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Review Article

The Global Rise of Robotics in Education: A Comprehensive Bibliometric Analysis

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Abstract - *Using robotics in education has transformed teaching approaches and piqued student interest in a wide range of educational environments. This paper provides a comprehensive bibliometric examination of the field, tracing the evolution of robots in education from its inception to the present. The study indicates, based on a detailed investigation of multiple academic publications and sources, that research activity and publication trends have increased dramatically over the last 20 years. Key findings reveal that there has been a noticeable increase in publications and citations, particularly after 2019, demonstrating that robotics is becoming more widely acknowledged as a valuable teaching tool. Leading authors and nations who score particularly well are acknowledged as major contributors, with a focus on key publications and extensively cited sources that have changed the field. The report also delves into the key concepts and words driving current research, such as robotics curriculum integration, STEM education, and educational robotics. Thematic analyses demonstrate a shift in focus from general educational technologies to using robotics for targeted applications. This study not only traces the evolution of robotics in education but also highlights the crucial role of ongoing innovation in incorporating robots into educational systems and the potential for future research in this area.*

Keywords - *Educational robotics, STEM education, IoT in robotics, Student engagement, Bibliometric.*

1. Introduction

Across the world, robotics education development is considered one of the greatest pedagogical changes and technological trends. The more the subject goes into the educational systems, the closer robotics takes students to experiences and hands-on learning. It makes them creative, develops critical thinking, and encourages them to venture into complex, real-world problems. The role of robotics in the classroom underscores the increasing need for interdisciplinary education, whereby students marry knowledge of computer science, engineering, mathematics, and other subjects.

Thus, they would be better positioned for careers in a world where automation and technology take key roles in change with such kind of interdisciplinary education [1]. However, there are some challenges to integrating robotics into school curricula. Most educational settings face problems regarding access to technology, lack of adequate teachers' training, and a curriculum that adequately embeds the area of robotics into more general educational aims [2-4]. Despite all the odds, robots have great potential for improving education, filling digital literacy gaps, and enabling students to thrive in the twenty-first century. It is obvious that, going a bit more into the deep bibliometric analysis of robotics in education, this topic is rapidly developing and has huge implications for the future learning process. The research, educational, and legislative communities need to be quite clear about the trends, barriers, and opportunities concerning the use of robots as a means toward improving education outcomes worldwide. This also contributes to integrating robots into the classroom, facilitating access and inclusiveness of the educational environment. The following aspects can assist students with various educational interests and needs, including students with disabilities. The introduction of flexibility serves to level the playing field for learning so that all students, irrespective of background or prior achievements, can work constructively at a suitably challenging level [6].

Moreover, the utilization of robots provides the possibility of transforming the teaching pedagogy from the passive to the active, in which learners are responsible for their own learning process. This has the further benefit of capitalizing on learners' heightened confidence, self-initiated momentum, and improved comprehension of STEM subjects, thereby equipping them for successful lives in a progressively dynamic technological world. As robotics is further developed in schools, it is essential for researchers, teachers, and policymakers to be aware of the existing trends, challenges, and potential benefits involved with the technology [7]. A comprehensive bibliometric analysis of studies concerning robotics in education indicates that the area is fast developing with significant implications for the future of pedagogy. By overcoming the difficulties that accompany the implementation of robotics in schools and utilizing the possible advantages it can present, educators and policymakers can help students become better equipped to tackle the problems of the 21st century [8].

The field of robotics education is experiencing a global expansion; however, its integration into formal educational systems is still under great challenge. Although robotics has excellent potential in fostering creativity, critical thinking, and problem-solving capabilities, schools face huge obstacles in terms of lack of access to technology, poorly trained teachers, and poorly developed curricula to enhance the effective use of robotics. All this hampers its widespread application and restricts its scope in improving students' learning outcomes.

One of the gaps in the literature discusses the manner in which robotics can be embedded within educational systems in order to realize its advantages and defeat associated issues. Existing literature commonly concentrates on the advantages of robotics without duly discussing the practical limitations or proposing implementable solutions for its acceptance within varied educational institutions. Such a gap raises the need for more research on trends, issues, and the future of robotics in education in order to facilitate its effective adoption.

This study aims to bridge this gap by analyzing the major factors affecting the integration of robotics in education systems. By identifying challenges and opportunities, this study hopes to establish a basis for creating strategies that will allow policymakers and teachers to unlock the complete potential of robotics to equip students for success in a future driven by technology.

Robotics education is a foremost approach to K-12 and higher education that offers students experiential learning in creative and critical thinking. When it is used within the context of K-12, it is introduced as a core subject integrating the fundamental concepts of STEM. At the higher education level, it is an interdisciplinary model integrating computer science, engineering, and mathematics. Its effectiveness is challenged, however, by the limited access to technology, lack of teacher preparation, and lack of curriculum integration.

Despite these challenges, robotics can close digital literacy divides and foster active, inclusive learning environments. The research examines how the use of robotics, especially in tertiary and K-12 education, can be enhanced to equip students with future technological demands.

2. Methods

This paper conducts an exhaustive bibliometric analysis to investigate the global spread of robotics within the educational community. Bibliometric analysis is a quantitative methodological strategy to analyze and visualize trends and implications of scholarship embodied in a given field.

Bibliometric analysis gives more organized assessments of research production, thereby easing the process of identifying prominent authors, significant contributions, and emerging topics in the literature [9].

The methodological approach used in this research was geared towards producing readable and accurate results. Processes undertaken in bibliometric analysis include data collection, preprocessing, mesh extraction, normalization, mapping, analysis, and visualization, all of which play a significant role in delineating the area of robotics research in the context of education in a systematic manner.

The analysis uses two key tools: R Software and VOSviewer, which allow for in-depth data processing, visualization, and interpretation of academic publications [10].

2.1. Data Collection

The first step involved sensitive but specific data mining of research materials on robotics in education on Scopus, the largest repository of peer-reviewed research publications. In January 2024, a sensitive search was made, compiling a large but focused dataset using keywords such as robotics in education, educational robots, and STEM education with robotics [11]. In order to ensure the quality and relevance of the data, only peer-reviewed journal articles, conference papers, and reviews published in English were included.

2.1.1. Preprocessing

After data collection, cleaning and curation of the dataset were done. During this, all duplicates, irrelevant records, and missing entries were removed; these had to be valid for subsequent analysis.

Following this, preparing the dataset for analysis entailed extracting important information such as article titles, author names, journal names, keywords, and publication years [12].

2.1.2. Network Extraction and Normalization

The next step was to extract the networks, with special attention given to co-authorship, co-citation, and keyword networks. These networks describe the relations and collaboration between many authors, show core publications, and detect the presence of major research themes in the field [13]. Data normalization techniques have been applied to avoid bias in the results concerning heterogeneity in writing the name of authors, use of keywords, or citing behavior.

