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A BIBLIOMETRIC ANALYSIS OF ENGINEERING EDUCATION IN THE METAVERSE

Abstract. The Metaverse is a persistent and shared digital environment that blends physical and virtual reality, allowing for advanced multisensory interactions. Its acceptance has grown significantly since the COVID-19 pandemic. Nevertheless, despite its potential benefits for education, there are notable gaps in assessing learning processes within the Metaverse, especially concerning legal limitations and government oversight. This study aims to enhance the educational experience by promoting innovative, interactive, and engaging learning environments in various engineering disciplines, thereby equipping students with the skills necessary for success in a rapidly evolving technological landscape.This paper investigates the use of the Metaverse in engineering education through bibliometric analysis to identify key trends, challenges, and opportunities. By employing advanced tools like Publish or Perish and VOSviewer, the study analyzes bibliographic networks and statistical data to map the scholarly landscape and impact of this technology. The bibliometric analysis offers quantitative insights into research trends, citation counts, and author influence, which are presented in tables and charts for better visualization. This paper aim to enhance our understanding of how digital and immersive technologies are reshaping educational practices and boosting student engagement, motivation, and outcomes. The analysis underscores the importance of ongoing research and investment in the Metaverse as a vital resource for contemporary education, especially in engineering disciplines that thrive on interactive and hands-on learning environments. This research, despite certain limitations, lays important groundwork for understanding how the Metaverse can transform engineering education. By thoroughly analyzing and delineating the current landscape, it seeks to provide valuable insights that will guide future investigations and practical applications.

Keywords: Metaverse; Engineering Education; Virtual Reality; Extended Reality; Bibliometric analyses; VOSviwers.

1. INTRODUCTION

The Metaverse is defined as a perpetual and persistent multiuser environment merging physical reality with digital virtuality. It is based on the convergence of technologies enabling multisensory interactions with virtual environments, digital objects, and people, such as virtual reality (VR) and augmented reality (AR) [1]. The concept of the Metaverse originates from science fiction. The term "Metaverse" was coined by Neal Stephenson in his 1992 novel "Snow Crash." In this story, people create unique identities and engage in daily activities within the

Metaverse, a 3D virtual reality. The term "Metaverse" is derived from a combination of the words "transcendence," which refers to existence or experience beyond the normal or physical level, and "universe," meaning everything or a particular sphere of activity or experience [2]. Unlike earlier Metaverse platforms like Second Life, the modern Metaverse reflects the social values of Generation Z, where online and offline identities are seamlessly integrated [3], [4]. The term "virtual realm" describes a digital environment where avatars represent individuals, allowing them to participate in activities similar to those in the real world, such as politics, economics, society, and culture [4].

The metaverse, a shared 3D virtual space, holds significant potential for transforming education through immersive learning experiences using virtual reality (VR) and augmented reality (AR) technologies [5]. Research indicates that metaverse technology can enhance student engagement, motivation, and academic performance by providing personalized and interactive learning environments [6]. Educators are increasingly exploring applications in the metaverse to harness its immersive capabilities, aiming to create engaging and interactive educational experiences for students [7]. Although students may initially be skeptical about engaging with the metaverse, they acknowledge its potential as a social platform that promotes collaboration and engagement. This highlights the importance of combining metaverse experiences with traditional teaching strategies to achieve the best educational outcomes [8]. By leveraging the metaverse in education, educators can enhance interactive learning experiences, address accessibility challenges, and promote inclusive educational practices, ultimately reshaping the future of education.

Education has emerged as a primary application and innovation channel within the Metaverse, significantly enhancing students' cognitive engagement. However, it remains an underdeveloped concept requiring technological advancements, legal frameworks, and government oversight. This study explores the role of the Metaverse in training engineers to meet international standards and prepare for future digital transformations.

Scientific analysis and research are necessary to put on the right basis the selection of the appropriate software and the design of the teaching materials for the experimentation of engineering education in the metaverse, which is to be implemented in Faculty of Technics and Technology - Yambol under the project Metaverse Approach for a New Generation of Engineering Education and Collaborative Learning (MAGURA), as the frame of Project No. BG-RRP-2.004-0006-C02 "Development of research and innovation at Trakia University in service of health and sustainable well-being".

Very few studies have explored mobile learning, hybrid learning, and microlearning. Furthermore, no research has investigated the use of the Metaverse in engineering education.

Bibliometric analysis was applied to visually represent the relationships between the main concepts [9]. This visualization through mapping allows researchers to identify the background of a research field, the relationships between key concepts, and possible future trends [10]. Conversely, content analysis was used to conduct a thorough examination of the studies reviewed, aiming to identify the research themes that the authors emphasized when discussing the Metaverse in education.

Our analysis includes a review of the most cited works, leading authors, and predominant research themes within the scope of engineering education in the metaverse. We also explore the collaborative networks and the geographical distribution of research contributions, offering a holistic view of the global research landscape. The investigation provides a comprehensive overview of the current landscape of research. It identifies existing gaps and outlines prospective directions for future inquiry, thereby serving as an invaluable resource for educators, researchers, and policymakers who seek to harness the potential of the metaverse in engineering education.

This research utilizes bibliometric analysis to examine and map the use of the Metaverse in the field of education. It aims to identify trends, challenges, and opportunities for optimizing the integration of the Metaverse into academic practices. Ultimately, the article seeks to enhance our understanding of how digital and immersive technologies can transform educational approaches, providing insights to improve learning experiences and outcomes for engineering students worldwide.

2. RESEARCH METHODS

2.1. Data sources and search strategies

This study combines quantitative and qualitative synthesis approaches to review the metaverse in educational research published in the literature. The traditional systematic review is an important step before conducting any research, but reporting bias may be introduced, and the interpretation of results tends to be subjective during manual review [11]. Therefore, a systematic review with mixed methods, combining bibliometric analysis and content analysis, is necessary to scientifically identify a topic's knowledge base and evolution [12].

The search was conducted with the following keywords (metaverse OR virtual reality OR VR OR extended reality OR XR) AND (engineering education AND immersive education OR immersive learning OR immersive teaching) NOT (artificial intelligence OR deep learning OR machine learning) in all searches field of the Web of Science. As a result of the search, a list of 4386 publications was formed. The data from 2024 is not comparable to the other years because it only covers the time up to March 2024, but it is included because it shows a clear trend of increasing the number of publications in the area outlined by these keywords.

