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Inteligencia computacional, robótica educativa e inteligencia artificial en el ámbito educativo. Un estudio bibliométrico y modelación temática

Computational intelligence, educational robotics, and artificial intelligence in the educational field. A bibliometric study and thematic modelling

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RESUMEN

Este estudio aborda la convergencia entre tecnología y educación, explorando el impacto de paradigmas como la "inteligencia computacional", la "robótica educativa" y la "inteligencia artificial" en la investigación educativa. La metodología se definió en tres etapas. En la primera etapa se eligió la base de datos Web of Science y se desarrolló una cadena de búsqueda. La segunda etapa implicó la selección de estudios mediante criterios de inclusión/exclusión y el uso de PRISMA. La tercera etapa incluyó la extracción y análisis de datos cuantitativos y cualitativos, utilizando software bibliométrico, análisis de contenido y herramientas como R Studio, Bibliometrix, VOSViewer y Python. Se revela un crecimiento anual del 56,51%

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entre 2019 y 2023, con 208 obras. "Sustainability" lidera las revistas con 39 artículos, lo que indica concentración en revistas altamente productivas. El análisis de la coocurrencia de palabras clave revela áreas temáticas frecuentes, destacando "inteligencia artificial", "educación", "tecnología", "aprendizaje automático" y "Big data". La institución líder es la Universidad China de Hong Kong, mientras que China destaca con 61 trabajos a nivel de país. Destaca la importancia de considerar calidad y cantidad en la producción científica e identifica cinco temas clave en los resúmenes de investigación, sugiriendo áreas de investigación enfocadas en la integración de tecnología e innovación educativa.

PALABRAS CLAVE

Tendencias de investigación, aprendizaje automático LDA, desafíos éticos, análisis de impacto, innovación en educación.

ABSTRACT

This study addresses the convergence between technology and education, exploring the impact of paradigms such as "computational intelligence," "educational robotics," and "artificial intelligence" in educational research. The methodology was defined in three stages. In the first stage, the Web of Science database was chosen, and a search string was developed. The second stage involved the selection of studies through inclusion/exclusion criteria and the use of PRISMA. The third stage included the extraction and analysis of quantitative and qualitative data, using bibliometric software, content analysis, and tools such as R Studio, Bibliometrix, VOSViewer, and Python. An annual growth of 56.51% between 2019 and 2023, with 208 works, is revealed. "Sustainability" leads the journals with 39 articles, indicating concentration in highly productive journals. The analysis of keyword co-occurrence reveals frequents thematic areas, highlighting "artificial intelligence," "education," "technology," "machine learning," and "Big data." The lead institution is the Chinese University of Hong Kong, while China stands out with 61 papers at the country level. It emphasizes the importance of considering quality and quantity in scientific production and identifies five key topics in research summaries, suggesting areas of research focused on the integration of technology and educational innovation.

KEYWORDS

Research trends, LDA machine learning, ethical challenges, impact analysis, innovation in education.

1. INTRODUCTION

Advanced technology, particularly artificial intelligence (AI), is crucial across various sectors. In healthcare, AI expedites diagnostics and refines medical image analysis (Almalki et al., 2021). In education, IT integration has revolutionized the educational process.

"Computational intelligence," "educational robotics," and "artificial intelligence" have greatly influenced research and education. "Computational intelligence" improves data analysis efficiency, including in education (Hariri et al., 2019). Implementing "educational robotics" correlates with STEAM (Science, Technology, Engineering, Arts, and Mathematics skill development, fostering curiosity and teamwork (Arís & Orcos, 2019). Similarly, AI impacts various sectors, from finance to public services, through advances in machine learning and decision-making (Dwivedi et al., 2021).

This study is relevant in today's evolving technology context. Understanding how these tools optimize educational research and learning, seeking accessible solutions, and confirming their social impact is crucial (Wallace & Poulopoulos, 2022). Analyzing scientific production aids in identifying trends, focus areas, and knowledge gaps. Handling large data volumes demands advanced analytics for precise predictions and decision-making (Hariri et al., 2019).

This study examines the literature on "computational intelligence," "educational robotics," and "artificial intelligence" in education, analyzing research and experiences. Results are then scrutinized to identify patterns, trends, and significant contributions to the integration of technology and education.

This article was born as a result of the research project: "Including Education for Development (ED) in the ESO curriculum: promoting a model of critical citizenship and social empowerment in the face of the new challenges of the climate emergency, poverty and inequalities, exacerbated due to covid19" (Reference: 2020UE004), financed by the Andalusian Agency for International Development Cooperation.

2. BACKGROUND

The aim is to establish a theoretical foundation for understanding key concepts: "computational intelligence," "educational robotics," and "artificial intelligence".

2.1. Computational Intelligence

"Computational intelligence" enables computer systems to perform tasks requiring human intelligence (Gastaldo et al., 2014). It formalizes advanced mental processes through algorithms and computational models (Garrido Merchán & Lumbreras, 2023).

"Computational intelligence" within AI, develops and applies computational models inspired by physiological and linguistic paradigms. It includes machine learning, neural networks, fuzzy logic, and evolutionary computing (Demertzis et al., 2023).

