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A Knowledge Map of Knowledge Engineering Scientific Products from 2011 to 2021 on Web of Science: Scientometrics

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ABSTRACT

Drawing a knowledge map of scientific productivity in the field of knowledge engineering in the 2011-2021 period on Web of Science. This was an applied descriptive-analytical study using a quantitative research design. The research population consisted of all scientific products in the field of knowledge engineering, which included 7724 documents published in indexed journals on the Web of Science database in the 2011-2021 period. The data were analyzed in Excel. VOSviewer was used for constructing the bibliometric networks of researchers, institutions, and countries, Histcite was used for obtaining information through scientometrics methods, and Gephi was used for obtaining betweenness centrality, degree centrality, and eigenvector centrality. Xu, Yang from Beijing University of Science and Technology had the most collaboration with other researchers by publishing 69 documents in the field of knowledge engineering. Two Chinese universities were ranked in the first and second place and two Iranian universities were in the third and fourth place. Studies on Knowledge Engineering began in the US, the UK, Japan, France, and Australia in the 2010-2012 period. Meanwhile, publications in this field have been pursued with more intensity by China, Iran, Spain, and Russia since 2014. The findings indicate that many researchers are working in the field of knowledge engineering, with the Chinese researchers being the most active compared to other countries. Meanwhile, Asian countries seem to be more involved in this field. Furthermore, most of the journals of knowledge engineering were conference journals.

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1. Introduction

The world of public and private organizations and institutions has experienced significant transformations over the past two decades. Rapid technological advances, globalization, improved service quality, and a shortage of skilled workforce have created a fiercely competitive environment among organizations. Achieving success in such a competitive environment entails capitalizing on new resources and methods. Therefore, researchers have proposed new approaches through which knowledge and information technology are regarded as key organizational resources for creating a sustainable competitive edge (Musivand & Faraziani, 2015).

Knowledge management originates from the field of knowledge engineering, which involves the creation and development of knowledge-based or expert systems. Knowledge engineering emerged in the 1960s and 70s and attracted market and business attention in the early 80s. Knowledge engineering gave birth to artificial intelligence and shifted its attention to creating a computer program that simulated the behavior of experts in different disciplines. The process of knowledge engineering encompasses the identification, representation, coding, testing, and assessment of specialized knowledge. For instance, a knowledge base includes a collection of facts and interpretations of known knowledge activities. The disciplines of knowledge management and knowledge engineering overlap to a certain degree (Hassanzadeh, 2013).

Knowledge engineering has a life cycle similar to knowledge management. Knowledge engineering, like knowledge management, includes subjective and objective knowledge with an emphasis on the identification of subjective knowledge. In knowledge engineering, it is essential to first locate and identify expertise. Then, after collecting and selecting knowledge, it is represented based on the rules and different forms of knowledge representation. This process is similar to the classification of knowledge management—also called ontology in knowledge engineering—based on which a knowledge engineering system is established with knowledge management. Once knowledge is represented, it must be coded within the software and then assessed. Meanwhile, knowledge retrieval can provide access to deleted knowledge, thus restarting the knowledge engineering cycle (Hassanzadeh, 2013).

Knowledge engineering evolves alongside expert systems. Individuals or organizations faced with issues and problems generally make decisions and perform tasks based on their knowledge. Expert systems are made up of two main components; (1) a knowledge base that includes knowledge extracted from an expert in the respective field involving encrypted facts, rules, and relations, and (2) an interface that can aptly extract this knowledge. Knowledge engineering is now seen as a modeling activity limited only by the capacity and power of computers.

A knowledge system is a system that solves practical problems through knowledge about its scope and application. Whereas, an expert system is a specific state of the knowledge system that can only solve problems matching its existing knowledge base. That is, it finds a suitable solution by searching in its database and using techniques such as problem-solving to produce procedural knowledge, knowledge presentation methods, and case studies. These systems are called "knowledge-based systems" that can support knowledge engineering and management experts as agents with diagnostic planning. In the architecture of knowledge-based systems, the knowledge engineer acts as the interface between the discipline and the system that responds to user needs through knowledge base inquiries. A role that can only be used alongside other tasks defined in such an architecture (Money, McWorth, & Goebbels, 1998).

Knowledge engineering is not just a systematic method to attain and apply expert knowledge on implementing knowledge systems. Rather, it involves creating different aspects of human knowledge patterns, which generates a set of technical principles to access methods for acquiring and representing knowledge and assessing and developing knowledge systems. The importance of knowledge engineering has lately skyrocketed in management due to advances in decision making and undertaking, identification and management of invisible organizational assets, increasing innovations, and improved product quality of the knowledge system (Mahdi Feizi: class lecture notes).

Price proposed the study of science using scientific methods approximately 40 years ago. Since then, various techniques have been developed for analyzing publication data through scientometric research. Scientific documents offer one of the best ways for learning about the latest research and findings in any scientific field. Journal articles and conference papers comprise the main channel for publishing the results of knowledge management research (Bradford, 2013).

One of the key trends in scientometrics is studying the structure of science and its dynamics. Moreover, an effective way to efficiently represent the state of science is using knowledge maps. A knowledge map makes it possible to identify the sources and direction of knowledge trends as well as its limitations and gaps while providing the necessary information about each sub-area to research managers by identifying its main areas. The scientific fields in these maps are characterized by the level of scientific activity by their scholars, and the empty spaces indicate the less-explored or unknown fields of science. This makes it possible to monitor the growth, integration, or partition of different scientific fields over time (Norouzi Chakli, 2011).

The increasing number of scientific publications in the past few centuries has further exposed the need for exploring the process of scientific development. One of the methods of examining the amount of scientific production and mapping the structure of sciences is scientometrics, which particularly involves reviewing international indexes and abstracts (Okhoti et al., 2013).

1-1. Concept of Knowledge Map

A knowledge map is a visual representation of knowledge about knowledge. It helps to identify knowledge sources and knowledge structures by visualizing the structural links and elements of applied disciplines. It is made up of a knowledge base that stores a set of applied domains. Each domain has a hierarchical structure called a concept map with a small number of levels. Each level in this structure consists of a list of knowledge mapping nodes that represent the knowledge extracted from information sources within distributed systems. Knowledge maps not only help to identify sources of knowledge and information, but also situate them in the relations between the concepts of the application area.

According to Hao et al. (2014), a knowledge map is a technology aiding the knowledge representation, which shows the primary relationships between knowledge resources in different domains of the organization using graphs and helps to identify knowledge resources, create knowledge, and promote knowledge sharing in the organization; while also detecting, visualizing, and retrieving information, supporting strategic decisions, and re-engineering business processes.