The analyzed data were retrieved using the tools provided by Web of Science (4386 records). Harzing's Publish or Perish [13] tool with the same keywords is used to get a data file; researchers can collect the data from all types of databases, Google Scholar and Scopus. Using the Publish or Perish tool, 1200 documents published between 2013 and 2023 and until February 2024 were retrieved: Google Scholar (1000 records) and Scopus (200 records). This taxonomy should generate stronger connections with research on engineering education in the metaverse. The bibliographic analysis of the "citation network," "author's research area," and "paper content" regarding this topic is the basis for the following analyses. As a result, a bibliographic model of authors, their article titles, keywords, and abstracts is created by using Harzing's Publish or Perish tool to extract data from Google Scholar and Scopus. VOSViewer provides a visualization of data pertaining to co-authorship and co-occurrence related to the administration of engineering education within the metaverse.

2.2. Data cleaning

Exclusion of scholarly publications was made if: (1) it did not discuss the research questions about the Metaverse in education and in particular in engineering education; (2) does not advocate the topics related to the research questions we pursue in this publication; (3) conferences because in most cases the papers in them are not peer-reviewed (3) it is not in English, and (4) is not available online. In total, 85 studies were conducted, as identified in the Web of Science, Scopus, and Google Scholar databases. Both content analysis and bibliometric analysis were utilized. Data were analyzed and interpreted through these approaches for data triangulation to obtain a multidimensional perspective and enhance the validity of the study. For the bibliometric analysis and synthesis, VOSviewer software was used to create distance-based co-occurrence maps: terms extracted from keywords, titles, and abstracts were grouped and mapped according to their relatedness in a similarity matrix [14].

3. RESULTS AND DISCUSSION

3.1. Characteristics of identified literature.

The literature identification process is illustrated in Figure 1. Initially, a total of 4386 records were obtained from the Web of Science (WoS) database: Google Scholar 1000 records and Scopus 200 records. After removing ineligible items, we manually evaluated 2,271 records for their titles and abstracts. After screening, a further 653 records were excluded. According to the pre-set research questions, another 150 records were extracted. The initial search yielded 4386 records. The data was analyzed to understand publication trends, key authors, institutions, and research areas.

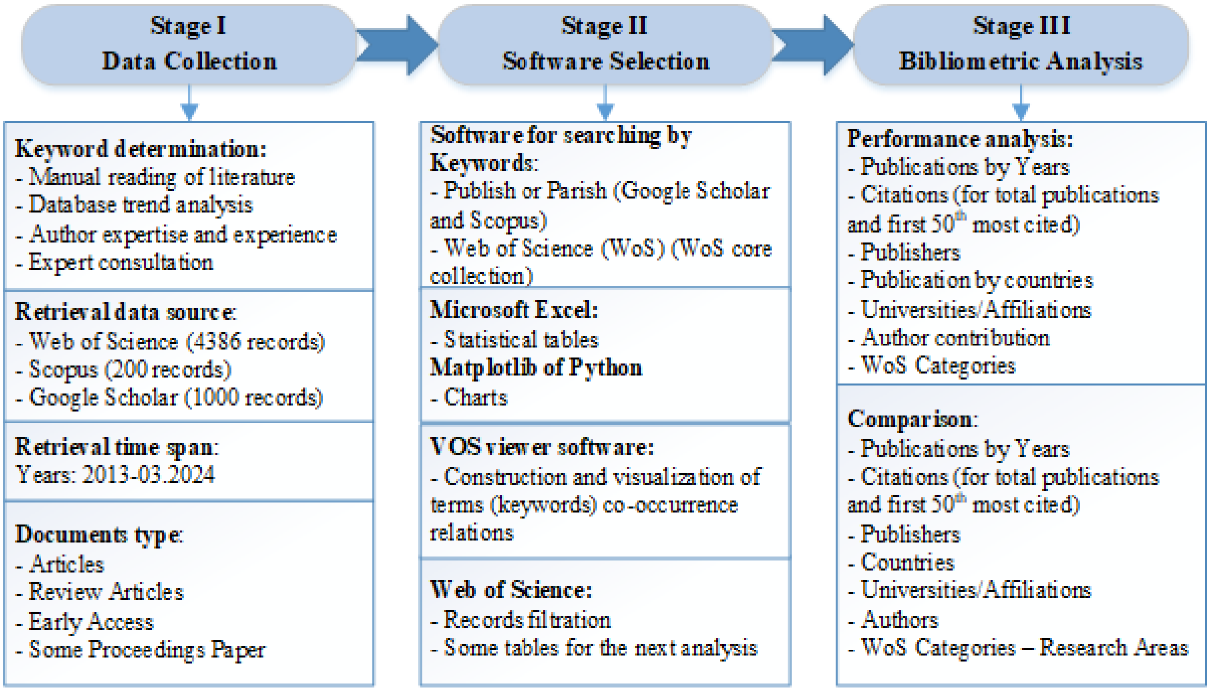

Figure 1. Literature Identification Process.

3.2. Bibliometric and Content Analysis

Bibliometric co-citation analysis determines the relation among research articles, titles, keywords, and abstracts. This is a tool for meta-analysis that helps figure out how strong any variable is, whether it has a positive or negative impact [15].

Bibliometric analysis with VOSviewer illustrated key concepts and their relationships in the literature. Content analysis explores the themes of studies in greater detail.

3.2.1. Publications by Years.

It shows the distribution of publications by year, both in the Web of Science (WoS) and Google Scholar databases in the article (Table 1.). The data reveals a recent surge in interest, with over 30% of WoS publications and around 38% of Google Scholar publications occurring in 2022 and 2023. The year 2024 already accounts for 7% and 5.22% of the publications in WoS and Google Scholar, respectively, despite being only a few months into the year.

Key Observations:

Peak Year for Web of Science: The highest percentage of publications in Web of Science was in 2023, with 30.187% of the total publications.

Peak Year for Google Scholar: Google Scholar saw its highest percentage of publications in 2022, with 17.25%.

Trends Over Time: Both databases have had their ups and downs over the years, but Web of Science really spiked in 2023 (Table 1; Figure 2).

Consistent Differences: Web of Science consistently outperforms Google Scholar in percentage each year, particularly in 2023.

Recent Years: In the years 2022 to 2024, both databases displayed different trends, with Google Scholar showing a more stable distribution compared to the sharp peak followed by a decline observed in Web of Science.

Table 1.

Searching publications from Web of Science and Google Scholar by year

Publication Years	Web of Science		Google Scholar	
	Record Count	% of 4386	Record Count	% of 997
2024	307	7.000	52	5.22
2023	1324	30.187	158	15.85
2022	846	19.289	172	17.25
2021	524	11.947	160	16.05
2020	352	8.026	145	14.54
2019	327	7.456	119	11.94
2018	233	5.312	60	6.02
2017	180	4.104	37	3.71
2016	107	2.440	29	2.91
2015	91	2.075	31	3.11
2014	47	1.072	19	1.91
2013	48	1.094	15	1.50

This chart (Figure 2) helps to visualize how the share of publications varies between the two databases over time, providing a clearer comparison based on relative proportions rather than absolute numbers. The bar chart illustrates the number of publications by year from 2013 to 2024, comparing data from Web of Science and Google Scholar.