2.2. Educational Robotics

"Educational robotics" is a learning method involving designing, assembling, and programming robots for educational use (Di Lieto et al., 2020). It serves as a pedagogical tool for teaching STEM and art concepts (Wallace & Poulopoulos, 2022).

"Educational robotics" cultivates students' computational thinking skills: problem-solving, abstraction, algorithm design, debugging, iteration, and generalization. They apply theoretical concepts in practical robot programming tasks (Chevalier et al., 2020).

2.3. Artificial Intelligence

"AI" develops computer systems for tasks needing human-like intelligence using algorithms and machine learning (Miró-Nicolau et al., 2022). It enhances efficiency, productivity, and reliability, surpassing human limitations and unlocking new applications in various industries (Dwivedi et al., 2021).

The challenges in AI include ethical, legal, social, and technological questions. Issues such as privacy, racial biases, economic losses, and the need to establish trust in the development, implementation, and use of artificial intelligence are highlighted (Thiebes et al., 2021).

3. METHODS

The methodology in this bibliometric study of scientific literature on computational intelligence, educational robotics, and artificial intelligence follows a three-stage process: Search Criteria and Data Collection; Study Selection and Data Extraction; Analysis.

3.1. Search Criteria and Data Collection

The first step was choosing the Web of Science (WoS) for its broad coverage and high- quality journals (Singh et al., 2021). Consider field coverage, article quality, and user- friendliness when selecting a database for bibliometric analysis. WoS offers multidisciplinary focus and extensive academic journal coverage (Birkle et al., 2020).

Once the database was selected, a search string was developed to identify articles relevant to bibliometrics. The search string considered the study's objectives, the scope of the field, the terminology used, and the search period (Krath et al., 2021).

The search string combined relevant keywords from each research area and was as follows: ("computational intelligence" OR "educational robotic" OR "artificial intelligence") AND ("research" OR "experiences") AND "education".

The search period defined the range of dates for scientific production to be considered within bibliometrics. For this study, a five-year period was adopted, considering the topics to be evaluated and data availability – specifically, publications from 2019 to 2023.

Inclusion/exclusion criteria selected relevant articles for bibliometric analysis, removing duplicates. Guidelines from the Web of Science Core Collection were followed, prioritizing factors like document type ("Scientific articles") and access type ("Open access").

3.2. Selection of Studies

For the selection of documents to be included in the bibliometric study, the recommendations of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) were followed, which contains a set of guidelines for researchers, allowing to improve the presentation of systematic reviews and meta-analysis.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines were followed for document selection, enhancing study transparency and reproducibility (Kraus et al., 2022). This approach documents the selection process comprehensively for future reproducibility (van de Schoot et al., 2021).

The study selection process employed the PRISMA flowchart, consisting of four steps: Identification (counting retrieved articles), Screening (removing duplicates and applying inclusion/exclusion criteria), Eligibility (reviewing full texts and applying stricter criteria), and Included (compiling the final list of eligible articles for bibliometric analysis). Refer to Figure 1 for details.

- Phase 1 (Identification): 2782 records were detected using search terms (computational intelligence, educational robotics, artificial intelligence) from WoS database, considering "all fields," "all document types," and "all data published in the interval from 2019 to 2023."
- Phase 2 (Screening): Search terms were applied to "article title," "abstract," and "keywords." A total of 2478 records were excluded, and 304 were included.
- Phase 3 (Eligibility): Only "Article" was selected as the document type to ensure the quality of the peer-review process. The search was also limited to "Open Access" for consistency. A total of 96 records were excluded, and 208 were included.
- Phase 4 (Include): Data referring to the study period were selected, identifying 208 articles.

3.3. Data Extraction and Analysis

The goal of data extraction is to collect, clean, and transform data into a coherent and structured format to obtain a reliable dataset for consultation or analysis.

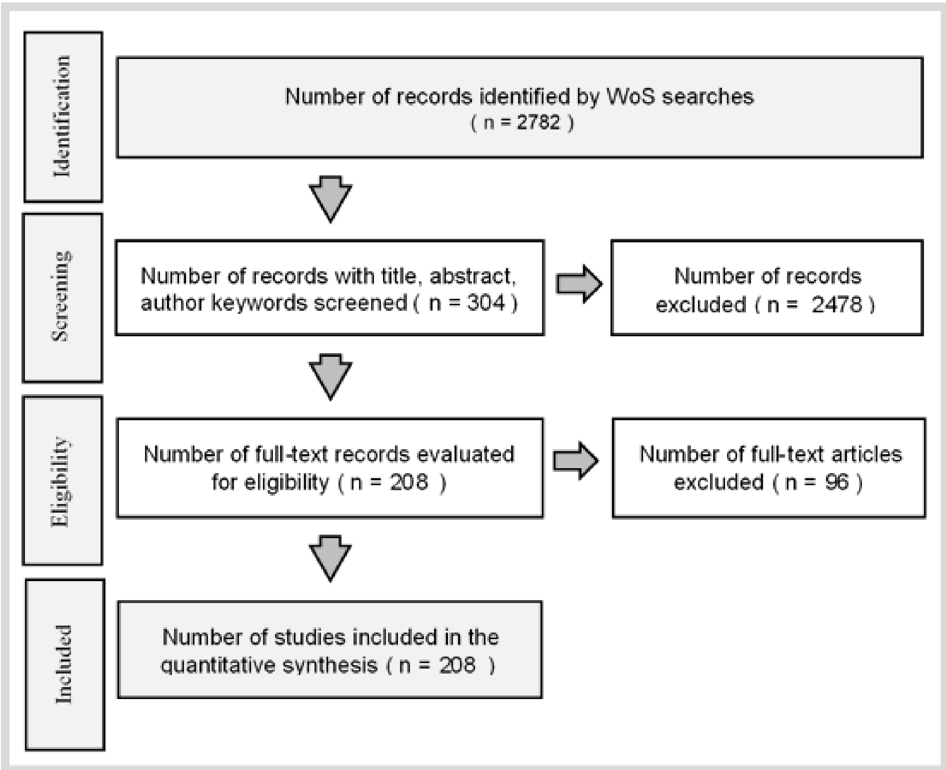
Data from WoS was exported in CSV (Comma-separated values), XLS (Microsoft Excel), and Bib (BibTeX) formats, containing bibliographic and content information for bibliometric analyses.