1-2. Scientific maps: an efficient tool for visualizing academic and scientific information

In today's world, information visualization through the graphical representation of social networks is a conventional technique that illustrates the intellectual relationships and structure of scientific knowledge. This new approach not only makes it possible to analyze traditional fields but also provides a key tool for investigating the interaction and evolution of sciences about other disciplines and specialties. This particular approach to visualization, or rather illustration and mapping of knowledge and information, ultimately creates a science map of a specialty, thematic area, discipline, or set of disciplines (Zavaraghi, 2018).

Morris and Martens (2008) proposed five main goals for drawing scientific maps: (1) drawing the social structure of a thematic field, (2) drawing the basic knowledge of a thematic field, (3) drawing the research sub-themes of a thematic field (4) drawing the overlapping relationships between the elements of a thematic field, and (5) drawing the transformations of a thematic field.

1-3. Practical steps for creating scientific maps

Step 1: Selecting analyzable data, which are generally sourced from the structured data of WoS and Scopus citation databases.

Step 2: Selecting the appropriate field or unit of analysis; namely (1) Authors (the most important field), (2) publications, (3) organizations, (4) countries and regions, and (5) thematic areas.

Step 3: Pre-processing raw data (extracting information or selecting a measurement unit) from online sources, where articles, patents, reports, books, and any source of the necessary information is extracted. This step employs text mining and data mining techniques.

Step 4: Analyzing and mapping the extracted data.

Step 5: Labeling the identified clusters (Zavaraghi, 2018)

Therefore, the development of knowledge and information in any thematic area requires policy-making and systematic analysis, which require accurate knowledge of the situation in each country in that thematic area. Such knowledge of the strengths and weaknesses in a thematic area can help to improve policy-making concerning scientific production.

Turning a blind eye to the amount of scientific production and the associated issues can bring about political, economic, scientific, industrial, and technological problems for any country and society. The thematic texts of every domain reflect its content richness and the content patterns in these texts can help to examine a domain's relations with other domains.

Several bibliographic and bibliometric databases can be found online nowadays that collect and maintain scientific documents and their citations. These databases are used to search for and retrieve information in most scientific fields. The largest of these databases are WoS, Scopus, Google Scholar, and MEDLINE, each providing specific information with specific features and criteria.

One of the empowering factors in the field of scientometrics that allows for discovering the structure of science is the citation relations, foundations, and techniques derived from the field of information visualization. Considering the significance of scientific products in each thematic area and the importance of knowledge engineering in organizations and by managers, this study investigates the scientific products and draws a knowledge map of the field of knowledge engineering on the WoS database.

1-4. Significance of the Study

The purpose of knowledge engineering is to model various aspects of the expertise of experts in specific fields concerning problem-solving and the production of knowledge-based systems to help non-experts. Knowledge engineering overlaps with knowledge management to a certain extent and involves a set of methods used by organizations to identify, select, organize, disseminate, and transfer important information, knowledge, and specialties that are part of the organizational memory. The significance of knowledge engineering for managers stems from its capacity to prevent rework and error and introduce a suitable organization of information and knowledge to the executive system of organizations and the decision-making process of their managers. Scientific productions demonstrate one of the most basic stages of development in a society or a field, and a review of studies in different thematic areas can help to figure out the temporal, spatial, authorial growth of a field, and its effects on society. Accordingly, this study explores and draws a knowledge map of the field of knowledge engineering using the Web of Science database.

2. Literature Review

To collect the literature review and complete the content, the researchers have obtained the information needed in this paper by searching in some databases such as Google Scholar, Science Direct, ProQuest, Irandoc, elmnet Background of knowledge engineering Safari, Razavi, and Ghiasi (2020) investigated the factors affecting IT governance quantum skills, and knowledge engineering in Iranian public libraries. Their findings show that little research has been conducted in these areas. Therefore, it is useful to identify the factors affecting these fields in Iranian public libraries, for comprehensive planning on developing IT governance, boosting quantum skills, and promoting knowledge engineering.

Felfernig et al. (2021) examined recommender systems for configuration knowledge engineering and showed how recommenders can support knowledge base development. This was an empirical study and the participants were computer science students. They showed how recommenders can be used to support knowledge engineering tasks through collaborative filtering of constraint sets, content-based clustering of constraints, and knowledge-based refactoring recommendations developed for industrial applications, graphical knowledge representations, and intelligent techniques for knowledge base testing and debugging. The study also conducts an in-depth analysis of existing research in the field of cognition psychology to further advance the state of the art in (configuration) knowledge engineering.

Thanachawengsakul, Wannapiroon, and Nilsook (2019) investigated the knowledge repository management system architecture of digital knowledge engineering using machine learning (KRMS-SWE), which yielded satisfactory results. This system was used to promote software engineering competencies by investigating documents, textbooks, and academic articles. The knowledge creation, storage, testing, and assessing of students' knowledge in software engineering is carried out using a knowledge verification process with machine learning and divided into six steps, namely: (1) pre-processing, (2) filtration, (3) stemming, (4) indexing, (5) data mining, and (6) interpretation and evaluation.

In their 2018 study "lessons from knowledge engineering methodologies for chatbot design and development", Cameron et al. created a chatbot using ontology to turn knowledge into a relational database to steer the conversation. They also examined chatbots by focusing on the methodological aspects of development in the area of mental healthcare. According to them, key issues in chatbot development are concerned with the difficulty in eliciting specific domain knowledge and codifying the domain knowledge, which has become a complex process. Knowledge collection and scripting are fundamental steps in chatbot development for healthcare purposes. Similar to expert systems, such chatbots must enjoy expert knowledge and be capable of representing the relationships between knowledge domains.

2-1. Background of scientific product mapping

Farshid, Abedi, and Jafari (2020) identified the features of scientific products in the field of small data indexed on WoS and explained their application based on scientific product keyword identification for separate scientific fields. Their study was descriptive and used a scientometric approach and content analysis through co-word analysis and social network analysis. Data analysis was done using Histcite, BibExcel, Gephi, and SPSS, while VOSviewer was used for data mapping.

According to their findings, the publication of small data has experienced an increasing trend in the past few decades with an average annual growth rate of 15.59%. Over 90% of these products were in the fields of computer science, engineering, mathematics, tele- communications, and physics. Co-word clustering in these domains created 8, 6, 7, 5, and 3 clusters, respectively. The greatest degree of centrality belonged to machine learning, IoT, and universal existence. The highest closeness centrality in these fields was seen in the words adaptation, bipartite graph, and machine learning, and the highest betweenness centrality belonged to machine learning, long-term evolution technology, and global existence. They concluded that theoretical discussions of small data have mostly evolved in mathematics and physics, while its applications are expanding in computer science and other fields.

