

A ten-year retrospective (2014-2024): Bibliometric insights into the study of internet of things in engineering education

Zakiah Mohd Yusoff¹, Siti Aminah Nordin², Norhalida Othman², Zahari Abu Bakar², Nurlaila Ismail¹

¹Advanced Signal Processing Research Interest Group, Faculty of Electrical Engineering, Universiti Teknologi MARA, Selangor, Malaysia

²Faculty of Electrical Engineering, Universiti Teknologi MARA, Johor, Malaysia

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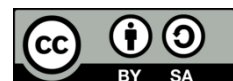
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ABSTRACT

This article presents a comprehensive ten-year retrospective analysis (2014-2024) of the evolving landscape of internet of things (IoT) studies within engineering education, employing bibliometric insights. The pervasive influence of IoT technologies across diverse domains, including education, underscores the significance of examining its trajectory in engineering education research over the past decade. Recognizing the dynamic nature of this intersection is crucial for educators, researchers, and policymakers to adapt educational strategies to IoT-induced technological shifts. Addressing this imperative, the study conducts a detailed bibliometric review to identify gaps, trends, and areas necessitating further exploration. Methodologically, the study follows a framework involving a comprehensive search of Scopus and Web of Science databases to identify relevant articles. Selected articles undergo bibliometric analysis using the Biblioshiny tool, supplemented by manual verification and additional analysis in Excel. This approach facilitates robust evaluation of citation patterns, co-authorship networks, keyword trends, and publication patterns over the specified timeframe. Anticipated outcomes include the identification of seminal works, key contributors, influential journals, and science mapping. The study aims to unveil emerging themes, track research trends, and provide insights into collaborative networks shaping IoT discourse in engineering education. This analysis offers a roadmap for future research directions, guiding educators and researchers toward fruitful avenues of exploration.

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Corresponding Author:

Zakiah Mohd Yusoff

Advanced Signal Processing Research Interest Group, Faculty of Electrical Engineering, Universiti Teknologi MARA

40450 Shah Alam, Selangor, Malaysia

Email: zakiah9018@uitm.edu.my

1. INTRODUCTION

Over the past decade, key trends in internet of things (IoT) research within engineering education have emerged, shaping the educational landscape. One significant trend is the integration of IoT into smart school systems, where web-based learning incorporates administrative services, service management, data analysis, and learning services, showcasing the potential of IoT to modernize the learning experience [1]–[4]. Another focal point has been the development of IoT industries, with research highlighting dominant IoT topics in diverse fields. This emphasizes the importance of considering the distribution of IoT across sectors when designing vocational education curricula [5]–[8]. The impact of intelligent environments implemented through IoT in university education has been extensively studied. Smart classrooms and intelligent environments positively influence various educational indicators, including motivation, participation,

interaction, satisfaction, and student attitude, underscoring IoT's potential to enhance teaching and learning in higher education institutions [9]–[12]. A noteworthy trend involves a shift towards hands-on learning and the reversal of traditional course sequences, exposing students to embedded systems and IoT early in their academic careers to improve motivation and learning through practical experience [13], [14]. The expansion of educational resources through IoT is evident in the development of databases like the sensor and electronics educational database (SEED). These databases support independent student learning by providing access to a broader range of electronic components and sensor technologies, extending educational resources beyond the confines of traditional classrooms or labs [3]. These trends underscore the increasing integration of IoT technology into various educational settings. The emphasis lies in modernizing the learning experience, enhancing practical learning, and preparing students for the challenges posed by the 4.0 industrial revolution [15], [16].

2. RELATED WORK

The incorporation of the IoT into engineering education has become a focal point of research in the last decade [17], [18]. This integration represents a dynamic and transformative intersection that harnesses cutting-edge technologies to not only enhance learning experiences but also foster innovation and equip students with the skills necessary for navigating the challenges of the modern engineering landscape [19]–[21]. The infusion of IoT technology into education caters to diverse learning styles by offering engaging and varied learning experiences. Specifically, integrating IoT into laboratory exercises provides students with practical exposure to embedded systems and IoT early in their academic journey. This hands-on approach is particularly advantageous for students who excel in tactile learning environments [14]. Moreover, the integration of IoT with web-based learning extends its benefits across various domains such as administrative services, service management, data analysis, and learning services [3], [14], [22], [23]. This comprehensive integration accommodates different learning preferences, ensuring a flexible and adaptive educational environment. Tailoring IoT applications to specific interests, such as environmental and sustainability issues, adds an extra layer of engagement. By integrating IoT into STEM education with a focus on these areas, students gain practical insights into monitoring and addressing environmental concerns. This approach provides a tangible application of engineering concepts within a context that resonates with environmentally conscious students [3], [24], [25]. Furthermore, IoT plays a crucial role in creating educational databases that support independent student learning [3], [25]. By offering access to a wider array of electronic components and sensor technologies, this approach is especially advantageous for students inclined towards self-directed learning [24], [26]. It empowers them to explore and experiment with diverse technologies, fostering a deeper understanding of IoT concepts and their practical applications [12].