Following this, a quantitative analysis was performed on the collected data, extracting results to gain insights into research status, publication trends, author productivity, institutional collaboration, and citation counts within the defined fields.

Qualitative analysis utilizes textual data to describe, analyze, and elucidate phenomena. In bibliometric studies, it aids in identifying thematic trends, research gaps, or emerging topics. This study employed text mining and content analysis to extract thematic trends from the scientific literature.

Bibliometric software, including R Studio with the Bibliometrix package (Derviş, 2020), , and VOSViewer, facilitated data analysis (Kraus et al., 2022). Python functions and the Gensim library aided in natural language processing (Murshed et al., 2023).

Figure 1. Flowchart of the selected sample based on PRISMA.



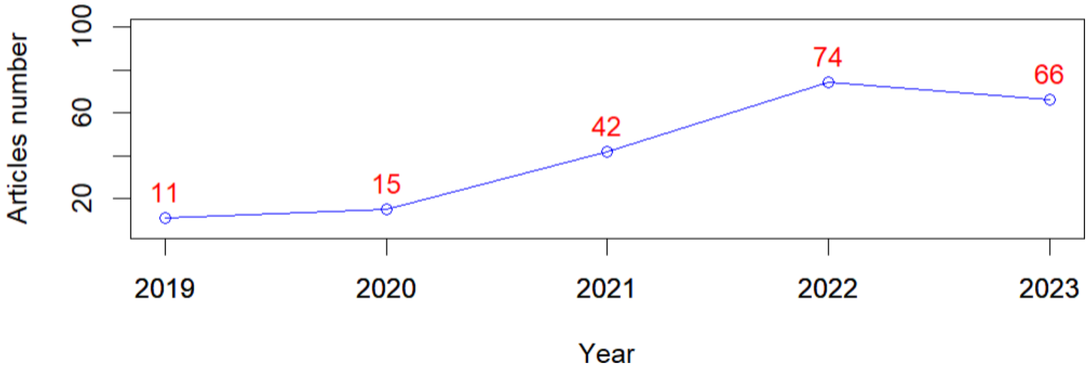
4. RESULTS AND ANALYSIS

4.1. Scientific Production and Subject Areas

From 2019 to 2023, there's been a fluctuation in scientific production concerning computational intelligence, educational robotics, and artificial intelligence, totaling 208 works. There was an annual growth of 56.51%, as depicted in Figure 2. In 2019, there were 11 publications, which significantly increased to 74 in 2022. However, by the end of 2023, there was a slight decrease, resulting in a total of 66 research papers.

In the past five years, research interest in applying computational intelligence, educational robotics, and artificial intelligence in education has surged due to technological advancements, the imperative to improve educational standards, and address modern generational challenges. Here are the results and analysis from the bibliometric review on these subjects.

Figure 2. Production timeline by total items



The results of the count indicate a fluctuating but growing dynamic in the research of these emerging fields, emphasizing the importance of continuous study of the evolution of scientific production to understand the trajectory and challenges in these constantly developing areas.

4.2. Journal Analysis

Table 1 reveals the prominence of "Sustainability," leading with 39 articles, showcasing its strong influence in sustainability research across related disciplines. Following closely is "Frontiers in Psychology." The substantial numerical disparity between "Sustainability" and subsequent journals, coupled with its proportion of articles, underscores its dominant role in scientific production.

Table 1. Top ten journals by number of articles.

Journal	Articles number	Proportion
SUSTAINABILITY	39	0.187500000
FRONTIERS IN PSYCHOLOGY	23	0.110576923
EDUCATION AND INFORMATION TECHNOLOGIES	9	0.043269231
BRITISH JOURNAL OF EDUCATIONAL TECHNOLOGY	7	0.033653846
FRONTIERS IN PUBLIC HEALTH	7	0.033653846
INTERNATIONAL JOURNAL OF EDUCATIONAL TECHNOLOGY IN HIGHER EDUCATION	6	0.028846154
IEEE ACCESS	5	0.024038462
COMUNICAR	4	0.019230769
JOURNAL OF ENVIRONMENTAL AND PUBLIC HEALTH	4	0.019230769
APPLIED SCIENCES-BASEL	3	0.014423077

In the bibliometric analysis of journals, Bradford's Law is considered. This law posits that within a thematic area, there are a few highly productive periodic publications, a larger number of regular producers, and an even larger number of other producers with low productivity.