Erfan Manesh, Hamzei, Rajabzadeh, and Assarha (2019) investigated the suppression of scholarly journals through a case study of journal citation reports from 2010 to 2014. They explain that journals indexed by Clarivate's WoS are temporarily suppressed from the journal citation reports if they manipulate their impact factor through excessive self-citations and citation stacking with other journals. Their research was a descriptive applied study based on scientometric indicators, with a research population of 225 journals suppressed from the journal citation reports during 2010-2014. The research data was collected from the journal citation reports and WoS. Their results showed that journals from 177 different thematic areas had a history of suppression, with the highest suppression associated with electronics and electrical engineering, management, and artificial intelligence.

Moreover, the US, the UK, the Netherlands, and Germany had the greatest number of suppressions. In terms of duration, 41.3% of the journals were suppressed for one and 38.2% for two years. Moreover, 65% of the suppressed journals were ranked in the first and second quartiles of their respective domains a year before suppression.Considering that two Iranian journals have a record of suppression, raising awareness among researchers and editorial board members alongside regular monitoring of the journals' citation performance can help to avoid suppression in the future.

Rezaee, Akbari, and Padash (2017) mapped innovation knowledge using scientific and research articles in ACECR database and IRANDOC theses in the 2005-2013 period. This was a descriptive-survey applied study and analyzed 36 scientific records from ACECR and 557 records from Ganj database (IRANDOC) to draw the communication network of the innovation-related domains. According to their results, 25 institutions contributed to the publication of Persian articles and 90 institutions to the publication of theses. Islamic Azad University was ranked first with 14 articles and 53 thesis documents. Payame Noor University and Allameh Tabatabai University were ranked second and third in the production of theses, while Allameh Tabatabai University and Tarbiat Modares University were ranked second and third in the production of research articles in the field of innovation knowledge.

In their research entitled "Study of Subject Overlap between the Main Categories of Knowledge Management within the Web of Science", Hazeri, Ravari, and Ebrahimi (2014) investigated the thematic structure of knowledge management through a co-word analysis of WoS documents. They classified the topics using the hierarchical clustering method and determined the thematic similarity of the domains related to inclusion index calculation. Their findings show that the fields of management and computer science-information systems and information science/library science) have the highest number of documents in this field. They drew a power diagram of the keywords and 96 (out of a total of 5,570 keywords) were identified as the most popular topics.

In their study "Knowledge map of digital libraries in Iran: a co-word analysis", Hafezi, Ramezani, and Momeni (2018) drew a knowledge map of Iranian scientific products in digital libraries. They employed a scientometrics approach using the co-occurrence method and social network analysis indices. They analyzed a total of 554 scientific documents including books, articles, domestic and international conference papers, and master's and doctoral dissertations in Iran in all scientific fields concerning digital libraries until the end of 2013.

Thematic listing was used to collect data and Gephi and VOSviewer were used for visualization and thematic network analysis. The research results indicate that few studies have delved into this topic through a technical and applied approach. In addition, after two decades of studies in this field in Iran, the co-occurrence structure of the research domains is still immature compared to the international level, not to mention the poor and inconsistent correlation of concepts within clusters.

López-Belmonte et al. (2020) investigated augmented reality in scientific mapping training on WoS using a bibliographic approach. They used a documentary analysis technique based on scientific mapping and co-word analysis through an analysis unit of 777 reported WoS publications. Their results provided the language, knowledge areas, type of document, institutions, authors, sources of origin, countries, and most cited articles on augmented reality in the entire educational field. They also concluded that research on augmented reality has focused on teaching people to effectively use this technology in the learning environments it generates in its educational application and in attending to the diversity of students.

Shyagali et al. (2021) conducted a bibliometric analysis of oral hygiene-related scientific productions of Health Sciences University in central India, aiming to statistically analyze the available literature on oral hygiene. The documents were downloaded as Bibtex and imported into RStudio for analysis. The graphs and plots were generated using RStudio with the Bibliometric Package.

A total of 1148 documents were extracted by searching for India-related topics (journals, books, etc.) on WoS in the 991-2020 period. In this study, the Author list included a total of 3694 authors; authors per document were 3.22 and co-authors per document were 4.4; and the collaboration index of all publications was 3.35. They showed that the number of oral health publications has increased since 2010 accompanied by a gradual increase in the number of publications, likely due to the increase in the number of dental institutions and graduate students around the world. The total number of authors participating in oral health research was 3,694 with only 54 single-authored documents.

Baratlou (2021) compared the thematic trends of scientific productions related to COVID-19 in humanities and social sciences in Iran and the leading countries of the five continents on WoS. Bibexecl, Gephi, and SPSS and social network techniques and co-occurrence analysis were used for data analysis and VOSviewer was used for drawing the thematic clusters.

The number of clusters in these countries was as follows: the US (6), the UK (7), China (7), Australia (8), and South Africa (10); with 10 clusters, Iran was ranked 13th in Asia. Thematic overlaps were seen between China and Australia and the UK and US. There was no significant difference between the number of scientific products in humanities, social sciences, and health, while there was a positive significant difference between the amount of these products and the disease (infection) outbreak. There was also limited international research on COVID-19 in the humanities and social sciences. The diversity of topics in these studies reveals a need to be more active in understating the different effects of this crisis and controlling it.

In their study "Revealing research themes and trends in knowledge management from 1995 to 2010", Lee and Chen (2012) reviewed 10974 articles to build an intellectual structure. They used document co-citation analysis, pathfinder network, and strategic diagram techniques to provide a dynamic view of the evolution of knowledge management research trends.

2-2. Objectives

1. Identifying author bibliometric networks in knowledge engineering;
2. Identifying institutional bibliometric networks in knowledge engineering;
3. Identifying international bibliometric networks in knowledge engineering;
4. Identifying the word co-occurrence structure in knowledge engineering;
5. Identifying the thematic sub-areas in knowledge engineering;
6. Identifying the top scientific journals in knowledge engineering;
7. Identifying the language of scientific products in knowledge engineering;

8. Identifying the type of scientific products in knowledge engineering;
9. And, identifying the number of annual scientific product outputs in knowledge engineering.