A foundational study by [27]–[29] laid the groundwork by exploring the implications of IoT in educational settings. Their work emphasized the transformative potential of IoT technologies in enhancing hands-on learning experiences and fostering innovation within engineering education. Building upon this foundation, some existing studies contributed a pivotal piece that focused on the interdisciplinary nature of IoT integration. The study highlighted the role of IoT in fostering collaboration across disciplines, underscoring its importance in preparing students for the multifaceted challenges of the modern workforce [30]–[33]. Chen *et al.* [34] shifted the focus toward pedagogical aspects, investigating the impact of IoT on teaching methodologies. Their work underscored the potential for adaptive learning approaches and personalized education through the incorporation of IoT technologies, signaling a paradigm shift in educational strategies. In a notable contribution, existing work brought attention to the ethical considerations surrounding IoT in engineering education. The study underscored the importance of addressing ethical challenges related to data privacy, security, and responsible use of IoT technologies in educational contexts, adding a critical dimension to the evolving discourse [35]–[39]. This existing work encapsulates a decade of research, providing a comprehensive snapshot of the evolution of thought and scholarship surrounding IoT in engineering education.

In the realm of bibliometric insights into the study of the IoT in engineering education research trends, bibliometric studies conventionally cast a wide net, providing in-depth analyses of specific research domains. While numerous surveys, systematic mappings, and bibliometric studies have been undertaken in fields like IoT, this retrospective uniquely focuses on the intersection of IoT and engineering education. It addresses a significant gap by examining the evolution of research trends over the past decade and aims to unravel key insights into the integration of IoT within engineering education. The core objectives of this retrospective are outlined as follows:

- a. Develop and present an integrated methodology for conducting bibliometric analysis, encompassing data from established repositories such as Web of Science (WoS) and Scopus.
- b. Provide a detailed exposition of the data collection, cleaning, and integration processes integral to the proposed methodology.

- c. Evaluate the efficacy of the proposed methodology by applying it to conduct a bibliometric study on the trends and patterns within IoT research in engineering education.
- d. Employ a systematic approach to identify influential scholars, their affiliations, chosen keywords, and, significantly, establish connections between academic works. This analysis aims to illuminate the collaborative network and impact of key contributors to the field.
- e. Explore and delineate essential research trends within the intersection of IoT and engineering education, shedding light on the evolving landscape, and identifying areas that have garnered significant attention or require further exploration.

By addressing these research objectives, this retrospective not only contributes valuable bibliometric insights into the specific context of IoT applications in engineering education but also offers a comprehensive overview of the evolving research landscape in this domain over the specified ten-year period.

3. METHOD

3.1. Topic, scope, and eligibility

Bibliometrics, encompassing the consolidation, management, and analysis of bibliographic information sourced from scientific serves as a crucial methodology in this study [40], [41]. With a focus on top-tier publications, known for offering valuable insights into the theoretical perspectives shaping the evolution of the research domain, the study aimed to ensure data reliability by utilizing the Scopus and WoS databases for data collection [42]–[44]. This facilitated the retrieval of publications spanning from 2014 to January 2024 for subsequent analysis. Employing search strings, relevant articles were extracted to download the necessary data, as illustrated in Table 1. Scopus and WoS provide flexibility to download search results in various formats, such as CSV, Excel, and LaTeX. The obtained search results were downloaded and saved as a .bib file and BibTeX.

Table 1. Databases and corresponding search strings for retrieval

Database	Search terms
Scopus	TITLE-ABS-KEY ("internet of thing" AND "engineering education") AND PUBYEAR > 2013 AND PUBYEAR < 2025 AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACTKEYWORD, "Engineering Education") OR LIMIT-TO (EXACTKEYWORD, "Internet of Things"))
WoS	"Internet of thing" AND "engineering education" (Topic) and 2023 or 2022 or 2021 or 2020 or 2019 or 2018 or 2017 or 2016 or 2015 or 2014 (Publication Years) and English (Languages)

3.2. Screening

During the meticulous screening phase, a diverse array of potentially pertinent research materials underwent rigorous scrutiny to align with predefined research questions. The criteria employed at this pivotal screening juncture were intricately tied to the spheres of IoT, education, and engineering, ensuring meticulous selection of research items [45], [46]. This assessment adhered to distinct inclusion and exclusion criteria meticulously delineated in the study, as presented in Table 2. The primary criterion for inclusion revolved around literature in the form of research papers, serving as the cornerstone for deriving practical recommendations. This encompassed a broad spectrum, including reviews, meta-synthesis, meta-analyses, books, book series, chapters, and conference proceedings, all meticulously considered in this comprehensive study. Notably, the review focused exclusively on English-language publications, underscoring dedication to a thorough analysis concentrated on the years 2014 and 2024.

Table 2. The selection criterion is searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Timeline	2014 – 2024	< 2014
Literature type	All type	All type
Publication stage	Final	In press

3.3. Included

During this stage, duplicate papers were systematically removed from the initially retrieved list [47]. Employing the 'remove.duplicated' R command from the Bibliometrix package, duplicate records in the bibliographic data frame were meticulously purged, leading to the exclusion of 149 publications based on stringent duplication criteria as shown in Figure 1. In total, this culminated in a bibliometric analysis that involved 1816 documents, all subject to evaluation using Biblioshiny. The integration of data from Scopus

and WoS was executed seamlessly, utilizing the R package or Excel software with the aid of the 'combined.xlsx' code [48].