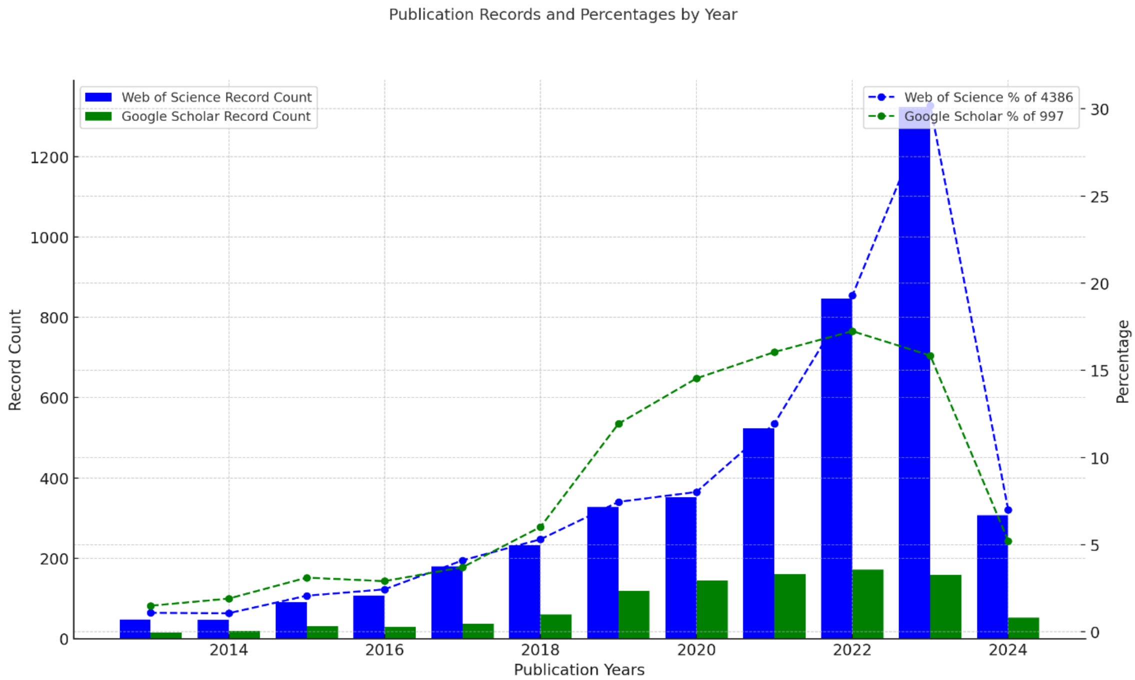

Figure 2. Publication Records and Percentages by Years.

3.2.2. Citations

The search for "Engineering Education in Metaverse" across Web of Science (WoS) databases yielded 4386 results, with a total of 42669 citations (Table 2) and an average of 9.72 citations per item. The h-index, which evaluates both the productivity and citation impact of publications, is 76.

Table 2.

Number of citations by year

Years	2013-2019 Average	2020	2021	2022	2023	2024	Total
Total citation by Years	523	3071	5204	8155	14871	7705	42669
The first 50 most cited publications	193	1152	1690	2311	3144	1349	9646

Figure 3. displays the annual citation data from 2013 to 2024. It includes the average number of citations per year for the period 2013-2019 and specific annual citation counts from 2020 to 2024. The total number of citations for the entire period and the overall average citations per year are also given. It is important to note that the data for 2024 is only up to March 2024, which affects the current trend analysis.

There is a clear and significant upward trend in the number of citations starting from 2020, indicating increased recognition and relevance of the work being cited during these years. The dramatic rise in citations, peaking in 2023, highlights a growing influence in the research community. With the data for 2024 being up to March, it is anticipated that the final number for 2024 will continue this trend of high citation counts, potentially surpassing previous years when projected for the entire year.

The average number of citations each year from 2013 to 2019 was just 523, which is a huge drop compared to the impressive 8533.8 from 2020 to 2024. This big change really shows how citation patterns shifted starting in 2020.

Figure 3. presents the 50 most cited publications along with their annual citation counts from 2013 to 2024. The data includes the average number of citations per publication for the period 2013-2019 and detailed annual citation counts for 2020 through 2024. The total citations per publication over the entire period are also provided. It is important to note that the data for 2024 is only up to March 2024, which affects the current trend analysis.

The data indicates a substantial increase in the number of citations for the top 50 publications starting from 2020, peaking in 2023. Given that the data for 2024 is only up to March, the final number of citations for 2024 is expected to be higher, continuing the upward trend. This trend highlights the growing recognition and significant influence these publications have attained in recent years. The variability in citation patterns among different publications suggests differing levels of influence and relevance within the research community.

Figure 3. visualizes the trend in the number of publications and citations over time. The graph clearly shows a steady increase in both publications and citations, with a particularly sharp rise in recent years.

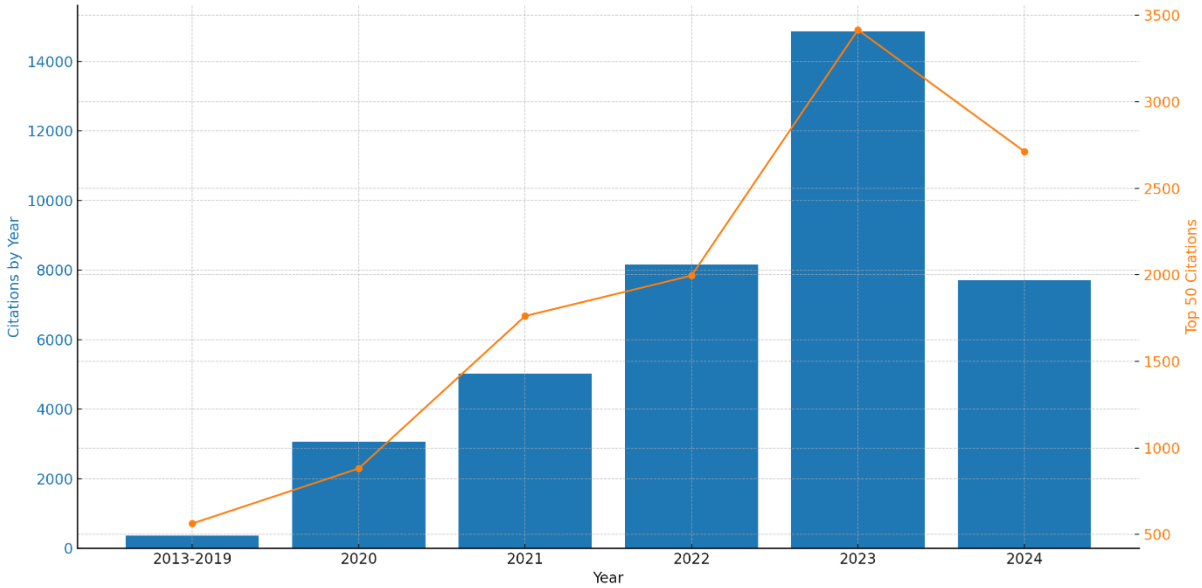

Figure 3. Number of total citations and citations for the first 50 publications by year (until March 2024)

3.2.3. Publishers

The search keywords in the databases Google Scholar, Web of Science (WoS), and Scopus were formed based on previous studies of the authors mentioned in this article based on the previous knowledge of the subject by the authors in the research team.