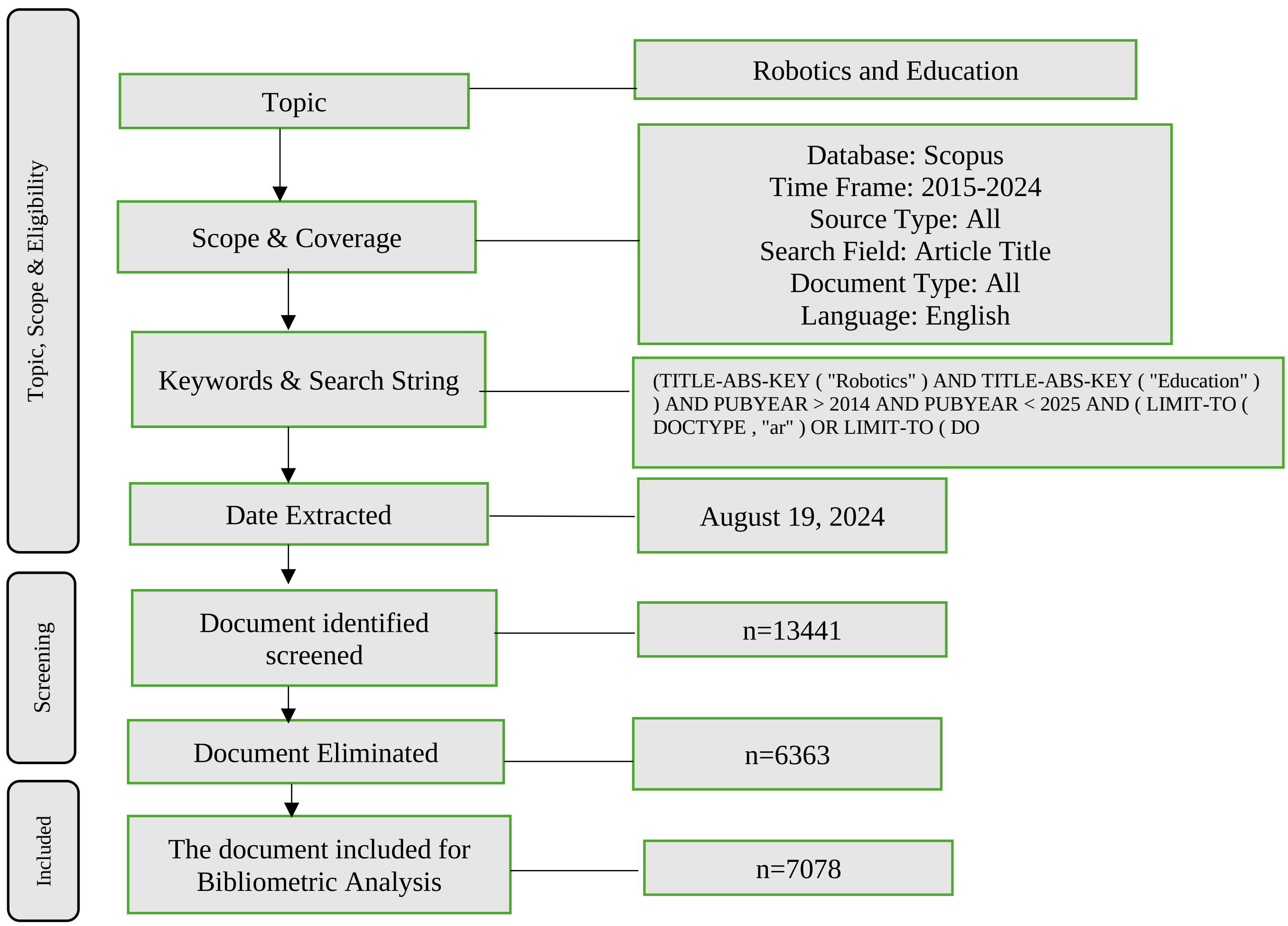

Fig. 1 Flow diagram of article searching strategy of robotics in education

2.1.3. Mapping, Analysis, and Visualization

In the final step, the retrieved networks were visualized to indicate interactions and trends in the field. The software VOSviewer supported the generation of visualizations of data, amongst others, a network diagram showing the most prominent authors, publications, and themes in research [14]. Visual depictions allow the easy comprehension of dynamics and framework regarding research in educational robotics. Indeed, examining these maps has brought out the major patterns, clusters of research, and new areas of interest in this discipline [15]. With the help of these methodologies, the present paper presents a detailed bibliometric analysis of the international uses of robotics in educational settings. These research results put forward the field's current status and provide information about future research and policy-making in this rapidly developing area.

2.2. Search Criteria and Data Cleaning

The keywords for the search in the study were well formulated to provide a comprehensive collection of research around the world in the area of robotics in an educational setting. The keywords used in searching Scopus include robotics in education, educational robotics, robotics and STEM, and educational technology [16]. In order to ensure data integrity, the search was limited to peer-reviewed journal articles, conference proceedings, and reviews in English. It involved an elaborate data cleaning process, including removing duplicates, irrelevant data, and missing entries, besides developing matching criteria for author names and keywords. This careful methodology provided a solid base for data collection and laid the ground for subsequent bibliometric analysis. In carrying out a comprehensive bibliometric analysis related to robotics in education, the methodology presented herein was performed with great attention to detail so that the data collected could be considered precise and representative of the general trends of research work on this topic throughout the globe.

The search keywords have been selected in a manner that will include a broad set of studies that may capture the different ways robotics are introduced into setups. For the search, the researcher used specific keywords related to robotics in education, educational robotics, robotics and STEM, and educational technology [17]. A search of the Scopus database, one of the most renowned databases of scholarly peer-reviewed articles, has been done. This strategic choice of keywords encompasses all significant aspects of robotics related to education: application in STEM education to broader implications in educational technology [18]. After data had been retrieved from Scopus, relevant records were consequently exported in comma-separated values .csv format to meet the requirements for bibliometric analysis. In view of Scopus' extraction limitation, bibliometric data was restricted to the first 7,078 returned entries, focusing on the top 100 most cited publications in this field. Subsequently, an elaborate data-cleaning process was conducted to ensure a perfect error-free dataset with no missing information while creating consistency in all the fields. These cleaned records were then compiled into a Microsoft Excel (.xls) file and saved as a tab-delimited Text file ready for further analysis using VOSviewer. At this stage, the foundation for an in-depth look into the global rise of robotics in the educational environment has been properly set.

2.3. Bibliometric Analysis

Bibliometric analysis is an efficient approach to ascertaining trends and the impact of research within different fields of study [19]. The analysis gives a meaningful understanding of citation patterns of research contributions and their relevance to developing public policy and increasing scientific understanding. It also helps a researcher in distinguishing main themes, predicting emerging trends, and logically organizing major focus areas. In educational robotics, bibliometric analysis uses-beyond titles and keywords and publication trends-co-authorship and citation networks to investigate research clusters. The sources primarily used for this study were based on the Scopus database, which represents comprehensive coverage.