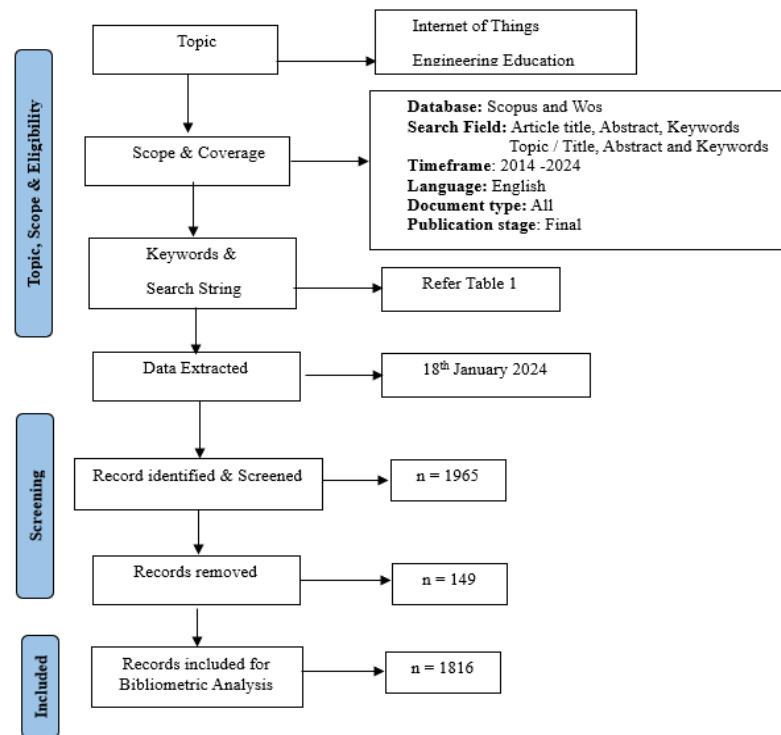


Figure 1. Framework on search methodology [49]

4. RESULTS AND FINDINGS

Table 3 presents a detailed overview of the dataset earmarked for bibliometric analysis. The study encapsulates a decade of scholarly output from 2014 to (January 2024), drawing from a diverse range of sources, including 894 journals, books, and other scholarly publications. The dataset, comprising 1,816 documents, stands as a rich and comprehensive source for bibliometric scrutiny. Noteworthy is the dataset's negative annual growth rate of -0.95%, suggesting a subtle decline in document production over the specified period, a trend meriting further investigation. The relatively low average age of documents (3.68 years) underscores the freshness and contemporaneity of the dataset, emphasizing its relevance. Impressively, the average citations per document stand at 10.76, indicative of the substantial impact and influence of the compiled works within the scholarly community. A deep dive into the dataset's vocabulary reveals 8590 keywords plus (ID), highlighting a nuanced exploration of topics and themes. Similarly, 4,387 author's keywords (DE) contribute to the granularity of the analysis, reflecting a diverse set of terms employed by authors. With 5,087 unique authors and 223 authors of single-authored documents, the dataset reflects both collaborative and individual scholarly contributions. The presence of 249 single-authored documents underscores the significance of individual authorship within the dataset. In essence, Table 3 provides a robust foundation for rigorous bibliometric analysis, promising valuable insights into academic trends, collaborative efforts, and the impact of research over the specified timespan.

Table 3. Overview dataset for bibliometric analysis

Description	Results	Description	Results
Timespan	2014:2024	Author's keywords (DE)	4,387
Sources (Journals and Books)	894	Authors	5,087
Documents	1816	Authors of single-authored docs	223
Annual growth rate %	-0.95	Single-authored docs	249
Document average age	3.68	Co-authors per doc	3.61
Average citations per doc	10.76	International co-authorships %	4.681
Keywords Plus (ID)	8,590		

4.1. Annual scientific production

Figure 2 illustrates the yearly citation framework and Figure 3 the average number of total citations received. Meanwhile, Table 4 presents a comprehensive overview of the average citations per year for the period 2014 to 2024. Throughout the years, the number of articles (N) varies, ranging from 20 to 352. The mean total citation (TC) per article provides insights into the average impact of each article, with values fluctuating between 0.8 and 24.79. Notably, the mean TC per year reflects the average number of citations an article receives annually, showcasing variations from 0.58 to 4.07. The Citable Years column indicates the decreasing number of years each article is considered citable. In the earlier years, from 2014 to 2018, the dataset reveals a generally increasing trend in both mean total citation per article and mean TC per year, suggesting a growth in the impact of the publications. However, from 2019 onwards, there is a noticeable decline, indicating a shift in the citation patterns. Table 4 provides a valuable snapshot of the citation dynamics over the specified timeframe, offering insights into the temporal evolution of the impact of the articles in the dataset.

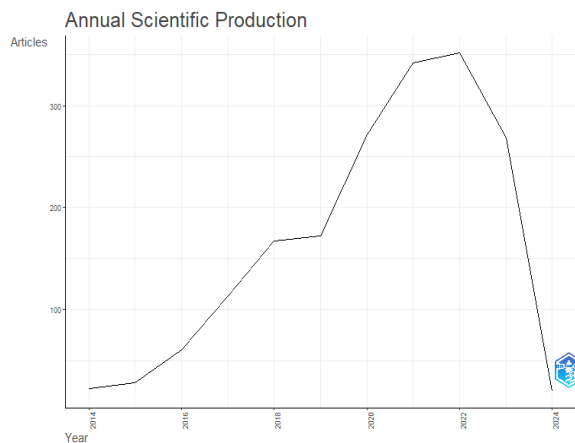


Figure 2. Annual scientific production

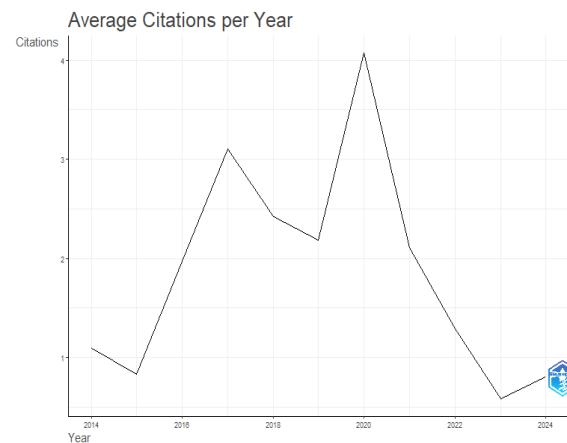


Figure 3. Average citations per year

Table 4. Average citations per year (2014 – 2024)

