of the documents have international coauthorship, suggesting significant global collaboration in this research field. Most of the documents are articles (848), followed by reviews (103) and early access articles (43). There are also a smaller number of articles classified as book chapters (18 as part of an article and 1 as part of a review), and articles classified as conference papers (10).

Table no. 1. Centralisation of articles extracted from WoS

Description	Results	Description	Results
Main information about data		Authors' Collaboration	
Timespan	1991:2022	Single-authored docs	195
Sources (Journals, Books, etc.)	573	Co-Authors per Doc	3,88
Documents	1028	International co-authorships %	23,54
Annual Growth Rate %	8,43	Document types	
Average citations per document	10,18	article	848
References	45048	article; book chapter	18
Document contents		article; early access	43
Keywords Plus	1375	article; proceedings paper	10
Author's Keywords	2966	review	103
Authors		review; book chapter	1
Authors	3693	review; early access	5
Authors of single-authored docs	192		

Source: authors, based on data extracted from WoS.

The timeline of publications (Figure 1) shows a clear trend of increasing interest in the intersection of AI and education, as reflected in the growing number of articles published over time. In the early period, from the early 1990s to 2016, the number of publications remained relatively low, with less than 10 articles per year. However, starting in 2017, we see a rapid and consistent increase in the number of publications per year. This indicates the growing recognition of the importance and relevance of the intersection between AI and education in the academic community.

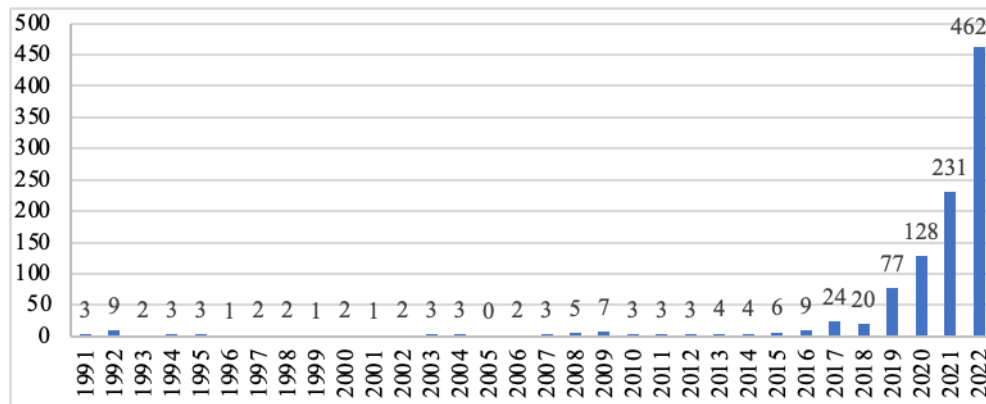


Figure no. 1. Evolution of the number of published articles

Note: The articles for 2022 also include early access ones.

Source: The authors, based on data extracted from WoS

In 2017, the number of published articles increased to 24, almost triple from the previous year. This upward trend continued, culminating in a surge in research in the last two years of the analysed period. This rapid growth can be attributed to several factors, including the increasing importance of AI in education, advancements in AI technologies, increased research, development, and investments in this field, and a growing need and demand for AI-related skills and abilities in the educational context. The main research trends indicate

an exponential growth in interest in the intersection between AI and education, with a notable acceleration of research activity in recent years.

Top Scientific Production by Countries

The United States leads the ranking with a total of 570 publications, indicating a leadership position in this field (Table 2). This can be attributed to a combination of factors, including advanced technological development, a strong culture of innovation, and significant investments in research and development in the field of artificial intelligence and education.

China, with 497 publications, comes very close to the United States, ranking second. This reflects China's rapid rise in the fields of technology and education, backed by significant R&D investments and a national strategy focused on promoting artificial intelligence in education. The United Kingdom and Canada also rank high, with 223 and 164 publications, respectively. These are countries with a strong tradition in the educational field and technological innovation, reflected in the high volume of research produced.