2-3. Research questions

1. What are the author's bibliometric networks in knowledge engineering?
2. What are the institutional bibliometric networks in knowledge engineering?
3. What are the national bibliometric networks in knowledge engineering?
4. What is the word co-occurrence structure in knowledge engineering?
5. What are the thematic sub-areas of knowledge engineering?
6. Which journals have published the most scientific products in knowledge engineering?
7. What is the language of scientific productions in knowledge engineering?
8. What are the types of scientific production in knowledge engineering?
9. And, what is the number of annual scientific product outputs in knowledge engineering?

3. Methodology

This was an applied descriptive-analytical study using a quantitative research design. The research population consisted of all scientific products in knowledge engineering, which included 7724 documents published in indexed journals on the Web of Science database in the 2011-2021 period. The data was collected in three steps:

Step 1: First, the WoS citation database was used to collect research data. Then, using the website's simple search tool, an inquiry was made for the phrase "knowledge engineering" in all fields and the publication timespan was limited to the 2011-2021 period. Finally, 7724 documents were retrieved.

"knowledge Engineering"
languages and document types: all languages and ALL FIELDS
Timespan: 2011-2021
Citation Indexes SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-SSH, ESCI, CCR-EXPANDED,IC

Step 2: considering the restrictions of WoS exports which allow for exporting only 500 records, the data was extracted in 16 steps. The process is also outlined below:

Save to Other File Format / Number of Records: 1-500 / Record Content: Full Record and Cited References / File Format: Plain Text / Send.

Step 3: In this step, the text files were entered into VOSviewer scientometrics software to draw the bibliometric networks of researchers, institutions, and countries. Moreover, Histcite and Excel were used for data analysis. Gephi was also employed to determine the betweenness centrality, eigenvector centrality, and degree centrality.

4. Findings

Question 1: What are the author bibliometric networks in knowledge engineering?

Table 1.
Author bibliometric networks

Row	Author	documents	Organizational affiliation	country	H- index
1	xu, yang	69	Beijing University of Science and Technology	China	7
2	Zheng,ginghua	49	Alto University	Finland	26
3	li, tianrui	44	Southwestern University of Jiatang	China	7
4	lu, jie	41	University of Guang	China	3
5	premchaiswadi, wichian	36	Siam University	Thailand	9
6	kahraman, cengiz	34	Istanbul Technical University	Turkey	5
7	liu, jun	33	Jiangxi Higher University	China	9
8	oztaysi, basar	31	Istanbul Technical University	Turkey	22
9	zeng, xianyi	31	University of Lille	France	12
10	zhang, guangquan	30	University of Sydney	Australia	16
11	nalepa, grzegorz j.	30	Jagiellonian University	Poland	9
12	kasabov, nikola	27	Auckland University of Technology	New Zealand	37
13	liu, chunping	26	Dajou Central Hospital	China	17
14	dong, bo	26	Shenzhen University	China	20
15	ji, yi	25	Jiangsu University	China	11

The bibliometric networks of researchers in knowledge engineering are presented in Table 1. This network includes researchers with at least five scientific collaboration documents, consisting of 160 nodes and 363 edges and a density of 1.188. Network density indicates the number of links between researchers in the network. The closer it is to one, it indicates a stronger connection and network coherence, whereas closeness zero indicates a network disconnection (Fahimifar, Gholampour, and Gholampour, 2018: 53). Here, the network density of researchers in knowledge engineering enjoys an acceptable level of coherence. A review of the co-authored networks can show the relationships of researchers and their social structure in the network. Overall, when two or more researchers collaborate in scientific research work, it can be concluded that these researchers either work in a common thematic area or that their intellectual backgrounds and ideas are the same, thus laying the grounds for their collaboration.

The nodes represent researchers and links represent the co-authorship of researchers with each other. Accordingly, the size of the nodes indicates the number of co-authorships in the network. Therefore, larger nodes do not necessarily indicate more contributions and may show that they have published more articles compared to others. The number of collaborations depends on the total number of outgoing links. Researchers with the most scientific collaboration in the field of knowledge engineering include Xu, Yang from the Beijing University of Science and Technology with 69 published documents. In the second place, we have Zhang, Guangquan from Aalto University with 44 documents followed by Li, Tianrui from the University of Guang with 41 documents.

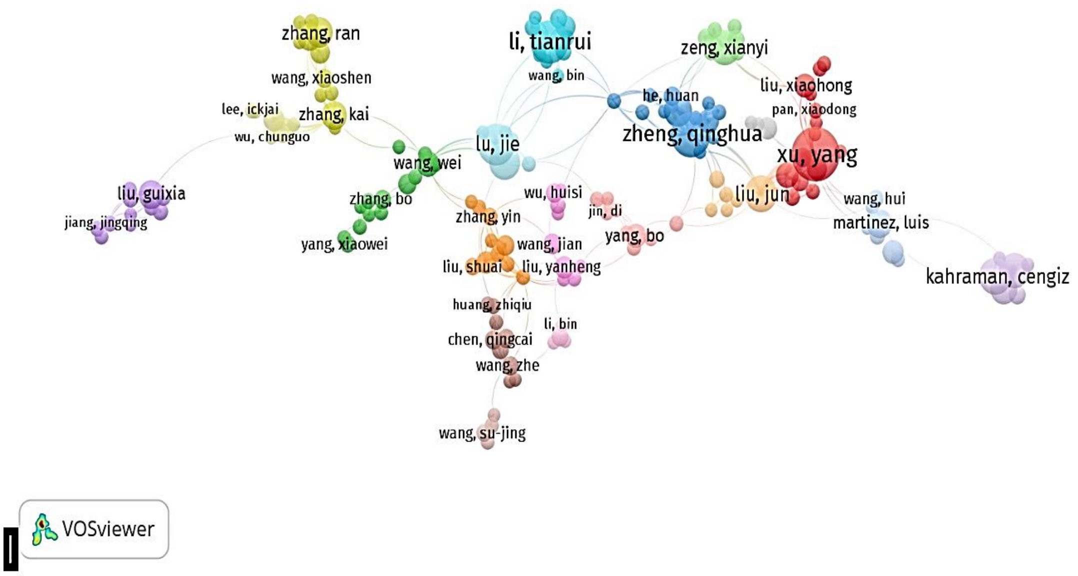

Figure 1. Author bibliometric network

Question 2: What are the institutional bibliometric networks in knowledge engineering?