Year	Number of articles (N)	Mean total citation TC per article	Mean TC per year	Citable years
2014	22	12	1.09	11
2015	28	8.32	0.83	10
2016	60	17.72	1.97	9
2017	113	24.79	3.1	8
2018	167	16.93	2.42	7
2019	172	13.05	2.18	6
2020	272	20.36	4.07	5
2021	342	8.43	2.11	4
2022	352	3.86	1.29	3
2023	268	1.16	0.58	2
2024	20	0.8	0.8	1

4.2. Most relevant sources

Table 5 offers a thorough examination of the top 10 most influential sources for articles on the IoT in engineering education. The ASEE Annual Conference and Exposition, Conference Proceedings lead the list with 89 articles, establishing itself as a consistent and significant contributor to the discourse. Following closely, the ACM International Conference Proceeding Series boasts 51 articles, reaffirming its pivotal role in research dissemination within this domain. Lecture Notes in Computer Science, encompassing subseries in Artificial Intelligence and Bioinformatics, emerges as a crucial scholarly source with 50 articles, reflecting a diverse exploration of IoT in engineering education. Noteworthy is the Proceedings of the 3rd International Conference on Emerging Technologies in Computer Engineering: Machine Learning and Internet of Things (ICETCE 2020), contributing 43 articles and highlighting a focused exploration of key themes. The Advances in Intelligent Systems and Computing series, IEEE Global Engineering Education Conference (EDUCON), and IEEE Access each play significant roles, with 42, 35, and 30 articles, respectively, showcasing their commitment to advancing understanding in this field. Additionally, the Journal of Physics:

Conference Series, Sensors, and Communications in Computer and Information Science contribute 30, 26, and 19 articles, respectively, offering specialized perspectives within IoT in engineering education. This comprehensive overview underscores the interdisciplinary nature of the field, with each source making distinctive contributions to the collective knowledge base, providing a nuanced understanding of research dynamics in IoT education within the engineering domain.

Table 5. Top 10 most relevant sources

Sources	Articles
ASEE Annual Conference and Exposition, Conference Proceedings	89
ACM International Conference Proceeding Series	51
Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	50
Proceedings Of 3rd International Conference on Emerging Technologies in Computer Engineering: Machine Learning and Internet of Things, ICETCE 2020	43
Advances In Intelligent Systems and Computing	42
IEEE Global Engineering Education Conference, Educon	35
IEEE Access	30
Journal Of Physics: Conference Series	30
Sensors	26
Communications In Computer and Information Science	19

Table 6 presents a comprehensive analysis of the top 10 journals in the field, providing a detailed examination of their h, g, and m indices, as well as total citation counts derived from both Scopus and WoS. These metrics serve as critical indicators of a journal's impact, influence, and the scope of its scholarly contributions. The IEEE Global Engineering Education Conference, Educon, stands out with an impressive h-index of 12, g-index of 18, and an m-index of 1.091, accompanied by a substantial total citation count of 390. This underscores its significance as a key player in the academic landscape since 2014, with a consistent publication output. Engineering journal follows closely with an h-index of 11, g-index of 14, and an m-index of 1.375, supported by a substantial total citation count of 2,544. This journal has made a substantial impact since its inception in 2017, with a notable number of publications. IEEE Access, with an h-index of 10, g-index of 30, and an m-index of 1.667, demonstrates a strong presence since 2019, contributing significantly with a total citation count of 1,137. The Proceedings of the 3rd International Conference on Emerging Technologies in Computer Engineering: Machine Learning and Internet of Things, ICETCE 2020, also stands out with noteworthy indices and a growing influence since 2020. Sensors, ACM International Conference Proceeding Series, and ASEE Annual Conference and Exposition, Conference Proceedings exhibit distinctive characteristics, each contributing uniquely to the scholarly landscape. Additionally, Computer Applications in Engineering Education, IEEE Internet of Things Journal, and Procedia Computer Science complete the top 10 list, showcasing their respective indices and citation counts.