The top 10 publishers from a total of 208 in this field, shown as a percentage, are: IEEE (36.28%), Springer Nature (13.38%), MDPI (8.48%), Elsevier (7.62%), ACM (6.86%), Taylor & Francis (3.49%), Wiley (3.17%), Frontiers Media Sa (1.73%), Iated-Int Assoc Technology Education & Development (1.62%), Emerald Group Publishing (1.09%). This information also highlights the diversity of publishers contributing to this research area (Figure 4).

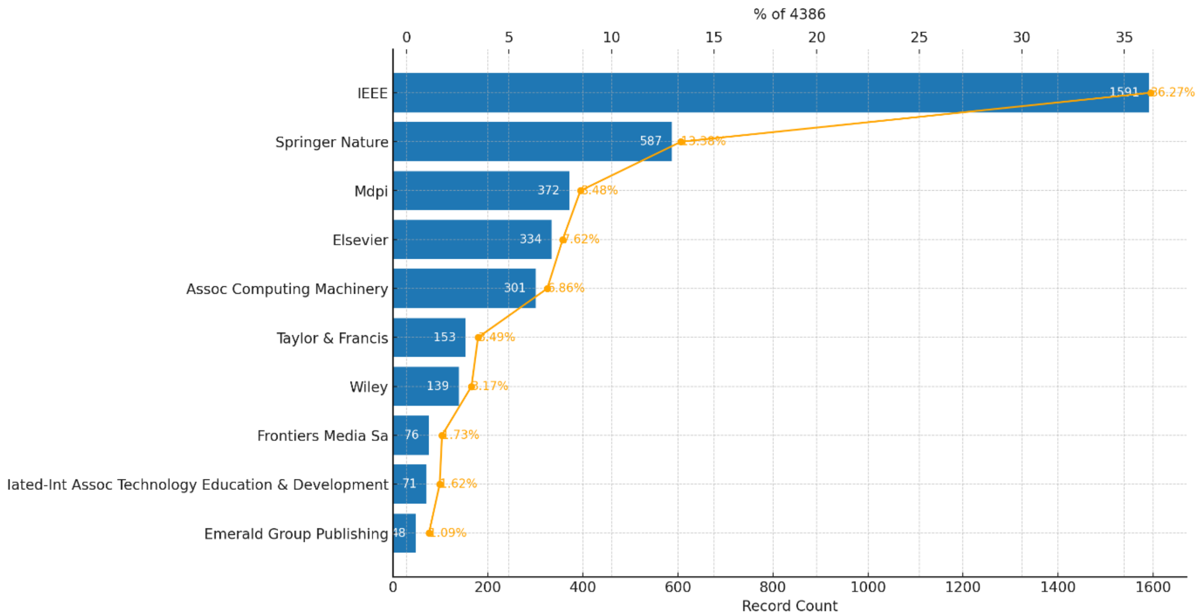

Figure 4. Publications Record by Publisher

3.2.4. Publication by countries

In terms of country contributions (Figure 5), the United States (21.98%) and China (21.11%) lead the way, followed by South Korea (6.84%), Germany (6.13%), England (5.88%), Spain (4.72%), Italy (4.61%), Australia (4.58%), Canada (4.45%), and Taiwan (4.06). There are showing 10 out of 106 entries. It's worth noting that several other European countries, such as Spain, Italy, and Australia, also feature prominently. The percentage is calculated from a total of 4386

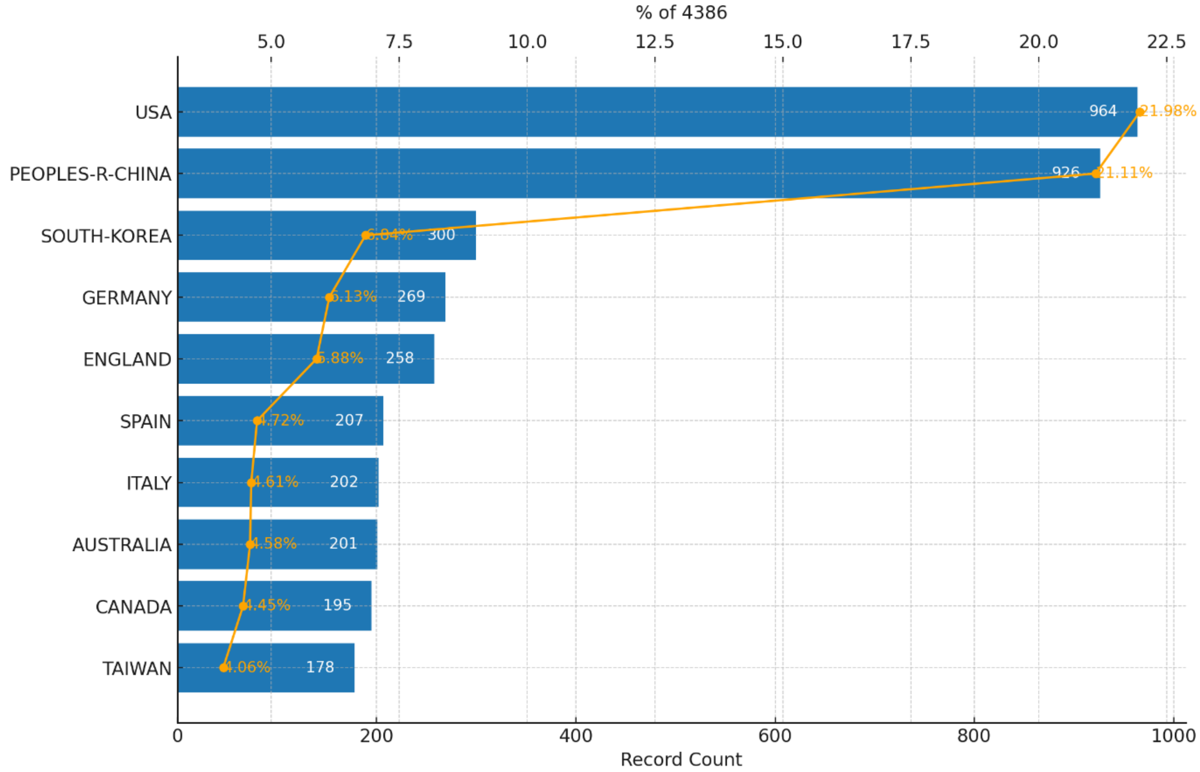

Figure 5. Country Production in Engineering Education

3.2.5. Publication by Universities/Affiliations

The total count of all entries by Universities/Affiliations is 3625. The percentage is calculated from a total of 4386 WoS records (Table 3).