Germany, Spain, India, Australia, Italy, France, Saudi Arabia, and Turkey round out the top 10, with publication numbers ranging from 107 in Germany to 50 in Turkey. The presence of these countries highlights the wide geographic distribution of research in this field, with significant contributions from Europe, Asia, North America, Australia, and the Middle East. A wide variety of countries contribute to research in the field of artificial intelligence and education, with the United States and China leading the way. This indicates the global relevance of the topic and the broad involvement of the international academic community.

Table no. 2. Top production by country

Region	Frequency	Region	Frequency
USA	570	India	92
China	497	Australia	85
UK	223	Italy	82
Canada	164	France	72
Germany	107	Saudi Arabia	64
Spain	101	Turkey	50

Source: The authors, using biblioshiny, based on data extracted from WoS

The Top Most Relevant Affiliations

The ranking of affiliations highlights the academic institutions that lead research in this field, providing a view of the diversity and global distribution of these research efforts (Table 3). The University of Toronto ranks first with 29 articles. It is one of Canada's most prestigious universities, renowned for its strong programmes in technology and education fields. Additionally, it is distinguished by significant investments in research and innovation. McGill University, which ranks second with 25 articles, is also one of the top Canadian institutions. This underlines the importance Canada attaches to the field of AI and education. Stanford University, ranked third with 16 articles, is one of the world's most recognised universities in technology and innovation. Its location in Silicon Valley provides a close link to the tech industry. King Abdulaziz University in Saudi Arabia, with 14 articles, and the Chinese University of Hong Kong, with 13 articles, reflect the growing importance given by non-Western countries to the research in this field.

Medical schools, such as Harvard Medical School, with 11 articles, also highlight the impact of AI and education in the medical field and in the professional training of physicians. Other leading universities include the University of Valencia, Carnegie Mellon University, Queen's University, and the University Health Network, each with 10 articles, indicating a varied and global interest in this research field.

Table no. 3. Most relevant affiliations

Affiliation	Articles
University of Toronto	29
Mcgill University	25
Stanford University	16
King Abdulaziz University	14
Chinese University of Hong Kong	13
Harvard Medical School	11
University of Valencia	11
Carnegie Mellon University	10
Queen's University	10
University Health Network	10

Source: The authors, using biblioshiny, based on data extracted from WoS

The top of the most relevant sources

This ranking (Table 4) provides a view of the most relevant and active sources of literature in this research field, ranked by the number of published articles. "Mobile Information Systems", with 27 articles, and "Frontiers in Psychology" and "Sustainability", each with 26 articles, are in the top three positions. These results were predictable, considering the large number of articles these journals publish annually, many in the thousands for the last two. Other significant journals include "Wireless Communications & Mobile Computing", "Computational Intelligence and Neuroscience", and "Education and Information Technologies", each with a significant number of articles on this topic. These journals show that there are a variety of research fields that intersect with AI and education.

Table no. 4. Most relevant sources

No.	Sources	Articles
1	Mobile Information Systems	27
2	Frontiers in Psychology	26
3	Sustainability	26
4	Wireless Communications & Mobile Computing	16
5	Computational Intelligence and Neuroscience	13
6	Education and Information Technologies	13
7	Applied Sciences	12
8	IEEE Access	12
9	International Journal of Artificial Intelligence in Education	11
10	International Journal of Emerging Technologies in Learning	11
11	Education Sciences	10
12	Frontiers in Education	10
13	Journal of Intelligent & Fuzzy Systems	10
14	Interactive Learning Environments	9
15	BMC Medical Education	7
16	Computers & Education	7

No.	Sources	Articles
17	Engineering	7
18	Mathematical Problems in Engineering	7
19	Scientific Programming	7
20	Sensors	7