Table 6. Top 10 journals, presenting their h, g, and m indices along with total citation counts derived from Scopus and WoS

Element	h_index	g_index	m_index	TC	NP	PY_start
IEEE Global Engineering Education Conference, Educon	12	18	1.091	390	35	2014
Engineering	11	14	1.375	2544	14	2017
IEEE Access	10	30	1.667	1137	30	2019
Proceedings Of 3rd International Conference on Emerging Technologies in Computer Engineering: Machine Learning and Internet of Things, ICETCE-2020	9	16	1.8	339	43	2020
Sensors	8	12	1	183	26	2017
ACM International Conference Proceeding Series	7	10	0.7	146	51	2015
ASEE Annual Conference and Exposition, Conference Proceedings	7	7	0.636	137	89	2014
Computer Applications in Engineering Education	7	9	0.875	86	14	2017
IEEE Internet of Things Journal	7	12	0.875	670	12	2017
Procedia Computer Science	7	11	0.875	249	11	2017

4.3. Top authors

Table 7 presents an in-depth analysis of the top 10 most productive authors. The prolific author Zhang Y leads the list with 17 articles, reflecting a substantial and consistent contribution to the scholarly discourse. Following closely are Li X with 16 articles and Wang Y with 15 articles, highlighting their

significant roles in advancing knowledge in this domain. Noteworthy is the fractionalized measure, which assesses the average number of articles each author contributes, providing a more nuanced understanding of their individual impact. Authors Wang X, Wang J, and Zhang L showcase impressive productivity with 14, 13, and 13 articles, respectively. The list continues with Liu Y, Li L, Li Z, and Yang Y, each contributing 13 to 12 articles, indicating a diverse group of highly productive scholars in the field. This comprehensive analysis not only highlights the quantity of publications but also emphasizes the fractionalized perspective, offering a more refined assessment of each author's scholarly output.

Table 7. Top 10 most productive authors

Authors	Articles	Articles fractionalized
Zhang Y	17	3.95
Li X	16	3.75
Wang Y	15	6.40
Wang X	14	6.79
Liu Y	13	4.04
Wang J	13	5.77
Zhang L	13	4.05
Li L	12	3.39
Li Z	12	3.57
Yang Y	12	4.43

4.4. Top affiliation and countries

Table 8 highlights a number of most relevant institutions that have produced a significant portion of the most relevant publications. These include King Saud University, University of Naples Federico II, Amity University, Tecnológico de Monterrey, Texas A&M University, Indian Institute of Information Technology, Nanyang Technological University, Zhejiang University, Arizona State University, and NOT REPORTED (presumably representing unaffiliated authors or a collective of institutions). This suggests that these institutions are playing a leading role in shaping the field and driving the research agenda. King Saud University, University of Naples Federico II, and Amity University emerged as standout contributors with 11 and 10 articles, respectively. Additionally, Tecnológico De Monterrey, Texas A&M University, Indian Institute of Information Technology, Nanyang Technological University, Zhejiang University, and Arizona State University all exhibited substantial research outputs, solidifying their positions as influential contributors to high-impact journals. The data shows a diverse geographical spread of institutions, with representation from countries across Asia, North America, Europe, and South America. This reflects the global nature of research in IoT engineering education and the increasing international collaboration in this field.

Table 8. Most relevant affiliation

Affiliation	Articles	Affiliation	Articles
Not reported	12	Texas A & M University	10
King Saud University	11	Indian Institute of Information Technology	9
University Of Naples Federico II	11	Nanyang Technological University	9
Amity University	10	Zhejiang University	9
Tecnologico De Monterrey	10	Arizona State University	8

Table 9 shows the most productive corresponding author's countries. The presented data highlights the number of articles, single-country publications (SCP), multi-country publications (MCP), frequency, and the MCP ratio for the top ten most prolific corresponding author's countries. Leading the list is China, demonstrating remarkable research productivity with 341 articles. Notably, China also holds a substantial number of SCP, indicating a robust national research effort. The MCP ratio for China is 0.038, suggesting a moderate collaboration level on the international stage. The United States follows closely with 114 articles, showcasing a balanced distribution between SCP and MCP. The MCP ratio for the USA is 0.053, indicating a relatively higher proportion of international collaboration compared to China. India, with 109 articles, demonstrates a significant research output. The SCP and MCP distribution are noteworthy, and the MCP ratio is 0.018, showcasing a moderate level of international collaboration. Germany, Spain, and Korea exhibit varying degrees of research productivity, with Germany leading in MCP ratio at 0.163, reflecting a strong tendency towards international collaboration. Spain and Korea also contribute significantly to the field, demonstrating unique research strengths. Italy, Mexico, Australia, and Brazil round out the top ten, each making substantial contributions. Italy's higher MCP ratio of 0.16 emphasizes a pronounced commitment to

collaborative research. This information is crucial for shaping future research directions and fostering international cooperation in advancing IoT studies in engineering education.

Table 9. Top 10 most productive corresponding author's countries

Country	Articles	SCP	MCP	Freq	MCP_Ratio
China	341	328	13	0.188	0.038
USA	114	108	6	0.063	0.053
India	109	107	2	0.06	0.018
Germany	43	36	7	0.024	0.163
Spain	29	27	2	0.016	0.069
Korea	27	27	0	0.015	0
Italy	25	21	4	0.014	0.16
Mexico	25	22	3	0.014	0.12
Australia	23	22	1	0.013	0.043
Brazil	23	22	1	0.013	0.043

Another intriguing aspect involves pinpointing the countries that have contributed citations to the field of IoT in engineering education over the last decade. This analysis is elaborated upon in Table 10. China emerges as the leading country in terms of total citations, amassing a substantial 3,480 citations. With an average article citation of 10.20, this underscores both the quantity and impact of Chinese contributions to the field. The United States follows closely, with 1,623 total citations and an impressive average article citation of 14.20. The high average suggests that American research in IoT and engineering education tends to be particularly impactful. New Zealand, while ranking third in total citations with 1,240, stands out with an exceptionally high average article citation of 310.00. This outlier figure suggests that New Zealand's contributions, though numerically fewer, are highly influential and widely recognized. Turkey and India, with 1,075 and 966 total citations respectively, exhibit notable impact, each with a unique average article citation. Turkey's average of 134.40 reflects a strong influence per article, while India's 8.90 indicates a larger body of work with relatively lower average impact. The United Kingdom, Pakistan, Korea, Germany, and Austria round out the top ten most cited countries, each making significant contributions to the field. Notably, Austria stands out with a high average article citation of 35.30, emphasizing the substantial impact of Austrian research.