Table 2 reveals that in Zone 1, comprising only 3 journals, they account for 34.14% of the evaluated articles, indicating high productivity compared to other journals. Zone 2 consists of 22 journals, representing a comparable 33.17% of publications with moderate productivity. In Zone 3, there are 68 journals, collectively covering 32.69% of publications, each with relatively low productivity.

These results confirm the validity of Bradford's Law in the context of the evaluated scientific production, highlighting the concentration of this production in a small number of highly productive journals and the descending distribution of performance as the number of journals increases.

Table 2. Division of sources according to Bradfoard's law zones.

A	B	C	D	E	F
1	3	3.23	71	34.14	23.67
2	22	23.65	69	33.17	3.14
3	68	73.12	68	32.69	1.00
-	93	100	980	100	-

(A) Zone (B) Journals (C) Percentage journals (D) Articles (E) Article percentage (F) Average articles per journals.

4.3. Keyword Analysis

The analysis of the co-occurrence of keywords offers a perspective on the thematic areas, methods and topics that are frequently the subject of research by authors in the research field (P. Gupta et al., 2022). Using VOSviewer, we analyzed the co-occurrence of all keywords (Author Keywords and Keywords Plus) of data extracted from WoS. This analysis allowed us to check the strength of the link between two keywords to determine the interest of a research field (Suhaila & Hamdan, 2023).

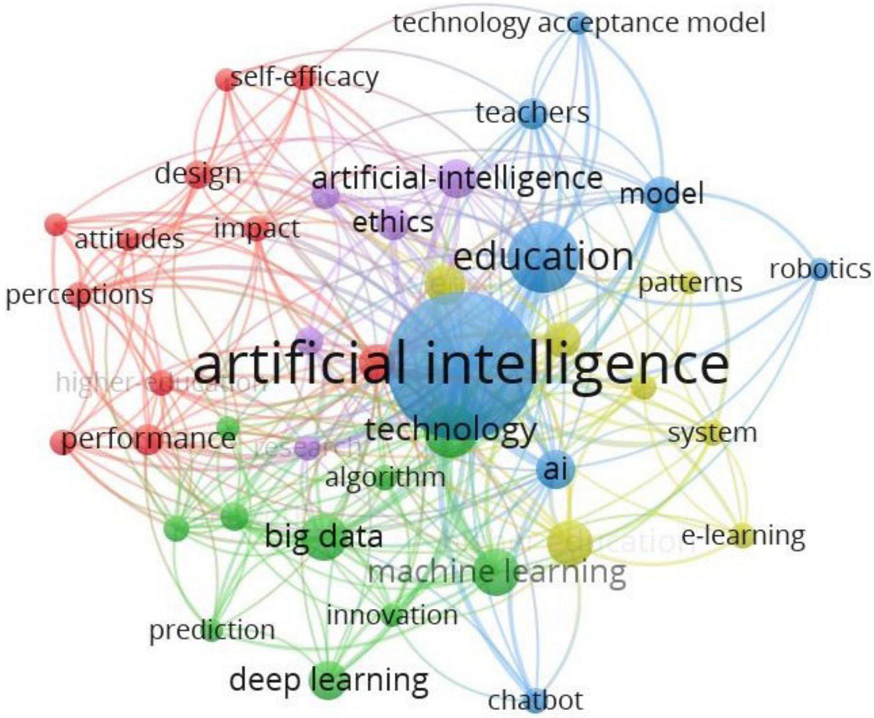
The total number of keywords found was 1104, of which 41 met the requirement of more than five occurrences of a keyword. The results of the software's own algorithm execution are checked. Then, all terms are verified and compared, grouped, and replaced with a single term (Suhaila & Hamdan, 2023).

Referring to Figure 3, there is the VOSviewer co-occurrence network map, where the node size represents the occurrence count, and the links between two nodes represent their co- occurrence in the same document. The closer two nodes are, the higher the number of co- occurrences of these two keywords (Y.-L. Liu et al., 2022).

In this sense, the keyword with the highest weight (largest node) is "artificial intelligence," appearing in 85 articles with a link strength of 157 to other keywords. Next is the keyword "education" (28 appearances, 60 links), followed by "technology" (18 appearances, 45 links), "machine learning" (15 appearances, 38 links), and finally "big data" (15 appearances, 33 links).

These keywords are integral to research areas examining the intersection of artificial intelligence (AI) and education, delving into AI's transformative role in education. The study further investigates the incorporation of technologies like machine learning and big data into academic training, emphasizing the crucial intersection of technology and pedagogy while discussing associated challenges and benefits.

Figure 3. Network map of keyword co-occurrences.