2.4. Thematic Evaluation

Thematic development is a complex research methodology that has matured to become the overriding technique for mapping changes, expansion, and maturity of a particular research subject over time through integrating concepts from various disciplines [19]. The methodology forms the basis for understanding the incremental development of a given area of inquiry. In the paper at hand, focusing on the growing trend of global robots in the educational sector, themes were generated through Biblioshiny, an online tool linked with the Bibliometrix R package. Through this approach, researchers can analyze the theme, important themes, and even inner changes. The extent and spread of the key terms for the authors on the combined axes provided a powerful illustration of considerable changes in the themes. They gave insight into new interests in research. The diagrams showed different sizes of alluvial areas, which changed according to the emphasis on the topic, creating a dynamic map of the global development of robotics in educational settings while representing changing trends and fields of scientific interest [20].

3. Results and Discussions

3.1. Descriptive Analysis

Within the educational robotics field, 7,078 documents from 2,369 sources have been produced from 2015 to 2024, with an annual growth rate of 4.57%. So far, an average citation count of 11.49 has been received by every publication, and the average age is 4.05 years. The total number of references cited is 195,561. In this domain, there are 23,682 unique Keywords Plus and 12,746 Author's Keywords, with a total of 23,932 different authors. Of the published documents, 507 have an author count of only one, while every document has, on average, 4.62 co-authors. International collaboration appeared in 17.44% of the documents. Papers given at conferences top the list of documents, numbering 3,392, followed closely by articles of the number of 3,160 and reviews totaling 514. This output is extremely diverse, underpinned by a high level of international involvement and a strong focus on progress influenced by conferences, marking research's active and collaborative nature.

Table 1. Overview of the bibliographic information

Description	Results
Main Information About Data	
Timespan	2015:2024
Sources (Journals, Books, etc)	2369
Documents	7066
Annual Growth Rate %	4.57
Document Average Age	4.05
Average citations per doc	11.49
References	195561
Document Contents	
Keywords Plus (ID)	23682
Author's Keywords (DE)	12746
Authors	
Authors	23932
Authors of single-authored docs	507
AUTHORS COLLABORATION	

Single-authored docs	559
Co-Authors per Doc	4.62
International co-authorships %	17.44
Document Types	
Article	3160
conference paper	3392
review	514

3.2. Publications and Citations per Year

The analysis of publication and citation patterns from 2015 to 2024 indeed follows a steeply increasing trend, confirming its growing interest and importance in the sphere of education. The steady year-to-year increase in the number of published works shows a fast-growing domain in which researchers are contributing novel findings and innovations at a very rapid rate. Significantly, specific intervals characterized by more intensive publication efforts correspond to periods of large technological progress, new educational strategies, or enhanced financial and institutional support. Peak periods indicate not just a greater quantity of research effort but an active response to the change at hand in opportunities and challenges of robotics education. The upward trends observed in publications and citations between 2015 and 2024 reflect robotics's escalating interest and significance within the educational sector. The increase in citations per paper supports the strong influence of existing research, suggesting that these kinds of studies are imperative to advancing the discipline. The upward trend reflects the relevance of robotic education research to both existing and potential academic inquiry, in addition to applications. Indications are towards heightened research activity across certain periods, typically followed by peaks reflecting technological advancement or pedagogical innovation, thereby demarcating milestones of innovation in the field. These trends have been useful in providing insight into the emerging areas of interest and influence of key studies as robotics in education evolves. Increased international collaborations represent the global scope and interdisciplinarity of the field, enhancing quality and relevance in research. These patterns can be drawn upon by researchers, educators, and different levels of decision-makers to deeply understand the development of the field and identify knowledge gaps that can direct further research efforts. Such a broad vision helps outline the roadmap for long-term progress in using robotics in multiple educational settings.

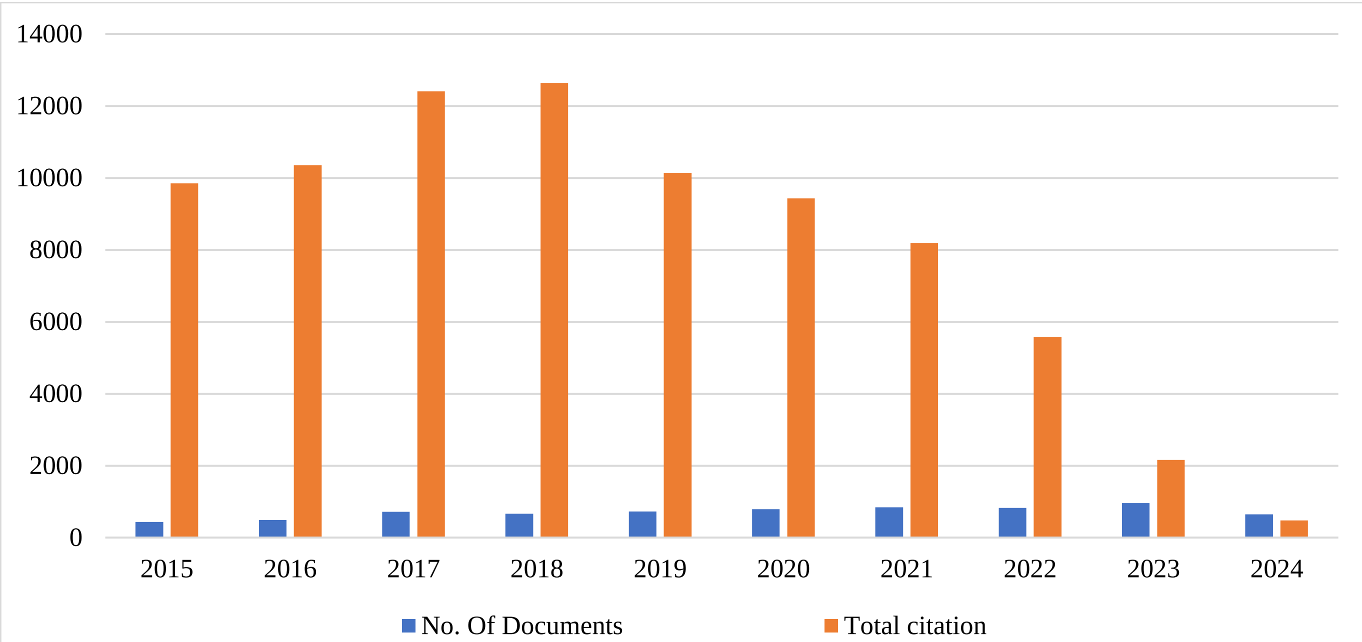

Fig. 2 Publication and citation trends

3.3. Most Productive Authors

Identifying the most productive authors is important to understanding key players in robotics and education research. In this way, such authors are recognized not only for their significant contribution to the development of the field but also for their role in diffusing knowledge through a large number of research publications. Author productivity analysis provides a number of interesting hints about the kind of institutional links and collaborative networks that drive scientific progress. The most productive authors in robotics education are those who have consistently published high-quality research articles, conference papers, and reviews over time. Their extensive output often reflects their expertise, dedication, and influence in the field. The number of publications, citation frequency, and the h-index values usually measure productivity. While the publication count suggests the amount of work done, citation counts depict the relevance and significance of the works that have advanced the field.