Table 2.
Institutional bibliometric networks

No.	organization	documents	Country	Institution rating in US News rankings
1	jilin university	267	China	448
2	southwest jiaotong university	160	China	691
3	ferdowsi univ mashhad	118	Iran	827
4	islamic azad university	96	Iran	395
5	istanbul tech university	79	Turkey	648
6	Xi'an Jiaotong University	79	China	290
7	university of technology sydney	64	Australia	160
8	soochow university	61	China	277
9	chinese academy of sciences	60	China	84
10	Nanjing University of Posts and Telecommunications	53	China	467
11	zhejiang university	52	China	110
12	dalian university of technology	49	China	303
13	beijing institute of technology	46	China	340
14	harbin institute of technology	44	China	206
15	Arizona State University--Tempe	44	USA	165

Table 2 shows the network of scientific collaboration among institutions in the field of knowledge engineering. This network consists of 516 nodes and 1651 edges. A list of the top institutions with at least five scientific collaboration documents is presented in Table 2. Accordingly, Jilin University, Southwest Jiaotong University, Ferdowsi University of Mashhad, Islamic Azad University, and Istanbul University had the most scientific collaboration and so the largest nodes. Furthermore, the presence of Iranian institutions in the top five list is remarkable and shows that Iranian institutions and universities are cognizant of the significance of knowledge engineering. Citation is a qualitative index that is used by some ranking systems as a criterion for performance evaluation of institutions and universities by showing the impact of their scientific productions at the international level.

The superiority of Chinese institutions and universities is clearly visible in this table. The Chinese Jilin University is in the first place with 267 documents, followed by the Chinese Southwest Jiaotong University with 160 documents and the Iranian Ferdowsi University of Mashhad with 118 documents. Islamic Azad University, Istanbul University, Xi'an Jiaotong University, and University of Technology Sydney, with 96, 79, 79, 64 documents, respectively, were next in line. In this table, the number of documents, the country of institutions, and the university rankings were based on the QS World University Rankings. The results of Table 2 demonstrate that among the 15 institutions with the most non-cited articles, 10 institutes were Chinese, two were Iranian, one from the US, Australia, and Turkey.

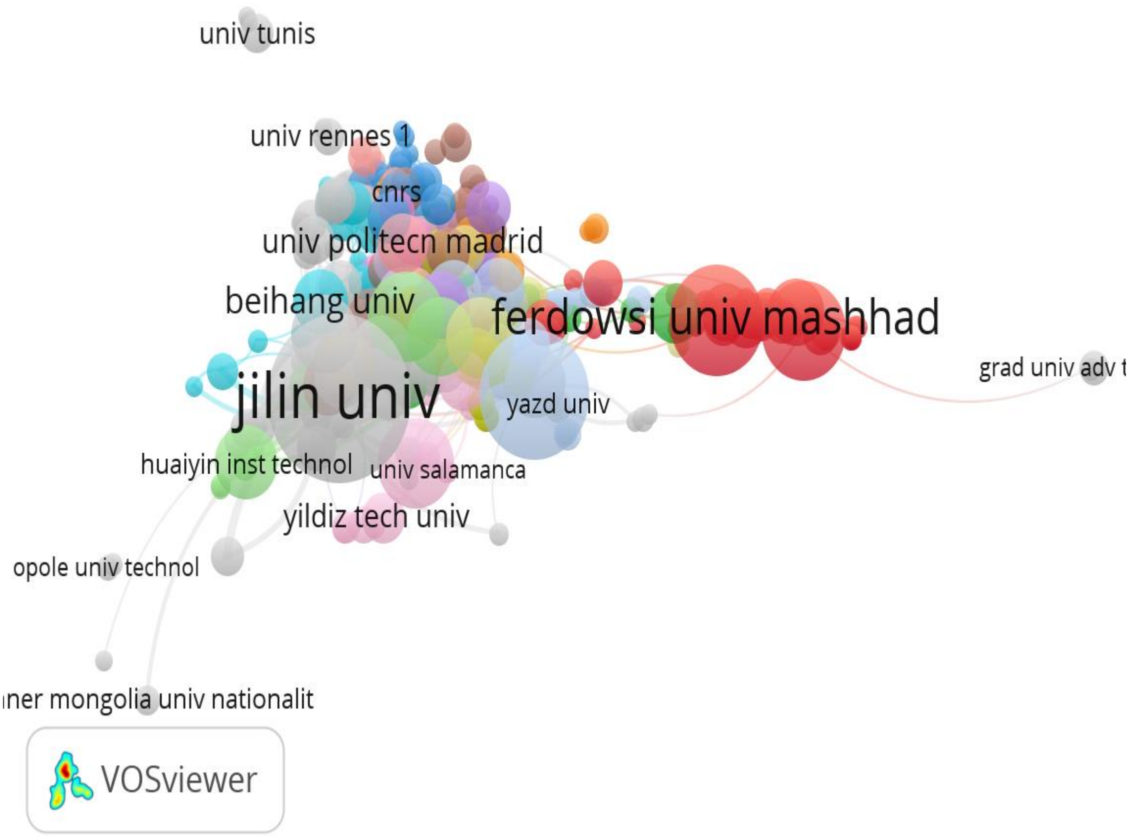

Figure 2: Institutional bibliometric networks

Question 3: What are the national bibliometric networks in knowledge engineering?

Table 3.
International bibliometric networks

Row	Country	documents	citations
1	china	2285	8371
2	USA	675	3647
3	Iran	641	1409
4	France	414	1343
5	Spain	321	738
6	England	298	1701
7	Italy	260	2209
8	Turkey	259	556
9	Australia	237	1438
10	India	200	628
11	brazil	184	738
12	japan	169	314
13	Russia	168	471
14	Canada	159	990
15	Poland	156	756

Table 3 presents the network of scientific collaboration of countries in the field of knowledge engineering. In the graph, nodes represent countries. This network is made up of 74 nodes and 624 edges.
Institutions of China, the US, Iran, France, and Spain had the highest level of scientific collaboration and so the largest nodes. A unique feature of VOSviewer in information visualization is the possibility of using different colors. The lower color spectrum of the graph shows the publication trend of countries in the field of knowledge engineering, with the US, the UK, Japan, France, and Australia stepping into this field from 2010 to 2012. Meanwhile, knowledge engineering publications have become more vigorous in China, Iran, Spain, and Russia since 2014.