Table 10. Most cited countries

Country	TC	Average article citations	Country	TC	Average article citations
China	3,480	10.20	United Kingdom	805	35.00
USA	1,623	14.20	Pakistan	797	113.90
New Zealand	1,240	310.00	Korea	640	23.70
Turkey	1,075	134.40	Germany	629	14.60
India	966	8.90	Austria	424	35.30

4.5. Keywords analysis

The foremost keyword as shown in Figure 4, "Engineering Education," surfaces a staggering 1,388 times, reflecting the overarching emphasis on the educational paradigm within the engineering community. As we delve deeper into the fabric of IoT integration, "internet of things" itself stands out prominently with 1,080 occurrences, signifying the increasing recognition and exploration of this transformative technology within the educational context. A notable theme that arises from this bibliometric analysis is the pivotal role of students in this evolving landscape, as indicated by the keyword "students," which occurs 349 times. This underscores the growing importance of tailoring educational approaches to align with the needs and expectations of the student body in the era of IoT. Furthermore, "learning systems" and "machine learning" are represented with 271 and 219 occurrences, respectively, highlighting the integration of cutting-edge technologies in educational methodologies. The synergy of technological advancements is evident in the prevalence of "artificial intelligence" (216 occurrences) and "deep learning" (208 occurrences) as keywords, emphasizing the intertwining of these sophisticated concepts with IoT in engineering education. As curricula adaptation is crucial for staying abreast of technological shifts, "curricula" emerges as a keyword with 159 occurrences, reflecting the dynamic changes in educational frameworks to accommodate IoT and related technologies. Findings also spotlight the role of educators and pedagogical approaches, with "Teaching" appearing 150 times. This emphasizes the continuous need for innovative instructional methods to effectively impart knowledge related to IoT in engineering education.

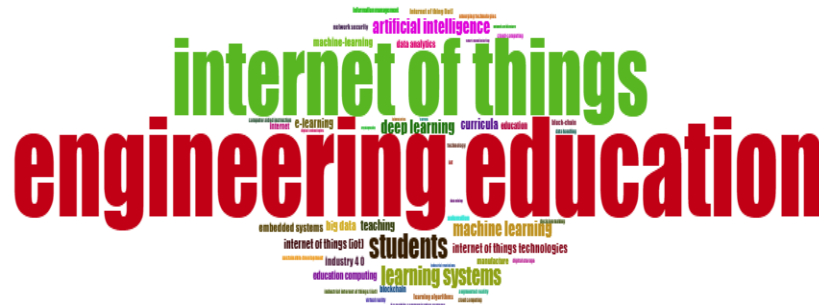


Figure 4. Wordcloud of IoT in engineering education

4.6. Conceptual structure

The main issues and patterns in the research are the focus of the conceptual framework. As shown in Figure 5, the co-occurrence network is created using the Walktrap algorithm [50], and normalization is accomplished using the association approach. Words that occur together in a document are linked together in a network, forming a conceptual structure that facilitates understanding different research field themes and the problems that go along with them. This approach also highlights how studies have changed throughout time. The co-occurrence network in Figure 5 shows how research on IoT has developed. Each network node in this depiction represents a term or research topic, and its size corresponds to its degree. The graphic consists of a network of circles and lines. The lines connecting the circles and the text boxes suggest that there is a strong relationship between engineering education and IoT. Engineering education provides the skills and knowledge that are needed to develop and implement IoT applications. The IoT, in turn, provides a platform for engineers to apply their skills and knowledge to solve real-world problems.