The h-index, which puts both the number of publications and the number of citations together, therefore gives an overview of the author's impact in the fields of robotics and educational research. It allows for identifying trends of research emphasis, the development of contributions over time, and the influence of the reviewed authors in forming emerging fields.

Table 2. Productive author

Author	Year	Freq	TC	TCpY
AHMED K	2015	7	502	50.2
AHMED K	2016	6	332	36.889
AHMED K	2017	6	134	16.75
AHMED K	2018	5	106	15.143
AHMED K	2019	2	75	12.5
AHMED K	2020	2	28	5.6
AHMED K	2021	2	28	7
AHMED K	2022	1	9	3
AHMED K	2024	1	1	1
CASTRO M	2016	2	43	4.778

Freq: No of frequency per year; TC: Total citation; TCpY: Total citations per year

3.4. Most Productive Countries

The global distribution can include the relative productivity and impact of countries in research related to robotics and education. The USA comes first, with 1,117 publications, accounting for 15.8 percent of total worldwide output-positioning it at the very frontline of research in robotics education. This leaderboard position is driven by its vibrant academic community, heavy funding, and large-scale research infrastructure, with top-tier universities and research centers contributing heavily to such output.

China takes the second position with 329 publications, accounting for 4.7% of the global total, indicating its growing contribution to robotics education. Its rise in research performance is fueled by the development of its academic and technological infrastructure in tandem with heavy funding for research and development. Chinese institutions and scholars are making their presence known internationally through pioneering work.

The United Kingdom has the third position, where 226 publications represent 3.2% of the worldwide research output. The involvement of the UK in robotics education research is further supported by its well-established academic institutions and comprehensive research initiatives. This partnership between academia and industry within the UK must nourish its magnificent publishing record, thus underlining its importance as a key player in this area. Beyond these leading countries, other nations are also making notable contributions to the field of robotics in education, albeit on a smaller scale. For instance, countries such as Germany, Japan, and South Korea are also active in this area, reflecting their strong technological bases and commitments to advancing STEM education. These countries contribute valuable research that further enriches the global understanding of how robotics can be effectively integrated into educational systems. Several factors, including the availability of funding, the strength of academic institutions, and the level of governmental and private sector support for research and development, influence the varying levels of research output among countries. Nations with well-funded research programs and good collaboration between universities and industry will naturally yield more meaningful research production, as we can see from the examples of the United States, China, and the United Kingdom. These countries have emerged as front-runners in the field of robotics education research, establishing trends and influencing worldwide discourse on the subject.

On the other hand, nations with less well-developed research infrastructures or lower funding levels may find it difficult to contribute equally. However, even in these regions, there are pockets of excellence where committed researchers are advancing the state of the art in robotics education. Although smaller in scale, these initiatives are vital to making robotics education progress globally in its reach, thereby benefiting students and educators everywhere.

The global distribution of research in robotics education also points towards the importance of global collaboration. As countries recognize the value of sharing knowledge and resources, cross-border partnerships are becoming increasingly common. These collaborations enable researchers to pool their expertise, access broader datasets, and tackle complex challenges that require a global perspective. Such international efforts are vital for advancing the field of robotics education, ensuring that innovations are disseminated widely and that all regions can benefit from the latest advancements in technology-enhanced learning.

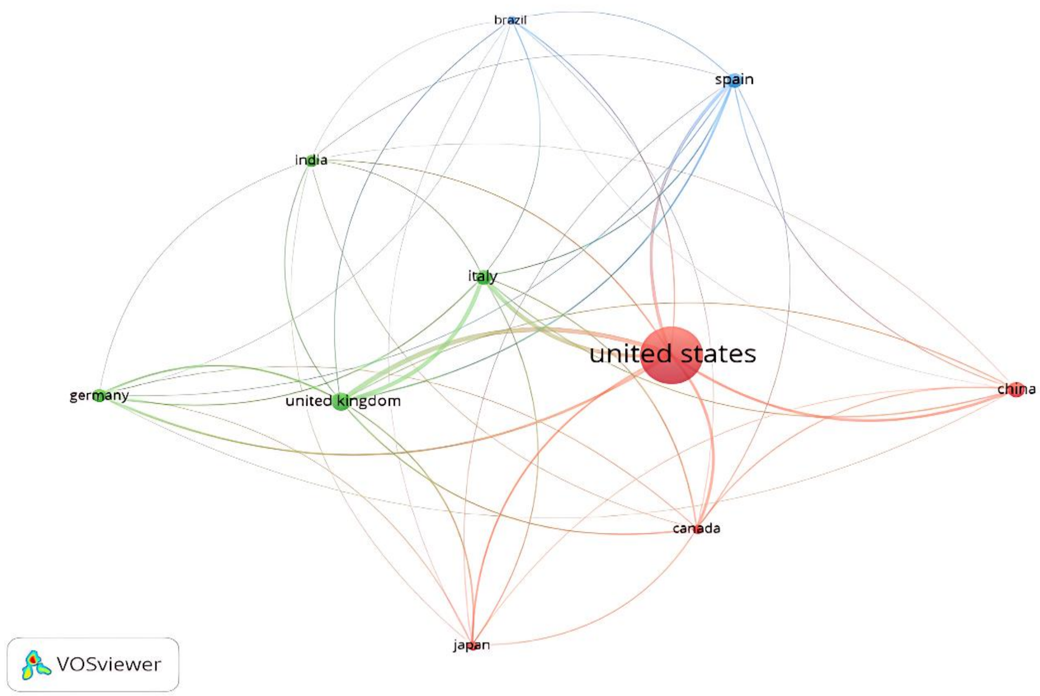

Fig. 3 Most productive countries

Italy has contributed 196 publications, representing 2.8% of the global research into robotics education. A focus on the integration of robotics into curricular and educational paradigms is reflected in Italy's contribution through its key research institutions. Spain follows with 167 articles, 2.4%, highlighting its strong position in classroom robotics through collaborative projects. Germany has 147 papers, or 2.1%, showing key competencies in engineering research with significant contributions to the field. India, with 124 articles (1.8%), illustrates the growing importance of robotics in the educational system through the establishment and growth of research centres. Canada, with 106 (1.5%), reflects a commitment to modern education through vibrant research and development activities and cooperation. Japan and Turkey, with 98 papers each, make up 1.4% and underscore a technological leap into progress, with an increased focus on robotics in education augmented by growing research infrastructure.