The analysis of affiliations/universities (Figure 6) reveals a diverse range of institutions contributing to this field. Nanyang Technological University (2.55%), the State University System of Florida (1.8%), and the Chinese Academy of Sciences (1.62%) are among the top producers of research in this area.

Table 3.

Records by Universities/Affiliations

Affiliations /Universities	Record Count	% of 4386
NANYANG TECHNOLOGICAL UNIVERSITY	112	2.554
STATE UNIVERSITY SYSTEM OF FLORIDA	79	1.801
CHINESE ACADEMY OF SCIENCES	71	1.619
UNIVERSITY OF CALIFORNIA SYSTEM	53	1.208
PENNSYLVANIA COMMONWEALTH SYSTEM OF HIGHER EDUCATION PCSHE	49	1.117
UNIVERSITY OF LONDON	49	1.117
PENNSYLVANIA STATE UNIVERSITY	40	0.912
KOREA ADVANCED INSTITUTE OF SCIENCE TECHNOLOGY KAIST	38	0.866

Affiliations /Universities	Record Count	% of 4386
SINGAPORE UNIVERSITY OF TECHNOLOGY DESIGN	38	0.866
TSINGHUA UNIVERSITY	38	0.866
Showing 25 out of 3625 entries		
10 record(s) (0.228%) do not contain data in the field being analyzed		

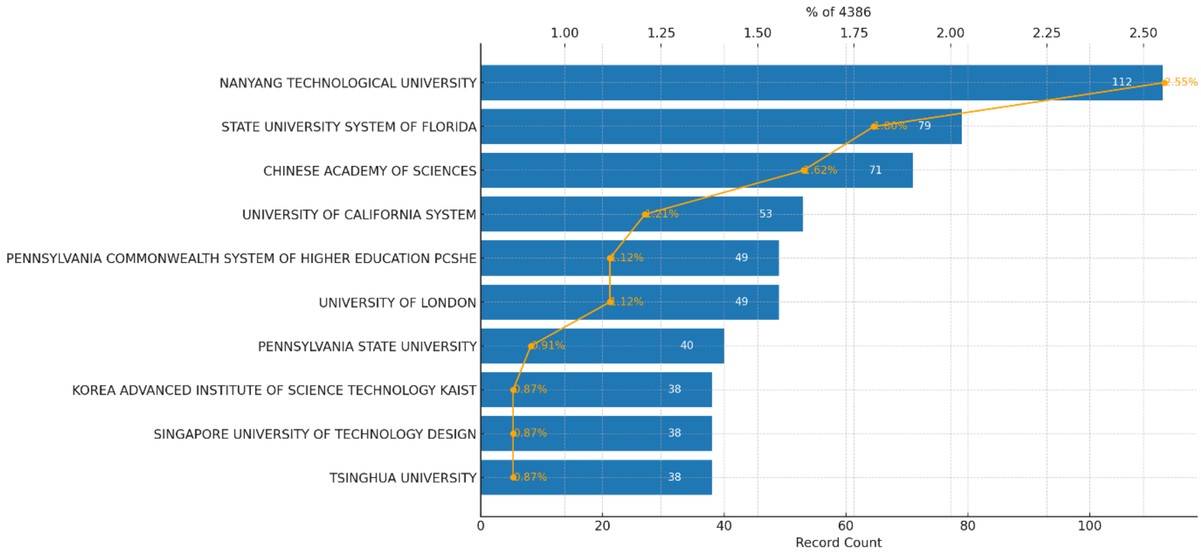

Figure 6. Publication Records by universities

3.2.6. Author contribution

Table 4. lists the most prolific authors in the field, with Niyato D (1.05%), Xiong ZH (0.78%), and Kang JW (0.71%) being the top contributors.

Table 4.

Records by Authors

Authors	Record Count	% of 4386
Niyato D	46	1.049
Xiong ZH	34	0.775
Kang JW	31	0.707
Kim J	30	0.684
Makransky G	22	0.502
Klippel A	21	0.479
Zhao J	21	0.479
Babu SV	20	0.456
Hui P	20	0.456
Lee J	20	0.456
Li Y	20	0.456
Showing 25 out of 12 731 entries		
1 record(s) (0.023%) do not contain data in the field being analyzed		

Implications for Bibliometric Analysis show these results:

Concentration of Expertise: The concentration of records among these authors may highlight key researchers and thought leaders in the field of engineering education in the metaverse.

Collaboration Opportunities: Understanding who the leading authors are can help identify potential collaborators and experts for future research projects.

Research Trends: Analyzing the work of these top authors could provide insights into the prevalent themes and emerging trends within the field.

Influence and Impact: The high record counts indicate that these authors greatly impact the direction and focus of research in engineering education within the metaverse.

Visual representation with a bar graph allows for a quick visual comparison of the contributions of each author, both in terms of absolute record counts and their percentage of the total records (Figure 7). The analysis of records by authors in the context of engineering education in the metaverse reveals that while a few authors have made significant contributions, the field remains broad with many other contributors. This distribution suggests a healthy diversity of research perspectives and a collaborative environment in the academic study of the metaverse's impact on engineering education.