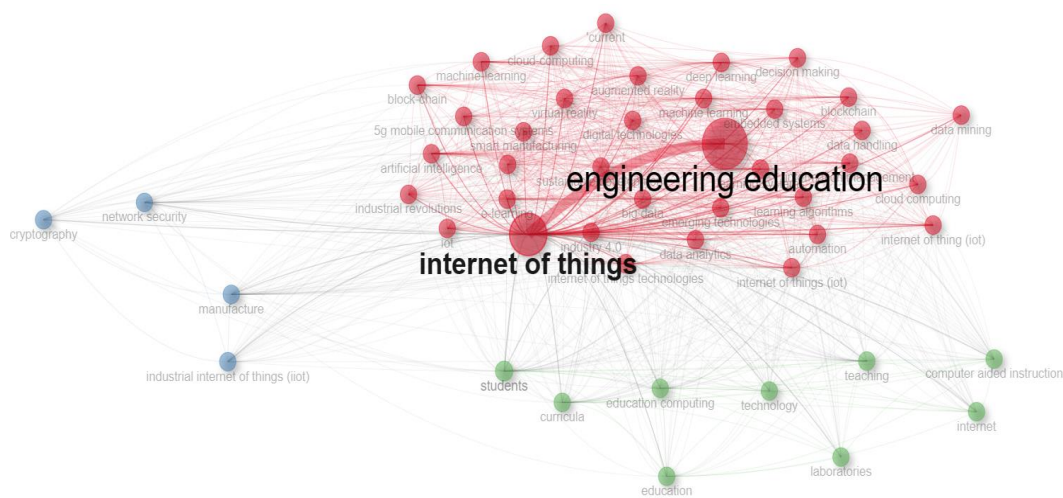


Figure 5. Co-occurrence network

4.7. Social structure

The social structure illustrates the connections among various research entities, encompassing authors or institutions. The prevalent form of social structure commonly employed is the co-authorship network [51]. This network serves the purpose of identifying consistent and impactful groups of authors and pertinent institutions within any given research domain. Table 11 portrays the co-authorship network for research related to the area under study. The metrics of Betweenness, Closeness, and PageRank offer valuable insights into the centrality and influence of each node within the network. Li Z, with a Betweenness value of 45.60, emerges as a pivotal figure in connecting disparate clusters, signifying a substantial role in facilitating knowledge flow within the community. Wang H, characterized by a Closeness value of 0.0141, exhibits a high level of proximity to other researchers, suggesting a central position in the information exchange network. Furthermore, the PageRank values assign importance to each node based on its

connectivity and influence. Wang H again stands out with a PageRank of 0.0374, emphasizing the substantial impact of their contributions in shaping the discourse on IoT in Engineering Education. These metrics collectively underscore the collaborative dynamics and influential roles played by researchers such as Li X, Wang Y, and Li Z in steering the trajectory of this research domain.

Table 11. Collaboration network

Node	Cluster	Betweenness	Closeness	PageRank
Li X	1	40.1716	0.0133	0.0316
Wang Y	1	34.8235	0.0135	0.0320
Li Z	1	45.6014	0.0135	0.0323
Yang Y	1	23.8829	0.0133	0.0271
Chen Y	1	11.0195	0.0127	0.0228
Zhang X	1	17.9981	0.0127	0.0239
Chen J	1	8.3482	0.0132	0.0188
Wang H	1	35.3679	0.0141	0.0374
Li Y	1	26.5692	0.0133	0.0264
Zhang J	1	4.8240	0.0122	0.0183

The collaborative network map as shown in Figure 6 portrays impactful partnerships between countries, revealing intriguing patterns of knowledge exchange and cooperative efforts. Notable collaborations include Austria and Switzerland, Belgium and Belarus, as well as Brazil's collaborations with Canada, Costa Rica, and Portugal. These partnerships underscore the transnational nature of IoT research, emphasizing the importance of global cooperation in advancing knowledge and practices within Engineering Education. The collaborations between Canada and Ecuador, as well as Canada and Thailand, highlight the diverse and expansive reach of collaborative efforts in this research domain. Furthermore, the interactions between China and Belgium, China and Malaysia, and China and Russia illustrate the broad scope of international collaboration, transcending geographical boundaries to enhance the collective understanding of IoT in engineering education. The findings from this collaborative world map not only provide insights into the interconnectedness of nations in IoT research but also contribute valuable information for policymakers, researchers, and educators seeking to foster a globally collaborative environment. These collaborative patterns lay the foundation for a more comprehensive and diverse approach to addressing the challenges and opportunities presented by IoT in engineering education.

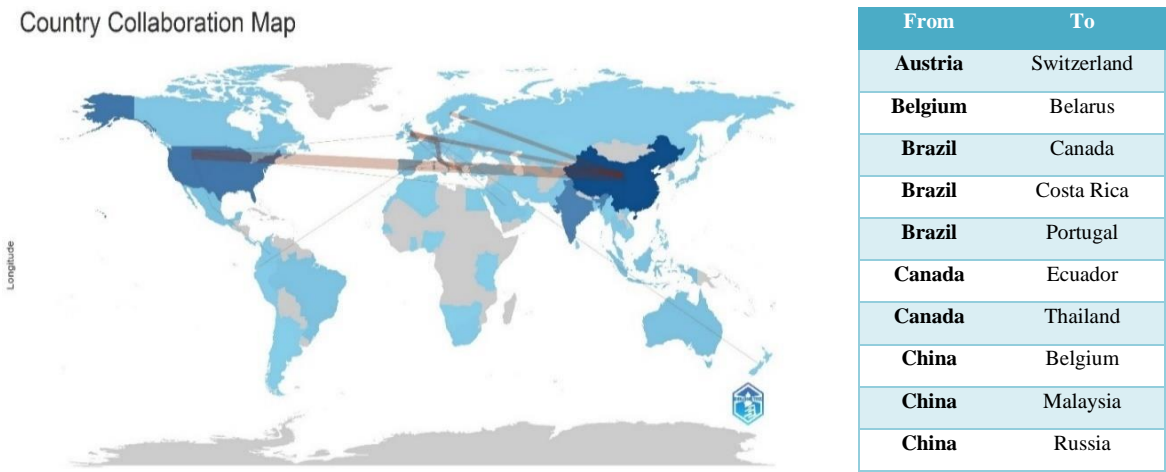


Figure 6. Country collaboration map

5. CONCLUSION

In summary, the comprehensive analysis of a decade's worth of scholarly output on the IoT in engineering education reveals a nuanced landscape. Despite a slight decline in document production over the years, the dataset remains relevant and impactful, with a relatively low average document age and a high average citation per document. The study highlights key contributors and trends, showcasing an interdisciplinary field with diverse perspectives. The temporal analysis of citation dynamics indicates a

noteworthy shift in patterns, with an initial growth in impact from 2014 to 2018 followed by a decline from 2019 onwards. This suggests evolving trends in the scholarly discourse. Notably, top sources like ASEE Annual Conference and Exposition, Conference Proceedings, ACM International Conference Proceeding Series, and IEEE Global Engineering Education Conference (Educon) play pivotal roles in shaping the field. Examining the top journals further reinforces the impact of specific publications, with IEEE Global Engineering Education Conference (Educon), Engineering journal, and IEEE Access standing out for their consistent output and influence.