4.4. Analysis of Authors

The author analysis allowed for the exhibition of collaboration patterns in research among authors (P. Gupta et al., 2022) in the field of computational intelligence, educational robotics, and artificial intelligence based on WoS research articles, using the co-authorship analysis tool in VOSviewer.

The program utilizes a mapping function to generate an author network, displaying details about each document's first author along with the default author thesaurus. Selection criteria for authors required a minimum threshold of one document and one citation.

These criteria aided in identifying the most pertinent authors of scientific documents in computational intelligence, educational robotics, and artificial intelligence, totaling 803 authors.

The resulting network map development identified 648 authors, with 23 elements (3.39%) closely interconnected, as depicted in Figure 4. Four clusters emerged: Cluster 1 in red comprises 8 authors; Cluster 2 in green includes 7 authors; Cluster 3 in blue consists of 6 authors, and Cluster 4 in olive color encompasses 2 authors.

The analysis highlighted the top three authors renowned for extensive collaboration with other researchers, denoted by the largest circles and labels: "Chui Tomas KF," "Chao Ching- Sing," and "Lin Xiao-Fan." These authors have contributed significantly to numerous scientific articles and exhibit substantial citation counts and link strength.

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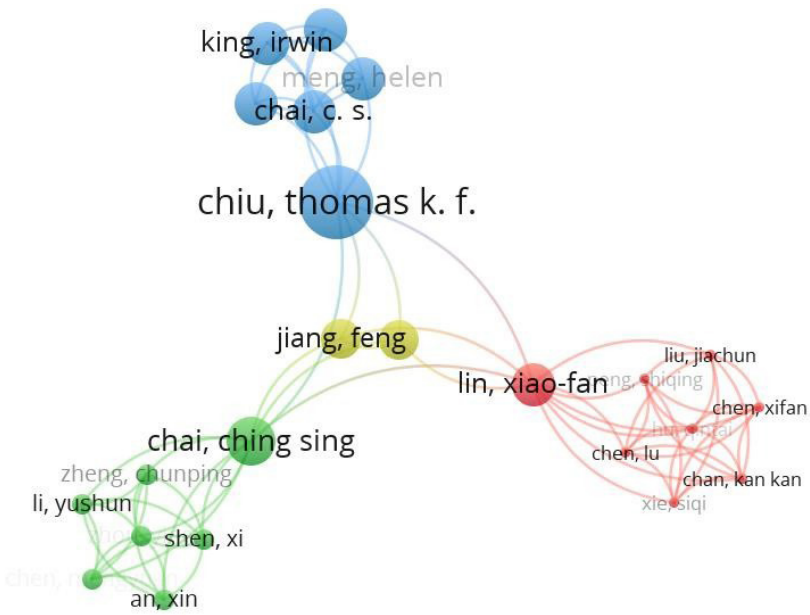
Figure 4. Author Network based on co-authorship



4.5. Research Institutions Analysis

The Chinese University of Hong Kong leads in computational intelligence, educational robotics, and artificial intelligence research, boasting 15 articles and showcasing its significant output. Notable international representation includes institutions like South China Normal University, Universitat Oberta de Catalunya, and Nanyang Technological Universityin Singapore, reflecting a globalized scientific focus. Table 3 offers valuable insights into research distribution and co-llaboration among institutions in these emerging fields.

Table 3. Top ten institutions by number of articles.

Institutions	Articles number	Proportion	Featured article
CHINESE UNIV HONG KONG	15	0.016304348	(Yau et al., 2023)
SOUTH CHINA NORMAL UNIV	11	0.011956522	(Chai et al., 2022)
SHANGHAI JIAO TONG UNIV	10	0.010869565	(Wang et al., 2021)
UNIV OBERTA CATALUNYA	8	0.008695652	(Bañeres et al., 2020)
NANYANG TECHNOL UNIV	7	0.007608696	(Jia et al., 2022)
UNIV MICHIGAN	7	0.007608696	(Poria et al., 2019)
UNIV SALAMANCA	7	0.007608696	(García-Valcárcel-Muñoz-Repiso & Caballero-González, 2019)
CENT SOUTH UNIV	6	0.006521739	(J. Yang et al., 2022)
CHARITE UNIV MED BERLIN	6	0.006521739	(Kosan et al., 2022)
EDUC UNIV HONG KONG	6	0.006521739	(Zhan et al., 2022)

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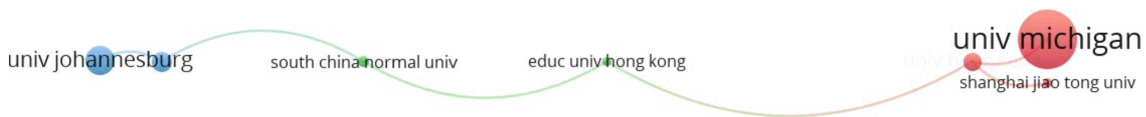
The analysis is complemented by identifying the main research-producing organizations and the co-authorship among institutions, with the creation of a visualization map of the co- authorship network using VOSviewer, as shown in Figure 5. A total of 424 organizations have published articles related to computational intelligence, educational robotics, and artificial intelligence.