Source: The authors, using biblioshiny, based on data extracted from WoS

The authors' impact is determined based on the number of citations, as well as the Hirsch index (h-index), and its more recent variants, the G index and the M index (Table 4). Dautenhahn, K., Kaplan, A., and Haenlein, M. lead the list, having the highest number of citations. However, the highest Hirsch (h-index), G, and M indices belong to other authors, namely Del Maestro R.F. (Emeritus Professor Emeritus in Neuro-Oncology at McGill University), Winkler-Schwartz A. and Yilmaz R., both from the Neurosurgical Simulation and Artificial Intelligence Learning Centre at McGill University. The high values of these indices indicate that these authors have a significant number of works in the database that have been cited by other researchers. On the other hand, in the case of Dautenhahn, there are two works that meet the search criteria, a large number of citations, but low indices. This is due to the fact that citation reporting is strictly done in relation to the number of works included in the database processed with Bibliometrix; as a result, the value of the indices cannot exceed that of the number of works. Additionally, Table 5 provides other relevant information about the authors, such as the start year (PY_start) when each author began publishing in this field.

Table no. 5. Authors' impact (descending order by the total number of citations)

Autor name	h_index	g_index	m_index	Total citations (TC)	Number of publications (NP)	Starting year (PY_start)
Dautenhahn K.	2	2	0.118	652	2	2007
Kaplan A.	2	2	0.4	644	2	2019
Haenlein M.	2	2	0.4	600	2	2019
Sheridan T.B.	1	1	0.125	245	1	2016
Del Maestro R.F.	5	7	1	193	7	2019
Winkler-Schwartz A.	3	6	0.6	169	6	2019
Yilmaz R.	3	6	0.6	164	6	2019
Ledwos N.	3	5	0.6	163	5	2019
Mirchi N.	3	5	0.6	163	5	2019
Kellnhofer P.	1	1	0.333	157	1	2021
Kim C.	1	1	0.333	157	1	2021
Li B.C.	1	1	0.333	157	1	2021
Matusik W.	1	1	0.333	157	1	2021
Shi L.	1	1	0.333	157	1	2021
Bissonnette V.	3	4	0.6	150	4	2019

Source: The authors, using biblioshiny, based on data extracted from WoS

The most cited documents

Documents are ranked based on the number of local citations, respectively, based on the WoS Core Collection and global ones, across all WoS databases (Table 6). The ratio between local and global citations (LC/GC Ratio) indicates the document's relevance to researchers in the specific field. Documents with a high LC/GC ratio may indicate that the

research is highly relevant to the specialised community. However, there are some exceptions to this trend. For instance, Kaplan A.'s 2019 article published in *Business Horizons* has 8 local citations but 574 global citations, indicating a broad impact within the academic community but not necessarily within the specific research community relating to the intersection between AI and education.

Table no. 6. Top of the most cited articles

Article	Year	Local Citations (LC)	Global Citations (GC)	LC/GC (%)	LC (n)	GC (n)
Chen et al., 2020. Artificial Intelligence in Education: A Review. <i>IEEE Access</i> , 8, pp.75264-75278.	2020	16	136	11.76	21.56	8.26
Sit et al., 2020. Attitudes and perceptions of UK medical students towards artificial intelligence and radiology: a multicentre survey. <i>Insights into imaging</i> , 11, pp.1-6.	2020	12	88	13.64	16.17	5.34
Winkler-Schwartz et al., 2019. Artificial Intelligence in Medical Education: Best Practices Using Machine Learning to Assess Surgical Expertise in Virtual Reality Simulation. <i>Journal of Surgical Education</i> , 76(6), pp.1681-1690.	2019	11	69	15.94	11.60	2.52
Mirchi et al., 2020. The Virtual Operative Assistant: An explainable artificial intelligence tool for simulation-based training in surgery and medicine. <i>PLOS ONE</i> , 15(2), e0229596.	2020	11	75	14.67	14.82	4.55
Sapci et al., 2020. Artificial intelligence education and tools for medical and health informatics students: systematic review. <i>JMIR Medical Education</i> , 6(1), e19285.	2020	11	38	28.95	14.82	2.31
Kaplan, A. & Haenlein, M., 2019. Siri, Siri, in my hand: Who is the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence. <i>Business Horizons</i> , [online] 62(1), pp.15-25.	2019	8	574	1.39	8.44	20.97
Huang, X., 2021. Aims for cultivating students' key competencies based on artificial intelligence education in China. <i>Education and Information Technologies</i> , 26, pp.5127-5147.	2021	7	24	29.17	18.17	2.83