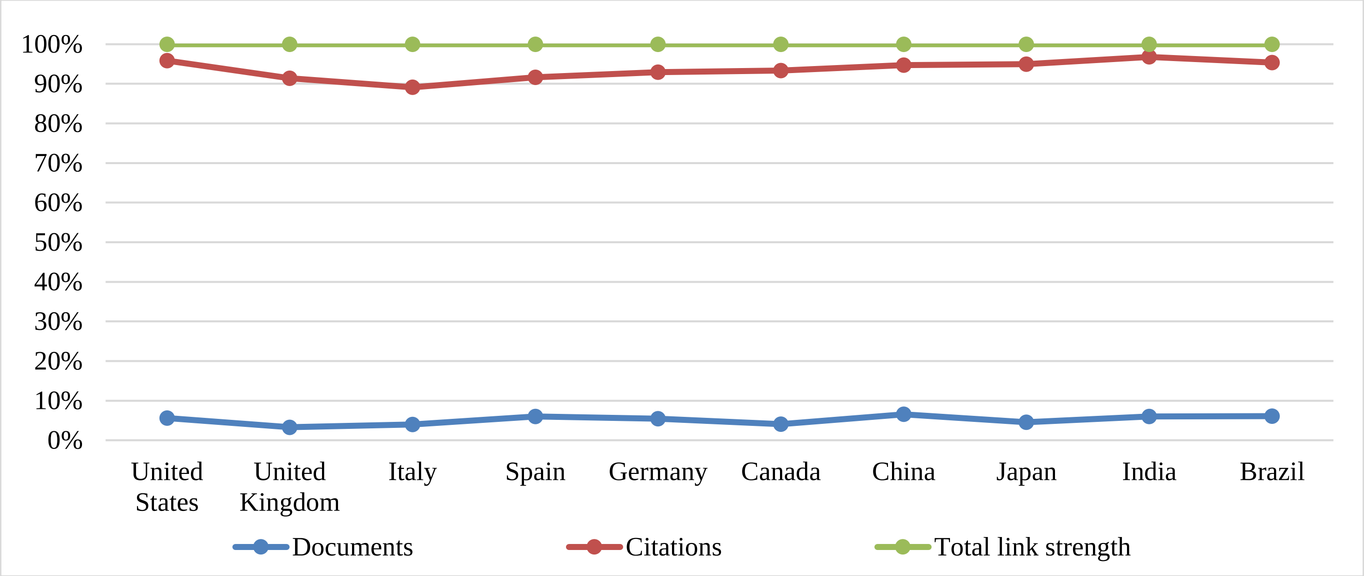

Fig. 4 Graphical representation of most productive countries

It is evident that the top ten robotic education research productive countries depict global interest in the area and international collaboration. Every country's contribution is a function of its special research environment, institutional strengths, and investments. The large share of the United States in global publication output puts it in a vantage position to set international trends and standards in research, driven by strong funding, advanced research facilities, and prestigious academic institutions. The various contributions from these leading nations underscore the international character of research pertaining to robotics education, with each nation's emphasis and resources significantly enriching the overall advancement of the discipline. Their combined endeavors play a vital role in promoting and influencing the future development of robotics within educational contexts.

3.5. Top Frequent Authors' Keywords

Mapping the keywords of top authors in educational robotics identifies trends and areas of focus. Dominant keywords include robotics, education, learning, and technology, strongly emphasising embedding robotics into education to enhance learning outcomes. The recurrent mention of curriculum development and STEM education gives evidence of a significant accent on synchronizing education methodologies with technological progress. This underlines the need to integrate robotics into academic programs to prepare learners to face emerging challenges. This kind of terminology characterizes the changed priorities of the domain in harnessing robotics to revolutionize education. This word cloud of authors' keywords underlines important focuses within the domain of robotics education, including such important terms as robotics, education, learning, technology, STEM education, and curriculum development. These keywords embody the discipline's commitment to introducing robotics into pedagogical techniques, innovating instructional strategies, and enhancing learning outcomes through technology. The repetition of the words indicates the critical need to revise educational curricula that make provisions for modern technological resources and align them with unending technological development.

Table 3. Top frequent author's keywords

Words	Occurrences
Robotics	3468
Education	2012
Human	1886
Humans	1583
Students	1527
Male	1428
Female	1379
Engineering education	1369
Article	1207
Clinical competence	1184