In generating the co-authorship map, the total number of citations received by all documents published by each organization was considered (van Eck & Waltman, 2023). There were 16 institutions meeting the minimum criteria of more than 3 documents and 1 citation each. Among them, 7 are closely related and clustered into three groups:

- Cluster 1: In red—Shanghai Jiao Tong University, University of Hong Kong, and University of Michigan. University of Michigan leads in citations (140) and link strength (1).
- Cluster 2: Comprises 2 items in green—Education University of Hong Kong and South China Normal University, with the highest citations (11) and link strength of 2.
- Cluster 3: Consists of 2 items in blue—Chinese University of Hong Kong and University of Johannesburg. University of Johannesburg holds the most citations (52) with a link strength of 1.

Figure 5. Co-authorship network among institutions using VOSviewer



Comparing earlier organization analyses indicates that scientific production in this field is primarily led by universities in developed nations. Notably, the University of Michigan (United States) ranks among the top 5 institutions in terms of document count and holds the highest citations and link strength among universities.

4.6. Analysis of Countries

Table 4 illustrates the distribution of scientific articles by country, with China leading with 61articles, underscoring its research prominence. Following are the United Kingdom, Spain, and the United States, with 20, 19, and 17 articles, respectively. However, beyond article count, the "Intercountry relationship" index (F in Table 4) reveals insights into scientific cooperation. Notably, countries like Saudi Arabia, Germany, and Canada exhibit significantinteraction, highlighting the value of global collaboration in these domains.

Table 4. Top ten countries by number of articles.

A	B	C	D	E	F
CHINA	61	0.2933	55	6	0.0984
UNITED KINGDOM	20	0.0962	14	6	0.3000
SPAIN	19	0.0913	13	6	0.3158
USA	17	0.0817	11	6	0.3529
GERMANY	10	0.0481	5	5	0.5000
AUSTRALIA	8	0.0385	6	2	0.2500
KOREA	7	0.0337	6	1	0.1429

A	B	C	D	E	F
SAUDI ARABIA	5	0.0240	2	3	0.6000
SOUTH AFRICA	5	0.0240	3	2	0.4000
CANADA	4	0.0192	2	2	0.5000

(A) Country (B) Articles (C) Frequency (D) Intra-country collaboration index (E) Inter-country collaboration index (F) Inter-country relationship.

Table 5 provides key insights into the impact of scientific production, ranking countries by total citations. The United Kingdom leads with 470 citations, reflecting its research prominence with a substantial average citation per article. Singapore, ranking fifth with 129 citations, stands out for its highest average citation per article within this group. Furthermore, Canada, Spain, and the United States demonstrate noteworthy average citation per article despite lower total citation figures. These findings underscore the importance of considering both quantity and quality in scientific production analysis.

Table 5. Top ten countries by number of citations.

Country	Total citations	Average article citations	Featured article
UNITED KINGDOM	470	23.500	(Nadarzynski et al., 2019)
SPAIN	245	12.895	(Prendes Espinosa & Cerdán Cartagena, 2020)
CHINA	230	3.770	(Y. Liu et al., 2019)
USA	210	12.353	(Luckin & Cukurova, 2019)
SINGAPORE	129	43.000	(Tam et al., 2023)
AUSTRALIA	86	10.750	(Cooper, 2023)
GERMANY	71	7.100	(S. Gupta et al., 2020)
CANADA	70	17.500	(Chu et al., 2022)
KOREA	65	9.286	(Lee & Lee, 2021)
SOUTH AFRICA	53	10.600	(Mhlanga, 2021)

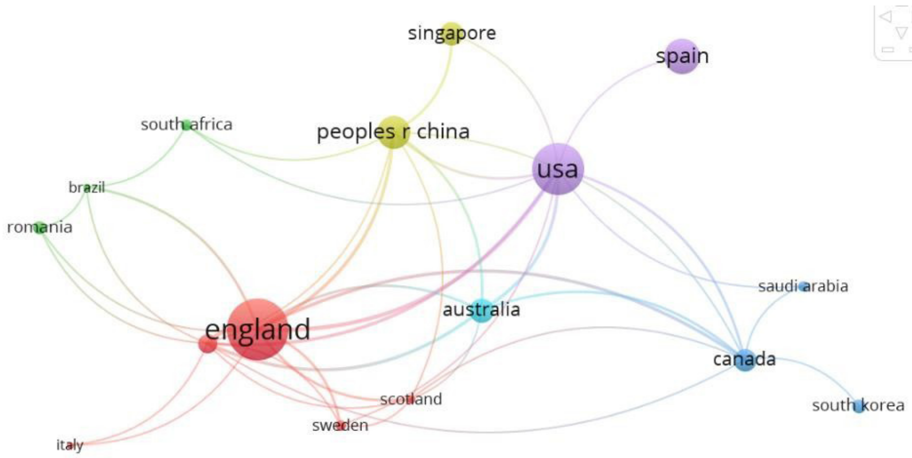
Analyzing collaboration between nations offers a comprehensive perspective on research and technical competencies in computational intelligence, educational robotics, and artificial intelligence fields. Utilizing VOSViewer's co-authorship mapping, co-authorship relationships based on citation are showcased and examined (Y. Yang et al., 2023).