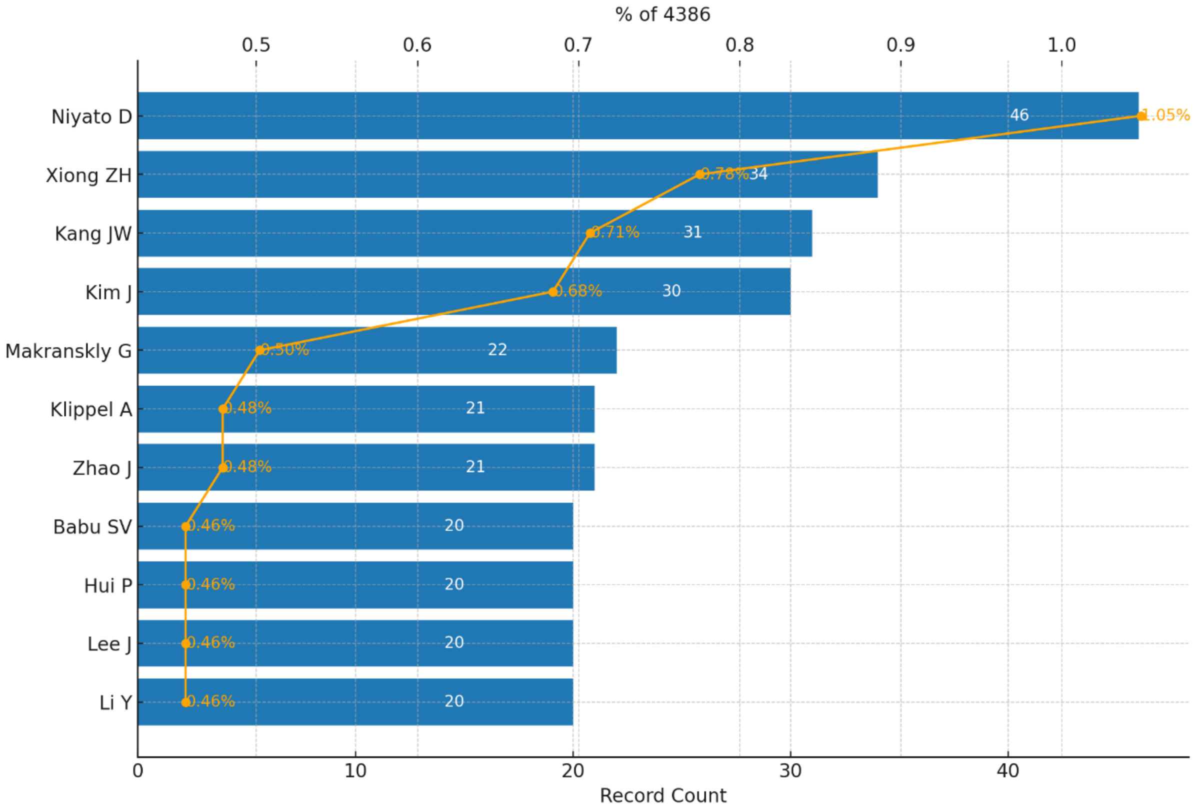

Figure 7. Publication Records by Authors in Engineering Education

3.2.7. Publication by Web of Science Categories.

The top categories are predominantly within the field of **Computer Science**:

Computer Science Information Systems: 867 records (19.767%)

Computer Science Interdisciplinary Applications: 818 records (18.650%)

Computer Science Theory Methods: 803 records (18.308%)

Computer Science Software Engineering: 725 records (16.530%)

Computer Science Artificial Intelligence: 630 records (14.364%)

Computer Science Cybernetics: 598 records (13.634%)

These categories collectively represent a significant portion of the research, emphasizing the critical role of computer science in developing and implementing metaverse technologies for engineering education.

Engineering Focus:

Engineering Electrical Electronic: 830 records (18.924%)

This category highlights the importance of electrical and electronic engineering in creating immersive and interactive educational environments fundamental to the metaverse.

Educational Research Integration:

Education Educational Research: 801 records (18.263%)

Education Scientific Disciplines: 335 records (7.638%)

These categories demonstrate significant efforts to integrate educational research with technological advancements, which is vital for the development of effective educational strategies within the metaverse.

Emerging Technologies:

Computer Science Software Engineering: 725 records (16.530%)

Computer Science Artificial Intelligence (AI): 630 records (14.364%)

These categories primarily emphasize the development of software solutions and AI applications, essential for building adaptive and intelligent educational systems in the metaverse.

Cybernetics and Telecommunications:

Computer Science Cybernetics: 598 records (13.634%)

Telecommunications: 518 records (11.810%)

Incorporating these categories highlights the significance of effective communication systems and cybernetic principles in the metaverse, which is essential for developing seamless virtual environments and interactive educational tools.

In conclusion, the data from Table 5. emphasizes the need for an interdisciplinary approach to integrating the metaverse into engineering education. The substantial representation of computer science and engineering fields indicates a robust technical foundation, while the inclusion of educational research highlights the importance of pedagogical innovation. This comprehensive approach is essential for maximizing the potential of the metaverse to transform engineering education.

Table 5.

Records by Web of Science category

Web of Science Categories	Record Count	% of 4386
Computer Science Information Systems	867	19.767
Engineering Electrical Electronic	830	18.924
Computer Science Interdisciplinary Applications	818	18.650
Computer Science Theory Methods	803	18.308
Education Educational Research	801	18.263
Computer Science Software Engineering	725	16.530
Computer Science Artificial Intelligence	630	14.364
Computer Science Cybernetics	598	13.634
Telecommunications	518	11.810
Education Scientific Disciplines	335	7.638
Engineering Multidisciplinary	206	4.697
Imaging Science Photographic Technology	200	4.560
Computer Science Hardware Architecture	187	4.264
Physics Applied	157	3.580
Materials Science Multidisciplinary	129	2.941
Chemistry Multidisciplinary	118	2.690
Ergonomics	100	2.280
Green Sustainable Science Technology	99	2.257
Multidisciplinary Sciences	87	1.984

Web of Science Categories	Record Count	% of 4386
Environmental Sciences	86	1.961
Environmental Studies	81	1.847
Engineering Civil	80	1.824
Automation Control Systems	78	1.778
Instruments Instrumentation	73	1.664
Engineering Industrial	60	1.368
Showing 25 out of 120 entries		