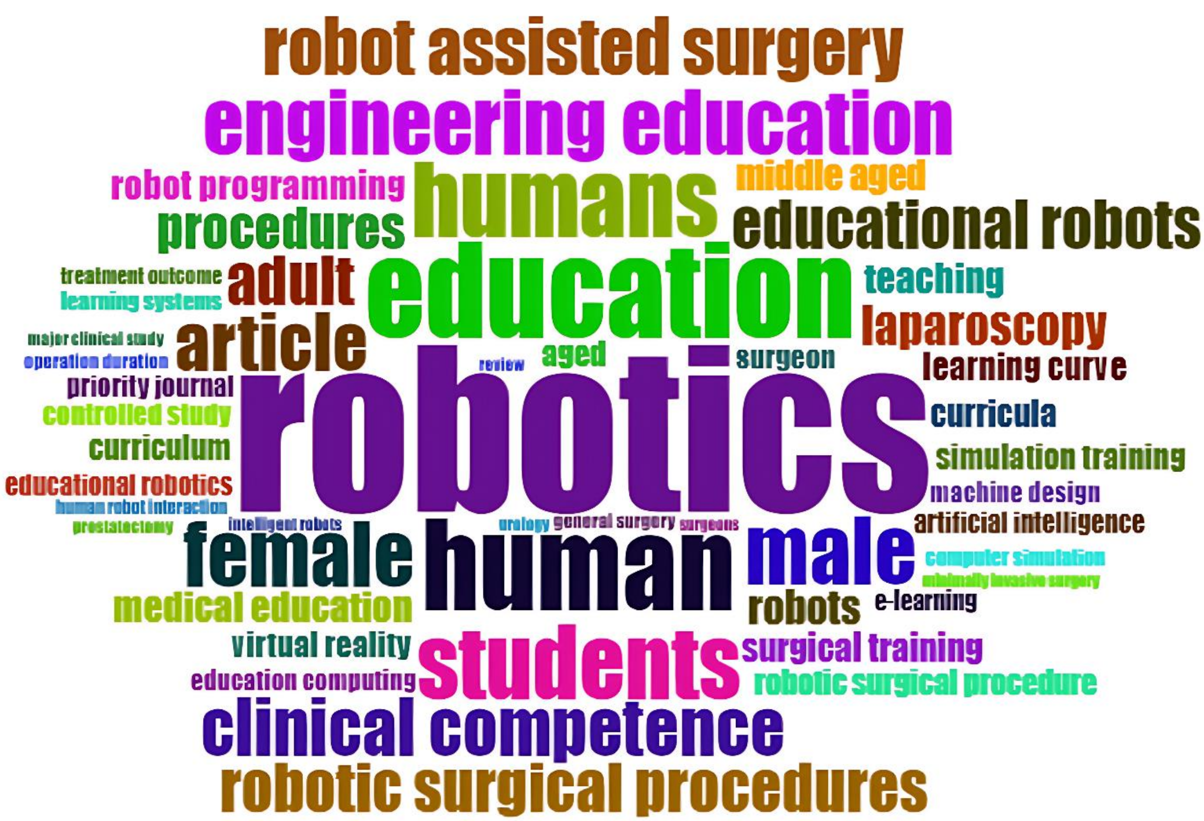

Fig. 5 Word cloud of top author's keywords

3.6. Thematic Analysis

Thematic analysis comes out as full of key insights on how research areas growing out of the robotics domain affect education. It has enabled mapping emerging and developing key themes over time, pointing to changes within the academic focus.

From 2015 to 2018, themes such as robotics, STEM education, and educational technology were at the core and still form a strong premise for further research. Prominent shifts towards more specialized themes-robotics integration, innovative teaching methodologies, and curriculum enhancement-have been observed between 2019 and 2024.

This, in a way, indicates that more research interest was garnered above practical applications and the shifting sands of pedagogical approaches, driven by increased awareness of robotics ability in the school setting and technological development. This word cloud of authors' keywords underlines important focuses within the domain of robotics education, including such important terms as robotics, education, learning, technology, STEM education, and curriculum development. These keywords embody the discipline's commitment to introducing robotics into pedagogical techniques, innovating instructional strategies, and enhancing learning outcomes through technology.