Note: LC (n) = normalised local citations; GC (n) = normalised global citations

Source: The authors, using biblioshiny, based on data extracted from WoS

The most cited references in the WoS Core Collection

Table 7 details the references cited and contains key works on the intersection of AI and CBE. As can be seen, a significant part of the research focusses on how digital technologies, including AI, can enhance educational practices. There is also a growing interest in using AI in medical education and in the training of health professionals.

The choice of specialised journals such as Nature, MIS Quarterly, and IEEE Access indicates an interdisciplinary approach to research that involves a variety of approaches and subdomains. In addition, there is a social concern about the impact of technology on education and work.

Table no. 7. Most local cited references

No.	Cited References	Citations
1.	Zawacki-Richter et al., 2019. Systematic review of research on artificial intelligence applications in higher education – where are the educators? <i>International Journal of Educational Technology in Higher Education</i> , 16(1), pp.1-27.	35
2.	Popenici, S.A.D. and Kerr, S., 2017. Exploring the impact of artificial intelligence on teaching and learning in higher education. <i>Research and Practice in Technology Enhanced Learning</i> , 12(1), pp.1-13.	28
3.	Topol, E. J. , 2019. High-performance medicine: the convergence of human and artificial intelligence. <i>Nature Medicine</i> , 25(1), pp.44-56.	26
4.	Frey, C. B., & Osborne, M. A., 2017. <i>Technological Forecasting and Social Change</i> , 114, pp.254-280.	25
5.	Pinto dos Santos et al. 2019. Medical students' attitude towards artificial intelligence: a multicentre survey. <i>European Radiology</i> , 29, pp.1640-1646.	23
6.	Wartman, S. A., & Combs, C. D., 2018. Medical Education Must Move From the Information Age to the Age of Artificial Intelligence. <i>Academic Medicine</i> , 93(8), pp.1107-1109.	21
7.	Luckin, R. & Holmes, W., 2016. <i>Intelligence unleashed: An argument for AI in education</i> . London: Pearson	20
8.	Braun, V. & Clarke, V., 2006. Using thematic analysis in psychology. <i>Qualitative Research in Psychology</i> , 3(2), pp.77-101.	18
9.	Roll, I., & Wylie, R., 2016. Evolution and Revolution in Artificial Intelligence in Education. <i>International Journal of Artificial Intelligence in Education</i> , 26, pp.582-599.	18
10.	Schwab, K., 2017. <i>The fourth industrial revolution</i> . Currency	17
11.	Chen et al., 2020. Artificial Intelligence in Education: A Review. <i>IEEE Access</i> , 8, pp.75264-75278.	16
12.	Esteva et al., 2017. Dermatologist-level classification of skin cancer with deep neural networks. <i>Nature</i> , 542(7639), pp.115-118.	16
13.	Timms, M. J., 2016. Letting Artificial Intelligence in Education Out of the Box: Educational Cobots and Smart Classrooms. <i>International Journal of Artificial Intelligence in Education</i> , 26, pp.701-712.	16

Source: The authors, using biblioshiny, based on data extracted from WoS

Most frequent author keywords

The top keywords are dominated by terms used in the search, as well as others suggesting a focus on specific AI technologies and how they can be applied in education (table 8).