Fifty-five countries have engaged in research on the studied topics, each with at least five published articles and one citation. Figure 6 depicts that 17 countries meet VOSViewer's criteria, with 16 maintaining robust connections. In the resulting map, node size indicates the number of citations issued by each country, while line thickness between nodes reflects the frequency and strength of cooperation relationships (M. Yang et al., 2023) (Kurata et al., 2023).

The co-authorship network illustrates the frequency of international collaborations among countries (Kurata et al., 2023), spotlighting the most active ones. Countries like England, the United States, Spain, and the People's Republic of China emerge as the most active participants, boasting the highest cumulative number of citations in research related to the studied topics.

In Figure 6, the top four countries represent 61.95% of total citations, indicating that most of the research in computational intelligence, educational robotics, and artificial intelligence originates from a select few countries or regions, predominantly from both developed and developing nations.

Figure 6. Network of countries based on co-authorship



4.7. Research topics

Python, along with the Gensim library and its Latent Dirichlet Allocation (LDA) model, was employed to analyze the primary topics within the abstracts of selected scientific articles. This approach facilitated the extraction of pertinent information to identify keywords from all the abstract texts.

The code initially preprocesses the data by cleaning the text and removing irrelevant information. Then, utilizing the Gensim library, an LDA model is constructed on the summaries to unveil underlying thematic patterns. Each topic is distinguished by a set of weighted keywords. Finally, the code showcases the top five topics along with their relevant keywords.

The result provides a structured view of the prominent topics present in the abstracts of scientific articles, which helps to understand the dominant thematic areas in the dataset and to propose interpretations adjusted to the findings, see Table 6.

Table 6. Gensim topic modeling results.

Cluster	Keywords	Topic	Interpretation
1	education, data, student, research, teacher, technology, intelligence, artificial, study, teaching	Education and Technology	The theme focuses on the fusion of education and technology, with keywords such as "education", "data" and "technology" in educational environments. Terms like "Student," "research," and "teacher" suggest an interconnectedness within education. The mentions of "intelligence" and "artificial" show the potential of AI. Applications in enriching teaching and learning experiences.

Cluster	Keywords	Topic	Interpretation
2	research, system, education, artificial, intelligence, learning, development, plant, result, vision	Research and Artificial Intelligence	Topic focused on the importance of research and its relationship with artificial intelligence. Keywords such as "research", "system", "artificial" and "intelligence", integration of AI into various research systems. Terms like "learning," "development," and "outcome," impact of AI on learning outcomes. The mention of "plant" and "vision", applications of AI beyond traditional education, context of plant sciences or computer vision.
3	ai, learning, education, student, research, technology, teacher, artificial, study, intelligence	Artificial Intelligence in Education	Topic associated with the role of artificial intelligence in education. The term "AI" focuses on artificial intelligence, with keywords such as "learning," "education," and "Technology." The presence of "student" and "teacher" AI affects both students and educators. This topic explores the integration of artificial intelligence technologies in educational practices, intelligent tutoring systems or adaptive learning platforms.
	research, education, ai, student, intelligence, artificial, learning, study, analysis, future	Future of AI in Education	The topic explores the future implications of artificial intelligence in education. Keywords like "future" and "analysis" delve into trends and predictions related to AI in education. "AI", "student" and "intelligence" mean a sustained focus on the impact of AI on students and the education sector.
5	education, study, learning, research, educational, result, artificial, intelligence, tax, design	Educational Design and Artificial Intelligence	The topic explores the intersection of educational design and artificial intelligence. Keywords like "educational," "Study," and "design" impact AI on the design of educational programs. Terms like "learning," "research," "artificial," and "intelligence" are AI-powered educational interventions. Mention of "tax" taxonomies or categorizations within this context

The analysis of term co-occurrence is valuable for uncovering research themes and trends (Van Eck & Waltman, 2014), particularly in the context of computational intelligence, educational robotics, and artificial intelligence, as covered in this study. To achieve this, a co-occurrence map was generated based on a bibliographic text file using VOSViewer.

The number of co-occurrences of two words extracted from the abstract field of a publication is 6172. The VOSViewer's own Thesaurus file and a requirement of at least 20 occurrences of a term were included in the processing.

In Figure 7, node sizes correspond to the term's score, indicating its frequency of occurrence. The color gradient reflects the average citation scores of the articles. Predominant themes, identified by higher occurrences and relevance scores, include "artificial intelligence" (19, 22.764), "education" (165, 22.003), "research" (148, 15.434), "study" (113, 13.215), and "technology" (112, 13.215).

The top five themes reveal research areas delving into the present and future of education, with a focus on integrating technology and innovative approaches such as artificial intelligence. AI plays a crucial role in shaping the future of education, posing both challenges and opportunities for skill development and curriculum adaptation in the AI era.