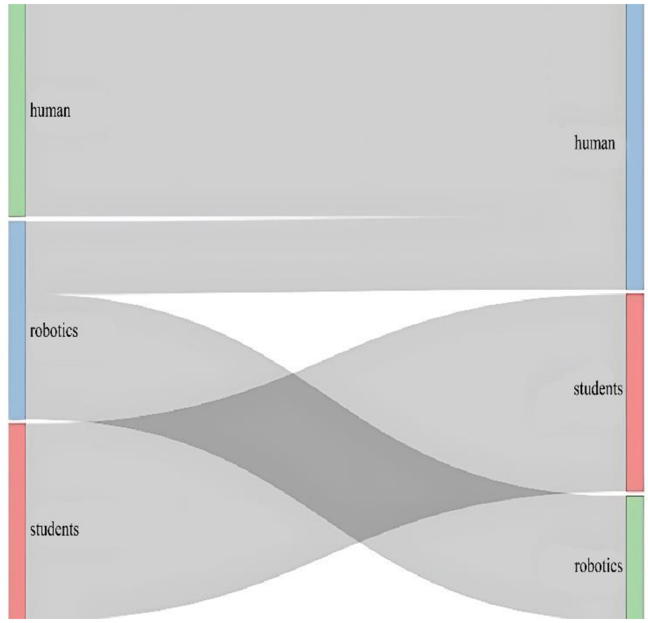

Fig. 6 Thematic evaluation

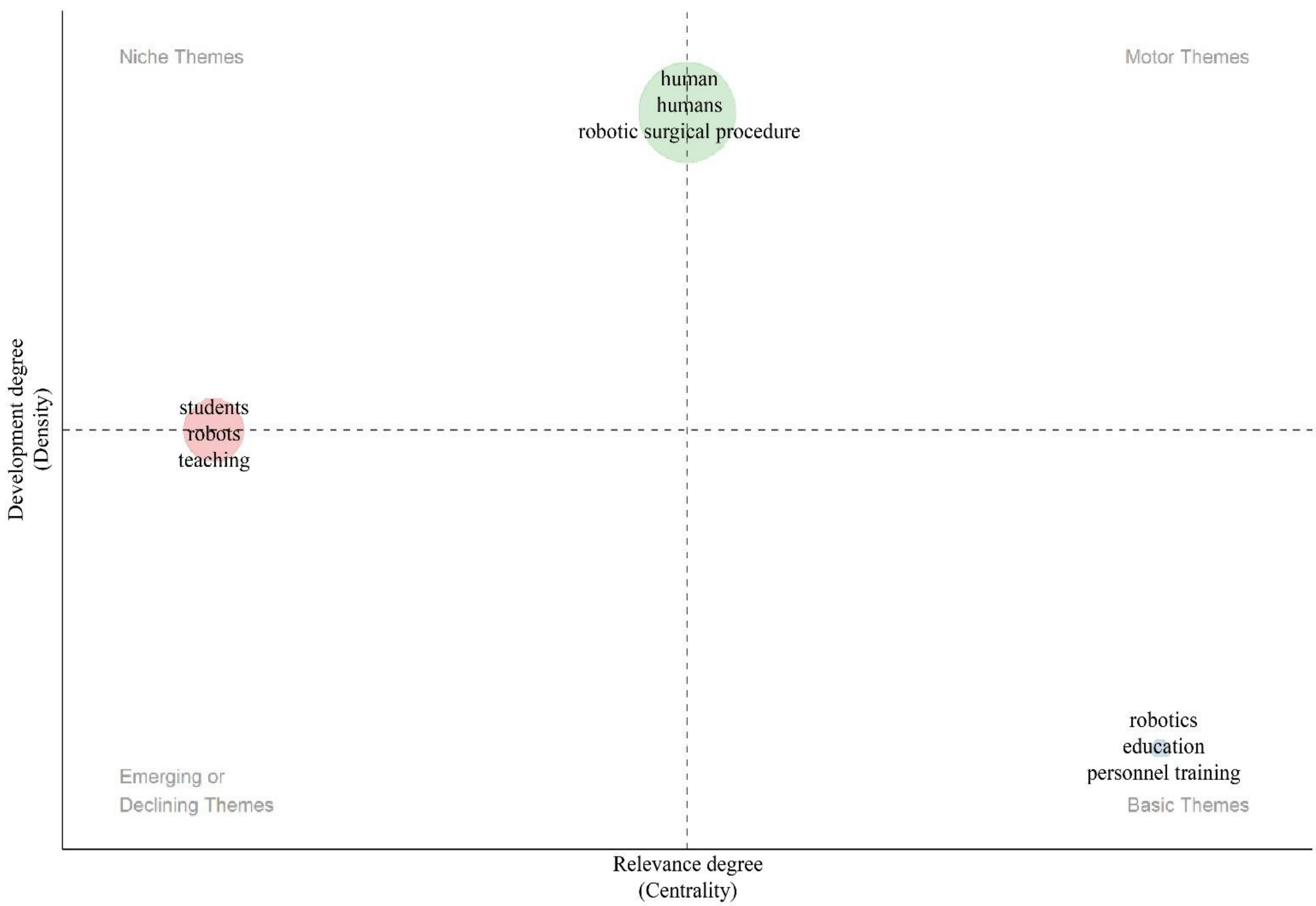

Fig. 7 Thematic map

3.7. Highly Influential Works

An overview of the most cited literature in the area of educational robotics represents core publications and respected journals. The Journal of Robotic Surgery, with 1,576 citations, greatly contributes to developing robotic technologies relevant for educational purposes. Surgical Endoscopy, with 2,770 citations, makes a statement about its impact on robotic systems used in surgical education. The Journal of Surgical Education has 1,065 citations and provides key insights into the use of robotics in medical education. Other important sources include Advances in Intelligent Systems and Computing, Lecture Notes in Computer Science, and ACM International Conference Proceedings, each of which is crucial to gaining important knowledge at the heart of robotics development and its practical application in educational settings. An overview of the most cited literature in the area of educational robotics represents core publications and respected journals. The Journal of Robotic Surgery, with 1,576 citations, greatly contributes to developing robotic technologies relevant for educational purposes. Surgical Endoscopy, with 2,770 citations, makes a statement about its impact on robotic systems used in surgical education. The Journal of Surgical Education has 1,065 citations and provides key insights into the use of robotics in medical education. Other important sources include Advances in Intelligent Systems and Computing, Lecture Notes in Computer Science, and ACM International Conference Proceedings, each of which is crucial to gaining important knowledge at the heart of robotics development and its practical application in educational settings.

Table 4. Cited sources

Sources	TP	TC	CPP	Cite Score	SNIP	SJR	Publisher
Journal of Robotic Surgery	179	1576	8.8	4.2	1.126	0.661	Springer
Surgical Endoscopy	142	2770	19.5	6.1	1.551	1.12	Springer
Journal of Surgical Education	70	1065	15.2	5.6	1.219	0.903	Elsevier
Advances in Intelligent Systems and Computing	214	1071	5.0	0.9	0.373	0.215	Springer
Lecture Notes in Computer Science (including subseries)	167	912	5.5	2.6	0.59	0.606	Springer
Lecture Notes in Networks and Systems	110	66	0.6	0.9	0.282	0.171	Springer
ACM International Conference Proceedings	177	773	4.4	10	1.881	2.64	Association for Computing Machinery
CEUR Workshop Proceedings	60	141	2.4	1.1	0.235	0.19	CEUR-WS
Journal of Physics: Conference Series	51	239	4	1.2	0.18	0.303	IOP Publishing Ltd.
Communications in Computer and Information Science	51	117	3	1.1	0.246	0.203	Springer Nature
Proceedings of the International Astronomical Union	49	17	0	0.1	0.028	0.121	Cambridge University Press
Journal of Endourology	46	747	35	5.5	1.226	1.076	Mary Ann Liebert

3.8. Highly Cited Papers

Highly cited publications in educational highly cited publications in educational robotics give a name to the discipline and yield numerous innovative ideas and new developments, driving further research and practice. Important contributions address fundamental challenges, introduce innovative ways to use robotics in educational contexts, and report the outcomes of these efforts. In this case, the high number of citations indicates their significance in establishing core knowledge and guiding future research. Such sources can be analyzed to understand the major themes and trends capturing interest in the academic circle, which would shed light on the present situation and future of robotics education.

Table 5. Highly cited papers

Papers	Paper Titles	TC	TC per Year	Normalized TC
WAKABAYASHI G, 2015, ANN SURG	Recommendations for Laparoscopic Liver Resection: A Report from the Second International Consensus Conference held in Morioka	1103	110.3	48.19
LEA C, 2017, PROC - IEEE CONF COMPUT VIS PATTERN RECOGNITION, CVPR	Temporal Convolutional Networks for Action Segmentation and Detection	1049	131.13	60.44
BELPAEME T, 2018, SCI ROBOTICS	Social Robots for Education: A Review	889	127	46.93

POTKONJAK V, 2016, COMPUT EDUC	Virtual Laboratories for Education in Science, Technology, and Engineering: A Review	593	65.89	27.55
SHERIDAN TB, 2016, HUM FACTORS	Human-robot Interaction: Status and Challenges	450	50	20.91
MCEVOY MA, 2015, SCIENCE	Materials that Couple Sensing, Actuation, Computation, and Communication	443	44.3	19.35
CALKINS H, 2018, EUROPACE	2017 HRS/EHRA/ECAS/ APHRS/SOLAECE expert consensus statement on catheter and surgical ablation of atrial fibrillation	409	58.43	21.59
ATMATZIDOU S, 2016, ROB AUTOM SYST	Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences	381	42.33	17.7
BROADBENT E, 2017, ANNU REV PSYCHOL	Interactions with robots: The Truths We Reveal about ourselves	326	40.75	18.78
KEPUSKA V, 2018, IEEE ANNU COMPUT COMMUN WORKSHOP CONF, CCWC	Next-generation virtual personal assistants (Microsoft Cortana, Apple Siri, Amazon Alexa and Google Home)	316	45.14	16.68

3.9. Co-Occurrence Network

A co-occurrence network is a helpful tool in analyzing the relations between key terms and themes relevant to robotics education research. Such an approach will enable the realization of general patterns, outlining significant areas of research, and revealing collaborative connections in the literature by viewing the frequency of the co-occurrence of certain keywords. In this network, each node signifies a keyword or a theme. Its size defines its relevance to the field under analysis. Edge dimensions show the strength of the association between topics. Clusters of strongly linked nodes underline significant areas of research. Weaker links underline young or poorly explored topics. Figure 8's co-occurrence network provides an overview of the present state of the art of robotics in education, pointing out the key emergent trends and suggesting future lines of research.