Table no. 8. Most frequent words

Words	Occurrences	Words	Occurrences
artificial intelligence	437	intelligent tutoring systems	15
education	99	internet of things	15
machine learning	92	curriculum	14
e-learning	48	information technology	14

Words	Occurrences	Words	Occurrences
deep learning	38	natural language processing	14
higher education	30	augmented reality	13
technology	26	learning	13
big data	25	artificial intelligence in education	12
virtual reality	25	computational thinking	11
covid	22	digital health	11
medical education	21	engineering education	11
robotics	21	neural networks	11
assessment	18	simulation	11
automation	16	skills	11
chatbot	16	training	11
industry 4 0	16	competency	10

Source: The authors, using biblioshiny, based on data extracted from WoS

Cocitation network of sources

The journal co-citation network consists of two clusters coloured red and blue (Figure 2). Clustering is done based on betweenness centrality, which measures how often a source acts as a bridge on the shortest path between two other sources, and closeness centrality, which measures the average distance of a source to all other sources in the network (Ulrik, 2001). The “Science” source has the highest intermediation score, indicating a central role in connections between other research sources, while the source with the highest closeness score is “Acad Med”, suggesting that it is closely tied to many other research sources. The first cluster (red) includes many medical journals like “Acad Med”, “J Med Internet Res”, “Science”, “Nature”, and “Plos One”, suggesting a lot of research at the intersection of medicine, education, and AI. The second cluster (blue) includes journals dedicated to education technology and AI, such as “Comput Educ”, “Comput Hum Behav”, “Ieee Access”, and “Lect Notes Comput Sc”. This indicates another significant research direction that focusses on the broad application of AI in education.

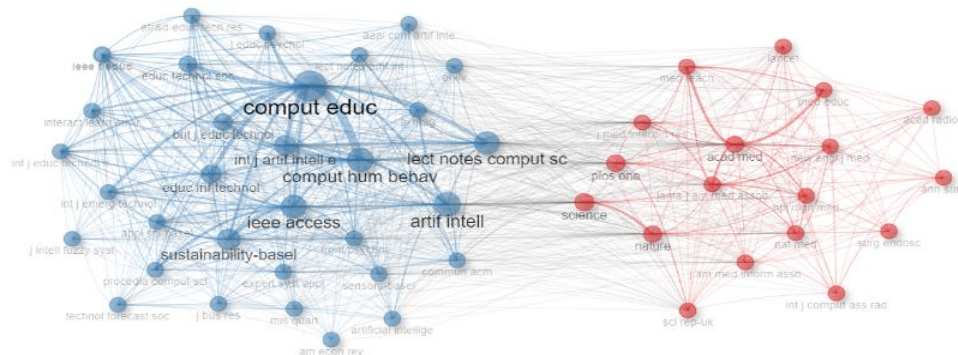


Figure no. 2. Co-citation network of sources

Source: The authors, using biblioshiny, based on data extracted from WoS

Collaboration network of authors

The author collaborations are divided into 10 clusters, indicating the existence of multiple research groups working together (Figure 3). In addition, it provides clues about key authors who might have significant influence in this field, either by promoting collaboration among other researchers or through their own academic authority.