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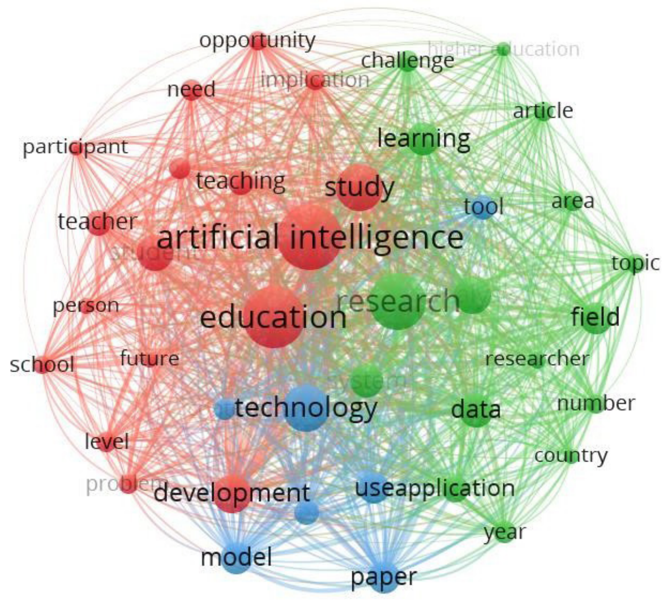
Figure 7. Network Map Data source based on VOSviewer.



5. CONCLUSIONS

This study offers a thorough examination of the connections among "computational intelligence," "educational robotics," and "artificial intelligence" within educational research. It highlights the increasing scientific output in these areas. These disciplines, integrated, are pivotal in driving today's educational transformation, promising to revolutionize teaching. They foster active student and teacher engagement, preparing them for a future shaped by technological innovation.

From 2019 to 2023, research in computational intelligence, educational robotics, and artificial intelligence exhibited a 56.51% annual growth, resulting in 208 works. While 2022 saw a surge with 74 additional contributions, 2023 experienced a slight decline, indicating the importance of ongoing analysis in these dynamic domains.

Journal analysis shows "Sustainability" leading with 39 articles, signifying its prominence in the researched topics. Utilizing Bradford's Law confirms concentrated scientific production in a handful of highly productive journals, with a descending distribution in performance.

Keyword co-occurrence analysis identifies prevalent thematic areas and research methods. Among 1104 keywords analyzed using VOSviewer, "artificial intelligence" emerges as most significant, followed by "education," "technology," "machine learning," and "Big data." These keywords signify the examination of the interplay between artificial intelligence and education, delving into their implications and challenges in academic instruction.

The academic landscape in computational intelligence, educational robotics, and artificial intelligence reveals the Chinese University of Hong Kong as the frontrunner with 15 notable articles, showcasing its substantial impact. Noteworthy contributions also come from global institutions like South China Normal University and Nanyang Technological University, reflecting a varied research spectrum. A comprehensive analysis identifies 424 collaborating organizations, with key clusters spearheaded by institutions such as the University of Michigan and Shanghai Jiao Tong University. A comparison reveals that universities from both developed and developing nations are at the forefront of scientific output, with the University of Michigan wielding significant influence.

China stands out in computational intelligence, educational robotics, and artificial intelligence with 61 articles, showcasing its prominent role. Notable contributors include the United Kingdom, Spain, and the United States. Collaboration is evident, notably in Saudi Arabia, Germany, and Canada. The United Kingdom leads in impact with 470 citations, emphasizing the importance of quality and quantity in scientific output. International collaboration involves 55 countries, with England, the United States, Spain, and China leading, representing 61.95% of total citations and highlighting research concentration.

Python, Gensim, and the LDA model were employed to analyze research abstracts in computational intelligence, educational robotics, and artificial intelligence. This process identified five primary topics: integration of education and technology, AI research, AI's role in education, future implications, and AI-driven educational design. A co-occurrence map visualizes dominant themes like AI, education, and research, indicating a focus on technology integration and educational innovation.

Among the future challenges and research lines regarding computational intelligence, educational robotics and artificial intelligence in education are several. Specifically, we note interest in:

- Exploring how the implementation of these technologies is progressing and assessing their effectiveness in improving, enriching, and enhancing the educational experience for students, teachers, and families. Additionally, understanding the real impact concerning preparedness for future challenges is crucial.
- Learning how the digital divide and inequity in access to these tools may affect, especially the most vulnerable groups particularly with a focus on gender impact.
- Examining contrasted experiences that address the training of teachers in the effective adoption of these technologies.
- Analyzing how the promotion of these technologies is happening at the public and private institutional levels.
- Finally, delving into the ethical issues underlying data privacy, particularly sensitive concerning minors, and the protection and security of students

AUTHOR CONTRIBUTIONS

Conceptualization, A.C.V. and M.E.M.; methodology and software A.C.V, M.E.M.; LLC and B.L.C.; validation, A.C.V.; M.E.M, L.L.C and B.L.C; formal analysis, A.C.V; M.E.M, L.L.C

and B.L.C.; investigation, A.C.V.; M.E.M, L.L.C and B.L.C.; resources, A.C.V. and M.E.M.; data curation, L.L.C and B.L.C.; writing—original draft preparation, A.C.V.; M.E.M; writing— review and editing, L.L.C and B.L.C.; visualization, A.C.V.; M.E.M, L.L.C and B.L.C.; supervision, A.C.M; M.E.M, L.L.C and B.L.C.; project administration, L.L.C. All authors have read and agreed to the published version of the manuscript.

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