The analysis of prolific authors, including Zhang Y, Li X, and Wang Y, highlights both the quantity and quality of their contributions. Integration of overall article count, and total citations reveals a growing interest in IoT engineering education over the decade, with a small group of authors significantly influencing the field. The examination of authors' local impact, considering h-index, g-index, and m-index, identifies key contributors such as Li X, Zhang L, and Mohammadian H. Institutions like King Saud University and the University of Naples Federico II play pivotal roles in shaping the field globally. The diverse range of influential institutions reflects the international nature of research in IoT engineering education. The analysis of corresponding author's countries showcases global collaboration, with China, the United States, and India leading in research productivity. Additionally, the examination of citation impact by country emphasizes the substantial contributions of China, the United States, New Zealand, Turkey, and India, providing valuable insights for future research directions and fostering international cooperation in advancing the field.

The analysis of keyword occurrences reveals a pronounced emphasis on "Engineering Education," signaling its central role within the engineering community. The growing recognition and exploration of the "internet of things" and the thematic prominence of "students" underscore the evolving landscape, emphasizing the importance of adapting educational approaches to meet the needs of students in the IoT era. The conceptual framework, depicted through co-occurrence networks and thematic maps, elucidates the interconnectedness between engineering education and IoT. It highlights the symbiotic relationship, where engineering education equips individuals with skills for IoT applications, and the IoT, in turn, provides a platform for real-world problem-solving. The thematic map underscores key themes such as "students," "curricula," and "teaching," reflecting the dynamic nature of the field.

The social structure analysis through co-authorship networks identifies influential researchers like Li X, Wang Y, and Li Z, showcasing their collaborative prominence and influential roles within the IoT in Engineering Education research community. The collaborative network map illustrates impactful partnerships between countries, emphasizing the transnational nature of IoT research and the importance of global cooperation. Collectively, these findings contribute to a comprehensive understanding of the evolving landscape, thematic trends, and collaborative dynamics in IoT engineering education. This knowledge is valuable for educators, researchers, and policymakers, providing insights to adapt curricula, foster global collaboration, and navigate the challenges and opportunities presented by IoT in engineering education.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Zakiah Mohd Yusoff	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Siti Aminah Nordin						✓		✓		✓		✓		
Norhalida Othman	✓						✓			✓	✓		✓	✓
Zahari Abu Bakar								✓		✓	✓		✓	
Nurlaila Ismail					✓		✓			✓		✓		✓

- C : Conceptualization
- M : Methodology
- So : Software
- Va : Validation
- Fo : Formal analysis
- I : Investigation
- R : Resources
- D : Data Curation
- O : Writing - Original Draft
- E : Writing - Review & Editing
- Vi : Visualization
- Su : Supervision
- P : Project administration
- Fu : Funding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY




Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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BIOGRAPHIES OF AUTHORS

Zakiah Mohd Yusoff    received the B.Eng. in electrical engineering and Ph.D. in electrical engineering from Universiti Teknologi MARA (UiTM), in 2009 and 2014, respectively. She is currently an associate professor at Electrical Engineering Studies, College of Engineering, Universiti Teknologi MARA (UiTM) Pasir Gudang, Malaysia. Her major interests include process control, system identification, and essential oil extraction system. She can be contacted at email: zakiah9018@uitm.edu.my.






Siti Aminah Nordin    is a distinguished senior lecturer currently affiliated with UiTM Pasir Gudang. She earned both her master's and Ph.D. degrees in electrical engineering from UiTM Shah Alam in 2014 and 2022, respectively, showcasing her commitment to academic excellence. With a specialized focus in the realm of electrical engineering, her research interests are notably centered around microwave filters, antennas, and electromagnetic wave area. She can be contacted at email: sitia181@uitm.edu.my.






Norhalida Othman    is a senior lecturer currently affiliated with UiTM Pasir Gudang. She earned her master's degree in engineering (Electrical-Power) from Universiti Teknologi Malaysia (UTM). With a specialized focus in the realm of electrical engineering, her research interests are notably centered around renewable energy and power system. She can be contacted at halida8142@uitm.edu.my.



Zahari Abu Bakar    is a senior lecturer in the Electronics Department at Universiti Teknologi MARA (UiTM), Johor Branch, Pasir Gudang Campus. He holds a Diploma in Electrical Engineering (Electronics) from UiTM Pulau Pinang, a Bachelor of Electrical Engineering (Hons), and an MSc. in telecommunication and information engineering from UiTM Shah Alam. His primary research interests include e-learning and machine learning. He can be contacted at email: zahar311@uitm.edu.my.



Nurlaila Ismail    received the M.Sc. and Ph.D. degrees in electrical engineering from Universiti Teknologi MARA (UiTM), Malaysia. She is currently an associate professor at School of Electrical Engineering, College of Engineering, Universiti Teknologi MARA (UiTM) Shah Alam, Malaysia. Her research interests include advanced signal processing, machine learning, and artificial intelligence. She can be contacted at email: nurlaila0583@uitm.edu.my.