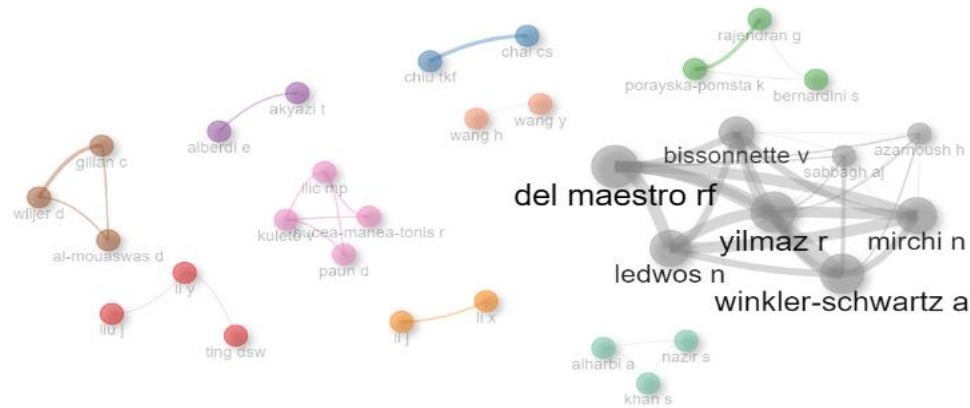


Figure no. 3. Collaboration network of authors

Source: The authors, using biblioshiny, based on data extracted from WoS

Collaboration network of countries

The country collaboration network is divided into 4 clusters, representing regional research groups (Figure 4). For example, countries like the USA, China, the United Kingdom, and Canada belong to cluster 1 (red), most European countries are in cluster 2 (blue), a few Asian countries are in cluster 3 (green), and Ecuador is the sole member of cluster 4 (purple).

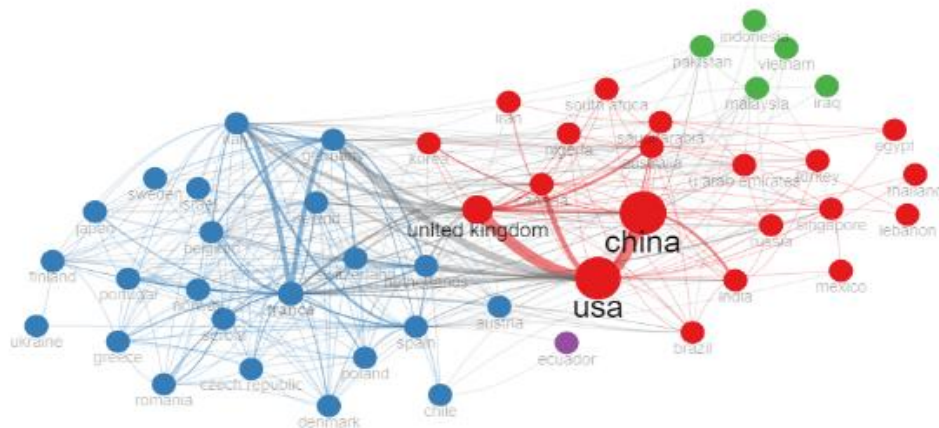


Figure no. 4. Collaboration network of countries

Source: The authors, using biblioshiny, based on data extracted from WoS

Thematic evolution

By comparing the two periods (figure 5), the interest areas are clearly evolving. While the first period focused on fundamental technological developments (AI, machine learning, and robotics), in the second period, we see a blend of technology (AI and E-learning) with major global events (COVID). This reflects the adaptability and interconnectedness of research with global events and developments.

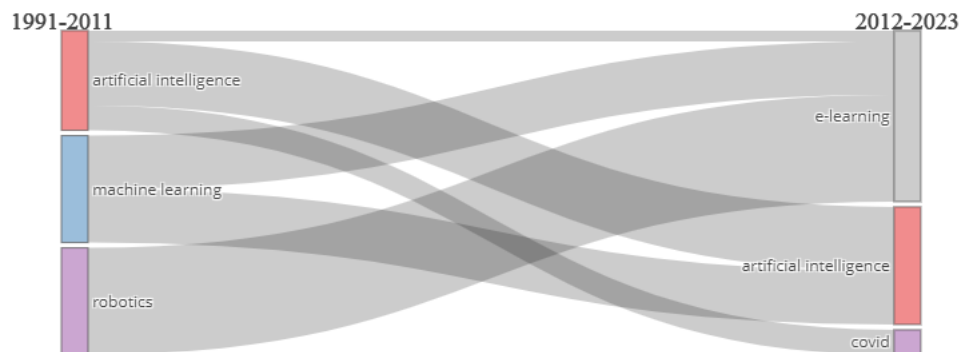


Figure no. 5. Thematic evolution during two periods of time
Source: The authors, using biblioshiny, based on data extracted from WoS

Thematic Map

The thematic map is divided into four areas and contains eight clusters, positioned according to density and centrality. Each of these clusters consists of several keywords (Figure 7). It is important to mention that the type of algorithm used for grouping/clustering influences the number and grouping method of clusters in the four zones of the thematic map. In this case, the Fast Greedy algorithm was used. The results show that in the quadrant with the “main themes”, there are two clusters with well-structured themes important for the research field, namely “e-learning, training, ethics” and “higher education, automation, chatbot”. The latter focusses on how technology and AI are integrated into higher education and their impact on the job market and student training. Furthermore, a growing interest in adaptive and personalised learning was also shown by the frequent appearance of terms like “intelligent tutoring systems” and “adaptive educational system”.