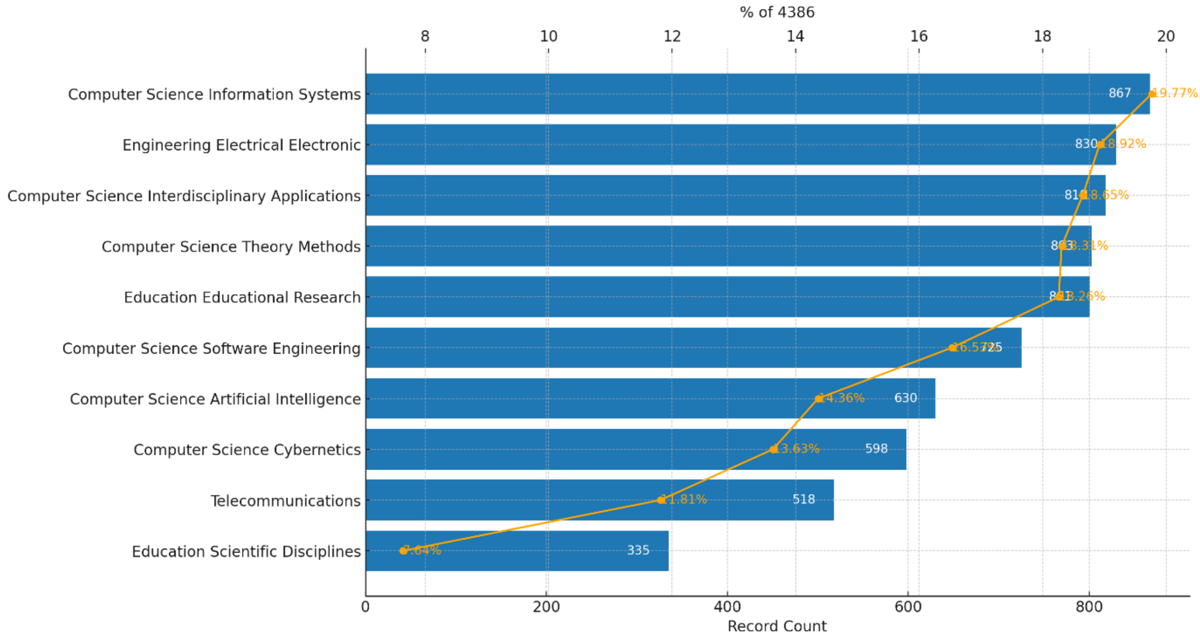

Figure 8. Publication Records by Web of Science Categories in Engineering Education

Based on the tables and figures provided, here is an analysis of the data:

Finally, the analysis of research areas (Figure 8) shows that the majority of publications fall under Computer Science (62.56%), Engineering (30.71%), and Education & Educational Research (24.76%). Other notable areas include Telecommunications, Imaging Science & Photographic Technology, and Chemistry.

In summary, the data showcases the rapidly growing interest in engineering education in the metaverse, with contributions from various countries, institutions, and publishers. The field appears to be interdisciplinary, spanning computer science, engineering, education, and other related domains. The provided tables and figures effectively capture and visualize the key trends and patterns within this research area.

3.3. VOSviewer results

VOSviewer is a software tool used for visualizing and analyzing bibliometric networks. It helps researchers identify patterns and relationships within large sets of scientific publications. This data typically includes information about publications, authors, keywords, and citations. VOSviewer supports various file formats like BibTeX, RIS, and plain text. In this article review, we have searched Google Scholar, Scopus, Web of Science.

To construct a map, VOSviewer uses the VOS mapping technique [9], where VOS stands for visualization of similarities. VOSviewer doesn't do any searching itself, you have to retrieve your search results and import them yourself. However, some techniques used in VOSviewer are also applied in other solutions and the information that the tool provides can be very useful to better understand your research area, especially if you are starting on a topic that is new to you like Explorer. Within the program, we can choose from several options to base the similarity on, depending on the data set and the type of analysis we want to do.

The keywords that VOSViwer identifies are represented in Table 6.

VOS is to map all these documents onto a two-dimensional chart so that the distance between the documents is related to the inverse of their similarity (they appear closer to each other if they are more similar), while at the same time, the documents must not overlap in visualization. As the sets get larger, the complexity increases and the exact position becomes more of a rough estimate, but still gives us a clear picture of overlap in related articles. The layout is created by optimizing the possibilities. The computer algorithm used tries all combinations until it finds an optimal performance.

The illustration of the results of this search can be seen in Figure 9.

Table 6.

Keywords that VOSViewer identifies

Id	Term	Occurrences	Relevance score
1	learning	26	1.6997
2	student	32	1.6225
3	education	32	1.3664
4	virtual reality	24	1.2557
5	experience	26	1.0869
6	study	27	1.0681
7	teaching	19	1.0298
8	article	10	0.9168
9	effectiveness	11	0.8526
10	technology	28	0.8277
11	immersive virtual reality	18	0.8245
12	use	16	0.7507
13	application	20	0.6396
14	research	17	0.6052
15	paper	21	0.4539

Keywords such as learning (26 occurrences, relevance score 1.6997), student (32 occurrences, relevance score 1.6225), education (32 occurrences, relevance score 1.3664), and teaching (19 occurrences, relevance score 1.0298) highlight a strong emphasis on educational practices and methodologies within the metaverse context. This suggests a significant interest in how virtual environments can enhance learning experiences and student engagement.

Virtual Reality and Immersive Experiences: Virtual reality (24 occurrences, relevance score 1.2557) and immersive virtual reality (18 occurrences, relevance score 0.8245) underscore the focus on immersive technologies. These keywords indicate a critical exploration of how virtual reality can be leveraged to create realistic and engaging educational simulations.

Technological Integration: Technology (28 occurrences, relevance score 0.8277), application (20 occurrences, relevance score 0.6396), and use (16 occurrences, relevance score 0.7507) highlight the integration of various technological tools and applications within educational settings. This includes discussions on the practical applications of technology in enhancing educational effectiveness and student outcomes.

Research and Publications: Keywords such as article (10 occurrences, relevance score 0.9168), research (17 occurrences, relevance score 0.6052), and paper (21 occurrences, relevance score 0.4539) indicate a focus on scholarly output and research dissemination in the field. These keywords reflect the academic discourse and the dissemination of findings related to engineering education in the metaverse.

Overall, the keywords identified by VOSviewer provide a comprehensive view of the prominent themes and topics within the literature on engineering education and the metaverse (Figure 9). The analysis underscores the importance of learning methodologies, virtual reality technologies, and educational research in shaping the future of engineering education within virtual environments.