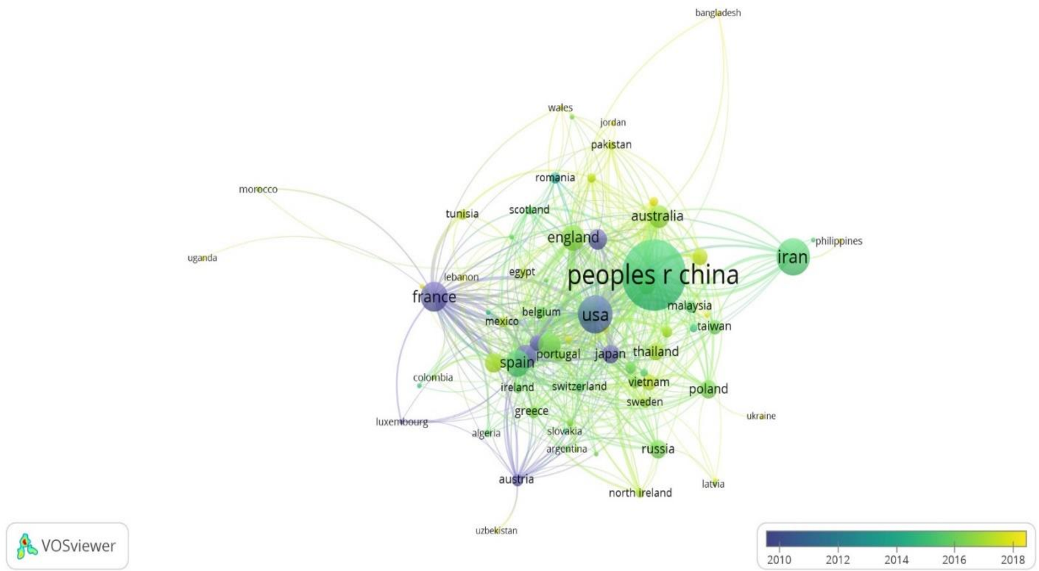

Figure 3. International bibliometric networks

Question 4: What is the word co-occurrence structure in knowledge engineering?

Table 4.
Word co-occurrence structure

Row	keyword	Oc-currences
1	model	195
2	design	131
3	algorithm	130
4	system	129
5	systems	121
6	framework	111
7	classification	103
8	management	98
9	knowledge	86
10	optimization	10

Table 4 represents the word co-occurrence structure in the field of knowledge engineering. The words model, design, algorithm, system, systems, framework, classification, management, knowledge, and optimization, with 195, 131, 130, 129, 121, 111, 103, 98, 86, and 10 instances respectively had the highest word co-occurrence in knowledge engineering. These are the most widely used knowledge engineering vocabulary.

Figure 4 presents 309 words with at least five repetitions in the documents, including 3379 edges between these nodes, which shows the highest number of word co-occurrence in this field.

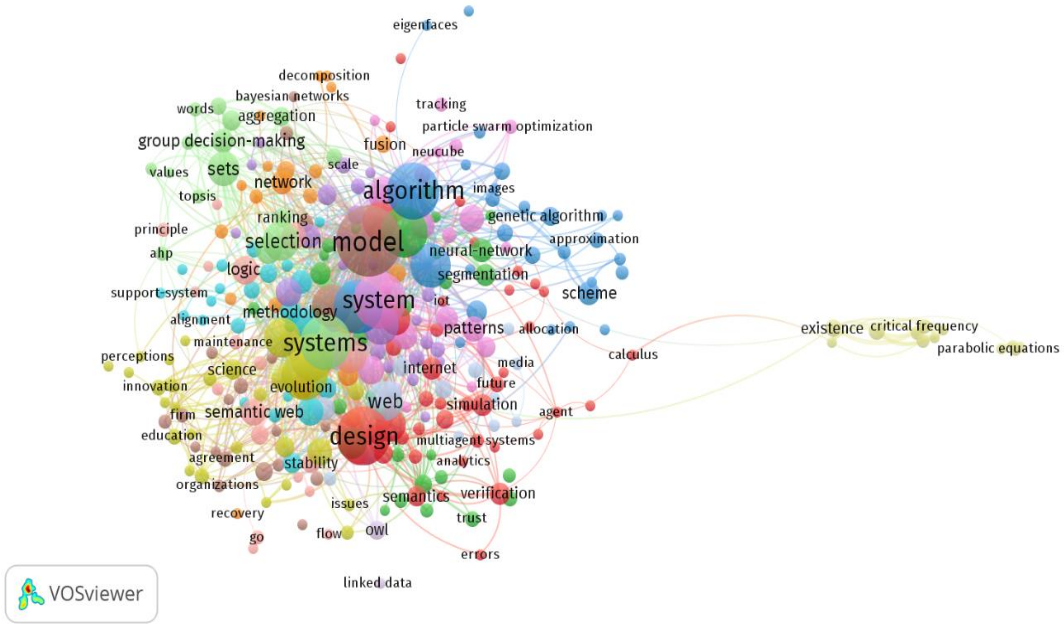

Figure 4. Word co-occurrence structure

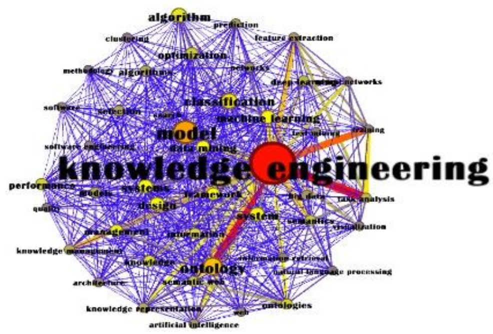

Figure 5. Betweenness centrality, degree centrality, eigenvector centrality

In Table 5, the total number of nodes and edges was 1000 and 16676, respectively. The Fruchterman-Reingold algorithm was used here. The size of the nodes is based on the betweenness centrality and the color of the node indicates the degree centrality, the color changes from red to blue a declining degree. Moreover, only nodes with a degree range of 100 and above were selected to draw the graph.

Among these words, the knowledge engineering node had the highest betweenness centrality (0.185135), degree centrality (607), and eigenvector centrality (1), followed by the word model with 383 for betweenness centrality, 0.57956 for degree centrality, and 0.721679 for eigenvector centrality.

Table 5.
Betweenness centrality, degree centrality, eigenvector centrality

Row	Subject area	Degree	betweenesscentrality	eigencentrality
1	knowledge engineering	607	0.180135	1
2	model	383	0.57956	0.721679
3	ontology	335	0.048898	0.644142
4	classification	284	0.037427	0.575887
5	system	256	0. 029549	0.547738

Question 5: What are the thematic areas of knowledge engineering?

Table 6.
Thematic sub-areas

Row	Subject area	documents	Percent
1	Knowledge Engineering	716	31.52
2	Ontology	232	10.21
3	Machine learning	171	7.52
4	Data analysis	160	7.04
5	Semantic Web	113	4.97
6	Deep learning	111	4.88
7	knowledge management	106	4.66
8	Organization	102	4.49
9	Representation of knowledge	95	4.18
10	Ontologies	93	4.09
11	Task analysis	81	3.56
12	Feature extractation	78	3.43
13	Cluster ring	74	3.25
14	Text extraction	71	3.12
15	Natural Language Processing	68	2.99

Table 6 shows the list of thematic areas of knowledge engineering, with the most scientific products being knowledge engineering, ontology, machine learning, data mining, semantic web, deep learning, knowledge management, organization, representation of knowledge, ontologies, task analysis, feature extraction, cluster ring, and text extraction among others. Some journals may have been indexed under two different thematic categories on Clarivate's WoS, which means an article too may have been indexed under two different thematic areas.