The “basic themes” are the most important for the research field, but are still underdeveloped. Here, two clusters are included; the largest one (consisting of 31 words) is dominated by terms such as “artificial intelligence, education, machine learning”, while the second one, “technology, covid, medical education”, is dedicated to the application of technology in medical education. Themes associated with keywords like “human-computer interaction” and “information technology” are emerging themes, poorly developed, and marginal compared to the AI and CBE fields.

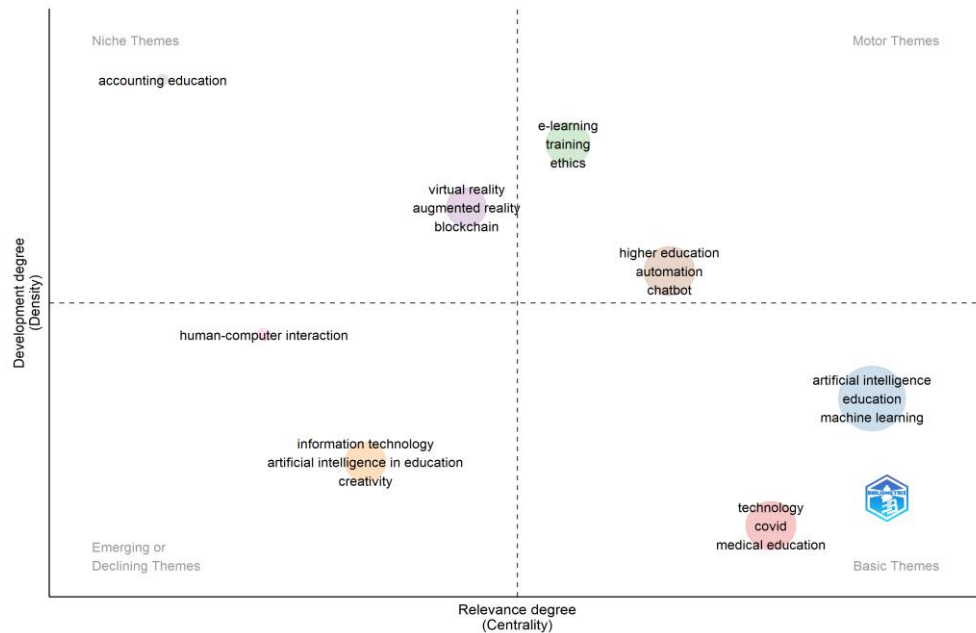


Figure no. 6. Thematic map

Source: The authors, using biblioshiny, based on data extracted from WoS

The research results provide a detailed insight into how AI intersects with the CBE field, which has multiple practical and theoretical implications. An interdisciplinary approach is observed, highlighted by works published in prestigious journals such as *Nature*, *MIS Quarterly*, and *IEEE Access*. This approach emphasises the complexity and vast thematic intersections between AI and CBE. Another relevant aspect is the focus of AI research on medical education, as suggested by the medical journals included in the cocitation network and references to articles in this field. This aligns with the literature that demonstrated the effectiveness of CBE in medicine (Brammer and Goodrich, 2021) and, at the same time, the great potential of AI to revolutionise teaching and learning methods in this field (Chen, Chen, and Lin, 2020).

The two highlighted periods underscore the adaptability of research to global events. Therefore, while the first period focused on fundamental technologies, the second placed more emphasis on education and incorporated major events such as the COVID-19 pandemic, also being a period when CBE was studied more intensively (Paek, Um and Kim, 2021). As technology continues to evolve, it is essential to stay in touch with trends to maximise the benefits of AI in education.