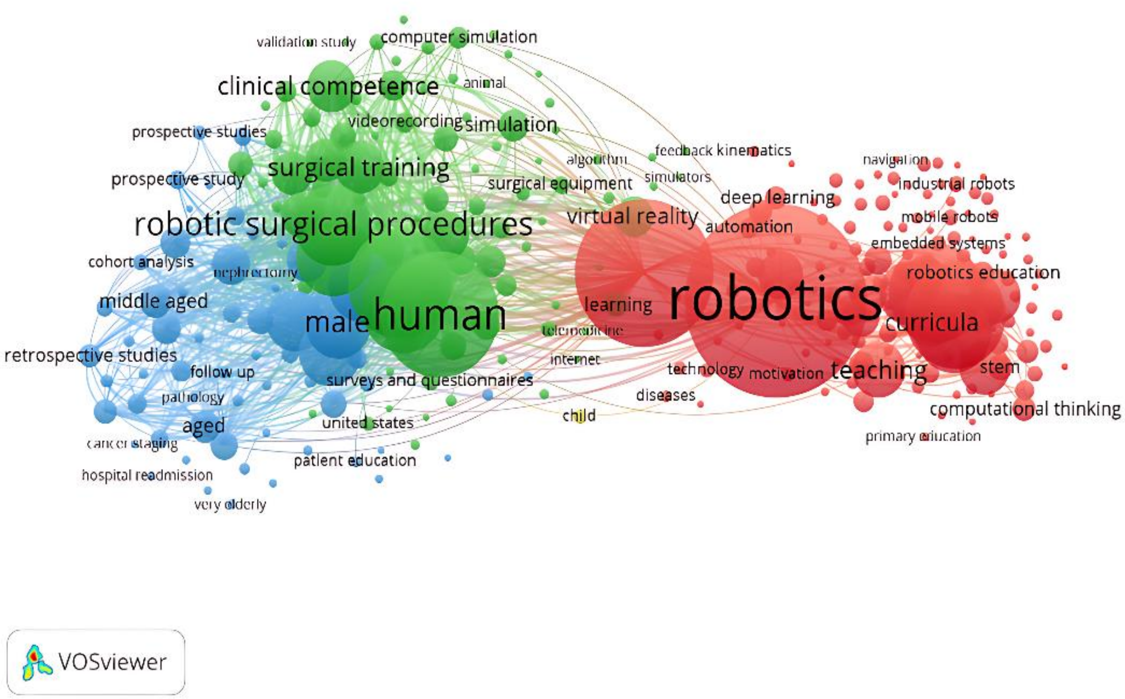

Fig. 8 Co-occurrence network

The map shows what is known and how topics are related, which eases new studies or collaborations from happening and, therefore, shapes the directions of further development. Moreover, from the viewpoint of network analysis, the detection of potential research gaps can be noticed, with underexplored research areas becoming evident. It also embodies the multidisciplinary nature of robotics in the learning environment, drawing artificial intelligence, pedagogy, and engineering to give a complete perspective on the subject. The given description will not only help researchers identify trends in the application domain but can also be used as a tool by educators and policymakers when developing effective robotics programs in educational settings.

4. Conclusion

This bibliometric review offers all-round insight into the growth trend within the field of robotics in education, pointing out a dramatic rise in both research involvement and interest over the last decade. The review shows that the United States, China, and the United Kingdom have been key players in driving innovation and laying out future research paths.

However, there is a major contribution gap based on regions such as Africa and parts of Asia, implying a need for greater global participation. Core themes, such as learning environments, STEM education, and educational robotics, demonstrate the focus on integrating robotics into educational curricula to enhance experiential learning and foster problem-solving skills. This shifting thematic focus indicates the beginning of a move toward more advanced approaches that align technological innovations with educational outcomes.

The research also identifies other key journals, including Surgical Endoscopy and Journal of Robotic Surgery, reflecting that much of the research in robotics is cross-disciplinary. While this analysis is informative, it is necessarily limited by the reliance on the Scopus database and a focus on quantitative indicators that might overlook the qualitative impact of research in the field of education. Mixed-method approaches in future studies will help counter these limitations and give more in-depth insights into the subject by integrating data from other sources.

Further insights concerning integrating robotics into educational settings, along with the consequences this has for pedagogy and learning, may be particularly advanced through qualitative research. Further, the geographical scope could be expanded to comparatively underrepresented areas to derive a more diversified and inclusive view of robotics education in classroom settings, bringing about more just educational practice at large worldwide. This bibliometric analysis will be of great value to researchers, teachers, and legislators interested in the topic of robots in education. In addition, it maps the current environment and underlines important trends, major contributors, and prospective research opportunities. If it is to grow in a direction set on guaranteeing that robots in education stay a vibrant and influential field, continuous analysis and reflection will be very vital.

4.1. Future Research Directions in Robotics Education

As education in robotics progresses, several emerging trends and new practices heavily impact the future of learning. However, several areas still have gaps to fill to ensure maximum utilization of robotics in educational settings. The following are some of the key areas with significant scopes for further research:

4.1.1. Emerging Trends in Robotics Education

Integrating Artificial Intelligence (AI) and Machine Learning (ML) into educationally oriented robotics systems is a vibrant frontier. Artificially intelligent robots can also cater to the individual learning styles of students through personalized and adaptive learning interactions. AI-driven investigations into how AI may improve robot-based learning are essential to developing intelligent systems for the heterogeneous requirements of learners. Cloud robotics platforms are also gaining traction, enabling remote control and collaborative learning environments, which became the focal point with the onset of the COVID-19 pandemic. Further investigation of the potential for cloud robotics to provide scalable and cost-effective learning solutions is warranted.

4.1.2. Innovative Practices in Curriculum Design and Pedagogy

A second area that is extremely well-suited for innovation is the creation of an interdisciplinary curriculum that successfully integrates robotics with other STEM fields, including mathematics, engineering, and computer science. Although some schools have already started introducing robotics into their curriculum, standard models are needed to inform teachers how to develop curricula that effectively integrate robotics with established education models.

Furthermore, Project-Based Learning (PBL) and maker-based education are being widely embraced as approaches that enable students to engage with robotics in real-world, hands-on applications. Future research on the effects of these instructional methods on students' engagement, learning outcomes, and retention in robotics education is needed.

4.1.3. Addressing Equity and Access Gaps

A significant gap in current research lies in exploring equity in robotics education. Although robotics has the potential to bridge digital divides, many schools still face barriers related to access to technology, qualified educators, and funding. Future studies should explore scalable solutions for providing equal access to robotics education across socio-economic groups, particularly in under-resourced areas. Moreover, research into adaptive technologies that ensure robotics education is inclusive of students with disabilities is essential to create more equitable learning environments.

4.1.4. Teacher Training and Professional Development

Although interest in the inclusion of robotics in educational settings is increasing, teachers usually are not sufficiently trained to provide instruction in robotics. There is a need to research professional development models of teachers aimed at robotics with a focus on follow-up support and hands-on training. Examining best practices for equipping instructors with the requisite skills and tools for teaching robotics at various levels of education will address this limitation.

4.1.5. Impact on Cognitive and Social Development

Though robotic education is commonly linked with the acquisition of technical competence, its prospective contribution to cognitive and social development is an almost unresearched area. In the future, research needs to explore the processes through which engagement with robotics affects students' problem-solving capacity, critical thinking, collaboration skills, and creativity. Additionally, studies should explore how robotics education helps develop soft skills such as communication and teamwork, essential for success in the 21st-century workforce.

4.1.6. Longitudinal Studies on Robotics Education Outcomes

Most current research focuses on short-term outcomes and immediate impacts of robotics education. However, longitudinal studies are needed to assess the long-term effects of robotics on students' academic trajectories, career choices, and readiness for future challenges. Investigating how early exposure to robotics education influences students' decisions to pursue STEM careers and the role it plays in shaping future educational pathways will provide valuable insights into its lasting impact.

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