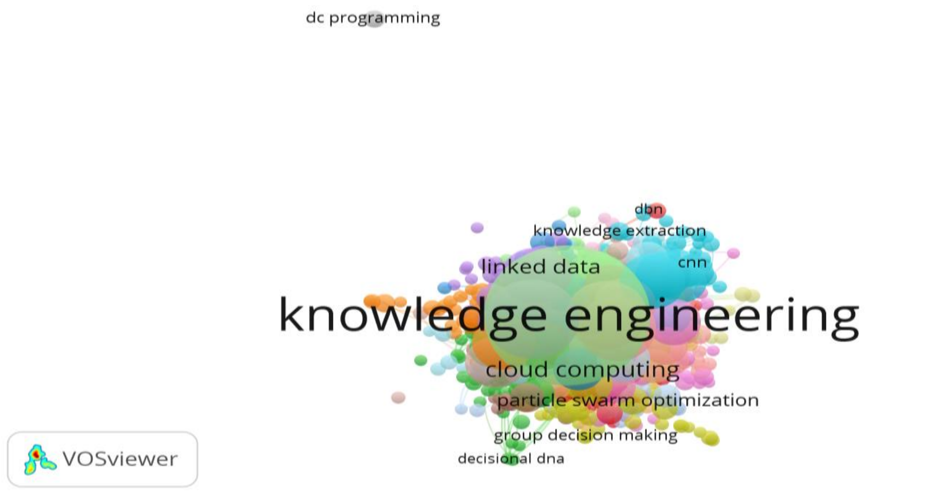

Figure 6. Thematic sub-areas

Question 6: Which journals have published the most scientific products in knowledge engineering?

Findings on knowledge engineering journals confirm that most of the scientific productions in this field have been published by 112 journals. Table 7 provides a list of 15 journals that have published the most scientific products in this field. Accordingly, The International Journal of Software Engineering and Knowledge Engineering (704), Data & Knowledge Engineering (463), and Knowledge Engineering Review (263) are among the top three journals in this field. Interestingly, IEEE Access with 97 published articles is among the top and the first quartile knowledge engineering journals. Moreover, most of these are conference journals.

Table 7.

Top scientific journals in knowledge engineering

Row	source	documents	Impact factor	Magazine rank	Quarterly Magazine
1	international journal of software engineering and knowledge engineering	704	0.24	-	3
2	data & knowledge engineering	463	1.992	-	2
3	knowledge engineering review	263	0.48	-	2
4	uncertainty modeling in knowledge engineering and decision making	213	-	-	-
5	data science and knowledge engineering for sensing decision support	196	-	-	-
6	developments of artificial intelligence technologies in computation and robotics	184	-	-	-
7	uncertainty modelling in knowledge engineering and decision making	180	-	-	-
8	th international conference on computer and knowledge engineering	138	-	-	-
9	software engineering and knowledge engineering: theory and practice	136	-	-	-
10	th international conference on intelligent systems and knowledge	130	-	-	-
11	foundations of intelligent systems	112	-	-	-
12	practical applications of intelligent systems	111	-	-	-
13	the international conference on intelligent systems and knowledge	97	-	-	-
14	IEEE access	97	0.59	-	1
15	foundations of intelligent systems	91	-	-	-

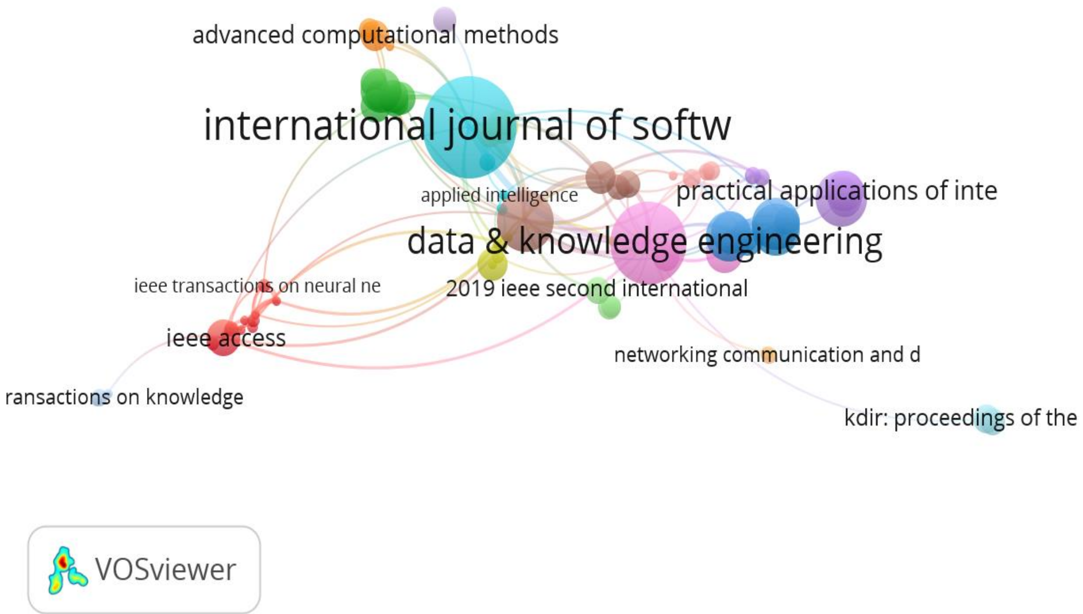

Figure 7. Top scientific journals in knowledge engineering.

Question 7: What is the language of scientific productions in knowledge engineering?

Language is a structured system of contractual signs used for communicating with others.

Table 8.

Language of scientific productions

Row	Language	documents
1	English	7185
2	Russian	7
3	Portuguese	6
4	Spanish	6
5	French	3
6	German	2
7	Chinese	1
8	Turkish	1

As shown in Table 8, English is the most popular language used by scientific communities. English (7185) is ranked first in terms of the language of published knowledge engineering documents, followed by Russian (7), Portuguese (6), Spanish (6), and French (3). Therefore, it can be concluded that English is accepted as the lingua franca by writers and researchers in various fields and scientific communities.