The results show a wide range of subdomains within AI that are relevant for CBE, from "deep learning" and robotics to adaptive educational systems. Thus, a great potential for AI is observed to contribute to various aspects of the educational process. There is a clear trend towards digitalisation, with terms like "e-learning", "virtual reality", and "information technology" being the centre of attention. This could suggest a fundamental shift in how education is delivered and experienced.

Another noteworthy aspect is the growing interest in adaptive and personalised learning, highlighted by the frequent appearance of terms related to adaptive educational systems. We observe a movement towards more personalised solutions in education that cater to the individual needs of students; as we know, this is a central trend in CBE (Chen, Chen, and Lin, 2020; Hwang et al., 2020; Brammer and Goodrich, 2021; Kuleto et al., 2021; Mhlanga, 2021). The evolution of education in recent decades, especially the transition from a traditional learning model to a competency-based one, emphasises its adaptability and the ongoing need for innovation in this domain. With a growing emphasis on developing practical skills and relevant knowledge, CBE has been proven to efficiently address real-world challenges.

Lastly, we want to stress the importance of this study; while there are previous bibliometric analyses that investigated the link between artificial intelligence and education (Hinojo-Lucena et al., 2019; Baek and Doleck, 2020; Hwang et al., 2020; Talan, 2021; Harto et al., 2022; Jia et al., 2022; Prahani et al., 2022), our research specifically focusses on the use of AI within CBE, thus making a significant contribution to fill a knowledge gap in this domain. By bringing a focused perspective to this specific subject, we hope that the results obtained will shape new insights into how AI can influence and optimise CBE processes in an innovative and practical manner.

Conclusions

The bibliometric analysis provided in this article reveals an exponential growth in academic interest in the intersection between AI and CBE. With a global presence of research and the involvement of numerous countries and top academic institutions, it is clear that this intersection represents a frontier zone for innovation in education. The increased emphasis on this topic in recent years indicates a rapid adaptation of the academic community to technological advancements and global challenges, such as COVID-19.

Thematic analyses highlight the evolution of AI in education, illustrating the shift from focussing on technological fundamentals to interdisciplinary approaches that combine technology with global events and various fields, such as medicine. In addition, collaboration networks underline the value added by cooperation and international knowledge exchange.

With respect to the limitations of the research, the Web of Science (WoS) database was used exclusively. Consequently, there is a possibility that relevant works indexed in other databases (such as Scopus) or published in regional or niche journals not included in WoS might have been excluded. Additionally, the exclusive selection of works in the English language can limit the global representation of research in the field of AI and CBE, and the search keywords employed can be deemed restrictive. However, we believe that these limitations had a relatively minor impact and that the conclusions drawn are valid.

As the main direction of future research, the authors aim to conduct a quantitative study investigating how the practical implementation of AI in CBE influences educational outcomes and the development of competencies among students. The key competencies considered will be those related to leadership. Therefore, the study will aim to assess the level of development of leadership competencies before and after the implementation of AI

in CBE, identify significant differences in student academic results, and analyse how technology impacts both academic performance and competency development.

From a theoretical standpoint, this work not only fills a gap in the specialised literature but also provides a solid foundation for future research. The intersection between AI and CBE is full of opportunities and challenges. The interdisciplinary approach and global collaboration will be essential to navigate this complex and dynamic research area. From a practical perspective, there are several significant managerial implications for educational institutions and leaders in the field of education. Thus, educational managers should evaluate and adapt educational programmes to include competency-based elements, reflecting the rapid advancement of artificial intelligence in education. This involves constantly reviewing and updating the content of the curriculum to meet the dynamic demands of the market. Additionally, managers must ensure that teachers and educational staff are prepared to use these technologies and align with technological developments in the field of education. Last but not least, it is essential for managers to continuously monitor trends in research and development in the field of artificial intelligence so that they can adjust educational strategies based on new discoveries and innovations.

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