Question 8: What are the types of scientific production in knowledge engineering?

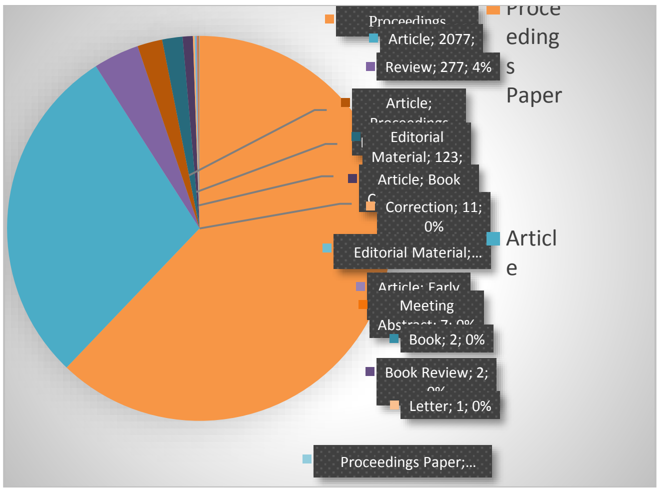

Figure 8: Type of scientific products in the field of engineering

According to Diagram 1, the primary type of scientific products in the field of knowledge engineering is associated with article collections (4481 documents), followed by research papers (2077 documents), and review articles (277 documents).

Question 9: what is the number of annual scientific product outputs in knowledge engineering?

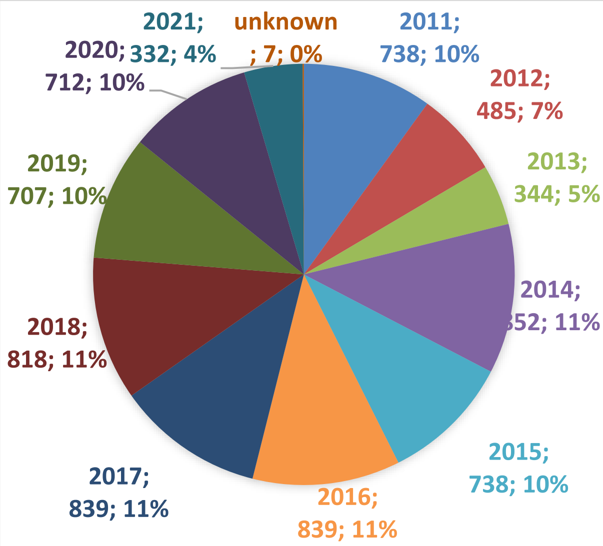

Figure 9. Number of annual scientific product outputs in knowledge engineering

According to Diagram 2, the highest annual output of scientific products in the field of knowledge engineering is associated with the year 2014 (852 documents), followed by 2016 (839 documents) and 2018 (818 documents). In other words, researchers have published the most knowledge engineering articles in these years.

5. Discussion and Conclusion

Research findings show that many researchers are involved in the field of knowledge engineering. Chinese researchers have been more active in this field compared to researchers in other countries. Similarly, Chinese institutions have made the most contribution to this field. The earnest attention of China to such fields as knowledge engineering may have been a contributing factor to this country's economic and industrial developments. With two institutions, namely Ferdowsi University of Mashhad and Islamic Azad University, Iran is among the most active countries in knowledge engineering.

In terms of scientific collaboration between countries, China has had the most scientific production, followed by the US, Iran, and France. These countries had the highest scientific production from 2011 to 2012. Since 2012, China, Iran, and Vietnam have continued their activities in this field. Asian countries seem to have paid special attention to knowledge engineering.

In knowledge engineering thematic sub-areas, most scientific products were in knowledge engineering, ontology, machine learning, data mining, semantic web, deep learning, knowledge management, organization, representation of knowledge, ontologies, task analysis, feature extraction, cluster ring, and text extraction.

International Journal of Software Engineering and Knowledge Engineering (704), Data & Knowledge Engineering (463), and The Knowledge Engineering Review (263) were the three top publishers of knowledge engineering articles, standing in the second and third quartiles. Interestingly, IEEE Access with 97 published articles is among the top and the first quartile knowledge engineering journals.

Moreover, most of these are conference journals. Furthermore, most scientific products were written in English in the form of article collections, research papers, and review articles. The highest number of documents were published in the years 2014, 2016, 2018, and 2015, respectively.

Safari, Razavi, and Ghiasi (2020) investigated quantum skills and knowledge engineering in public libraries in Iran, Felfernig et al. (2021) examined recommender systems for configuration knowledgeengineering, Thanachawengsakul, Wannapiroon, and Nilsook (2019) investigated the knowledge repository management system architecture of digital knowledge engineering using machine learning, and Cameron (2018) studies knowledge engineering methodologies for chatbot design and development. These research efforts reflect the importance of this field and its necessity for helping knowledge function more effectively. The findings of the present study also explored basic areas such as authorship, institutions, word co-occurrence, top journals, language, years, research types, and the subfields of knowledge engineering, which can be used by individuals, institutions, and anyone interested in the developments of this field.

Farshid, Abedi, and Jafari (2020) identified the features of scientific products in the field of small data indexed on WoS;

Erfan Manesh, Hamzei, Rajabzadeh, and Assarha (2019) investigated the suppression of scholarly journals through a case study of journal citation reports; Rezaee, Akbari, and Padash (2017) mapped innovation knowledge using scientific and research articles in ACECR database and IRANDOC theses in the 2005-2013 period; Hazeri, Ravari, and Ebrahimi (2014) investigated the thematic structure of knowledge management through a co-word analysis of WoS documents; López-Belmonte et al. (2020) investigated augmented reality in scientific mapping training on WoS; Shyagali et al. (2021) conducted a bibliometric analysis of oral hygiene-related scientific productions of Health Sciences University in central India; Baratlou (2021) compared the thematic trends of scientific productions related to COVID-19 in humanities and social sciences in Iran and the leading countries of the five continents on WoS; Lee and Chen (2012) reviewed research themes and trends in knowledge management. These efforts show the importance of scientific productions and drawing of their conceptual map. Similarly, the present study investigated the thematic necessity of knowledge engineering and scientific products. When researchers and organizations can access clear information on top authors, institutes, and universities in a discipline, they can foster better relations and interactions.

Considering the importance of knowledge and its engineering in all organizations, industries, and managerial decisions, the findings of this research can benefit knowledge engineering policies and planning and prevent rework. Moreover, the image presented for the intellectual structure of knowledge engineering in theoretical and applied areas can help to identify thematic gaps and trending topics and refrain from impractical and repetitive works

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