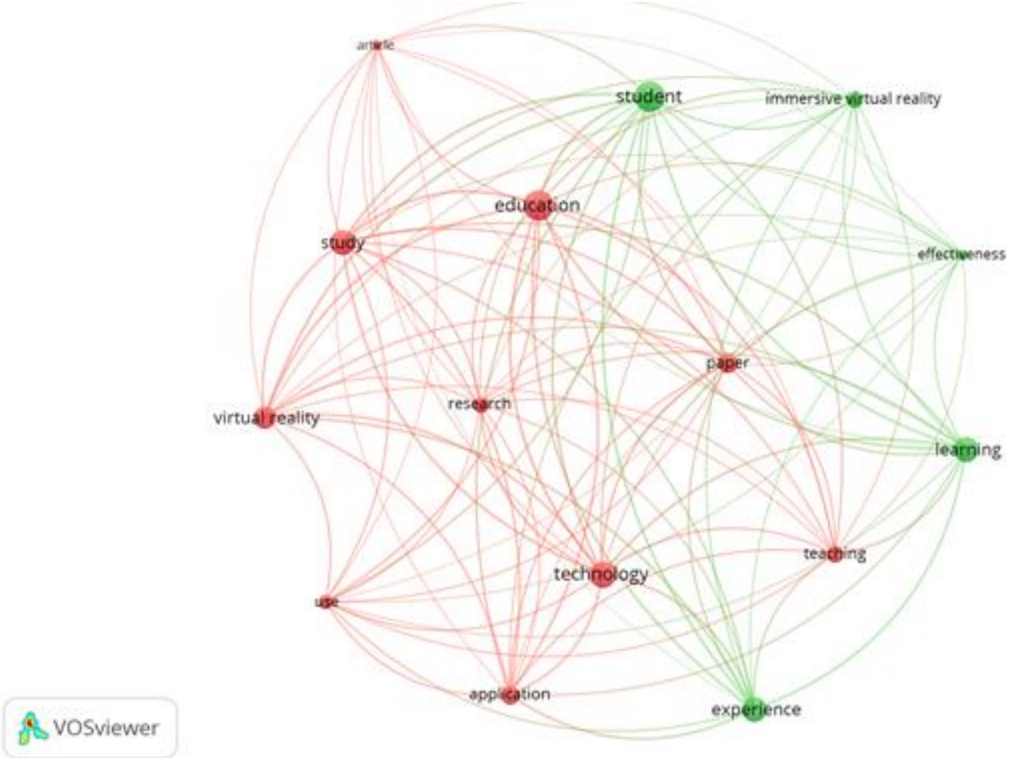

Figure 9. Results of the links according to term occurrences

Formation of the clusters. The terms selected according to the keywords identified by VOS are 21227, of which 189 meet the threshold. In the mapping, which was done according to the title, abstract, and keywords in the publications, only those terms with a minimum 25 number of occurrences were included. From them, 3 clusters were formed, represented with different colors (Figure 10).

The clustering process includes:

Data Input: Titles and abstracts of a set of publications are input into VOSviewer.

Term Extraction: Terms such as "education," "virtual reality," "metaverse," "learning," etc., are extracted.

Co-occurrence Matrix: A co-occurrence matrix displays the frequency of term pairs appearing together in the same publication.

Similarity Calculation: The calculation of similarity involves assessing the strength of the association between terms.

Network Construction: A network of terms is constructed based on the calculated similarities.

Clustering: The network is partitioned into clusters, where terms like "virtual reality" and "education" might form one cluster, while "experience" and "learning" form another.

Visualization: The clusters are presented in a two-dimensional map, with each cluster distinguished by a unique color.

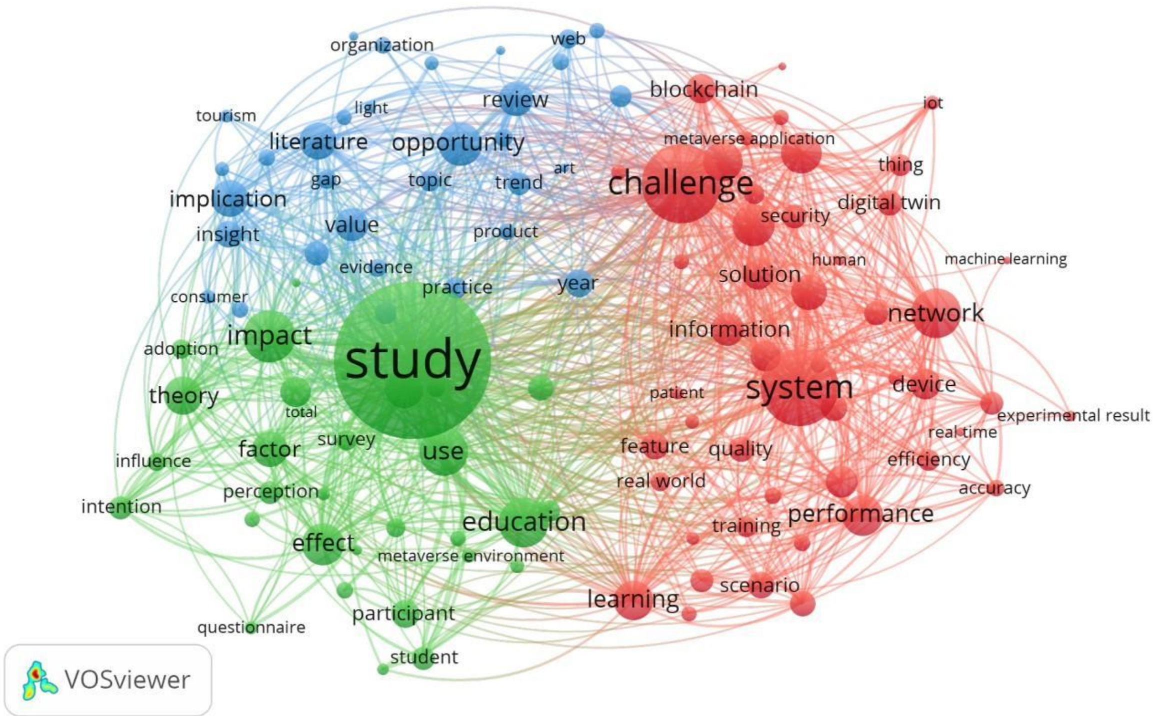

Figure 10. Clusters represented with different colours

One of the key features of VOSviewer is its ability to create maps based on terms extracted from the textual data of publications. This process allows researchers to identify and visualize the main themes and relationships within a set of publications, facilitating a deeper understanding of the structure and trends in the research area.

5. CONCLUSIONS

This study investigates the relationship between engineering education and the Metaverse through bibliometric analysis, offering a systematic overview of the research landscape. By utilizing tools such as Publish or Perish and VOSviewer, and analyzing data from major databases including Web of Science, Scopus, and Google Scholar, the study identifies key trends in publication patterns, citation metrics, and the interdisciplinary nature of the field. The findings indicate a fragmented but consistently growing body of research, with significant contributions from specific countries, institutions, and authors.

The study provides a quantitative overview of the field but emphasizes the necessity for more in-depth qualitative research on the practical use of Metaverse technologies in engineering education. Important areas that require further exploration include the integration of these technologies into the curriculum, ways to enhance learner engagement, and the effects of immersive environments on educational outcomes. Furthermore, the reliance on specific databases may have omitted relevant studies, highlighting the need for a wider range of data sources in future research.

This research, despite its limitations, provides a foundational understanding of the Metaverse's role in engineering education. By outlining the current landscape, it seeks to inform future studies and practical applications, promoting more interactive, engaging, and effective learning experiences in engineering disciplines.

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БІБЛІОМЕТРИЧНИЙ АНАЛІЗ ІНЖЕНЕРНОЇ ОСВІТИ В МЕТАПРОСТОРІ

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Анотація. Метапростір – це стабільне спільне цифрове середовище, яке поєднує фізичну і віртуальну реальність, дозволяючи здійснювати розширені мультисенсорні взаємодії. Визнання Метапростору значно зросло після пандемії COVID-19. Проте, незважаючи на його потенційні переваги для освіти, існують помітні прогалини в оцінюванні навчальних процесів у Метапросторі, особливо це стосується правових обмежень та державного контролю. Метою дослідження є вдосконалення освітніх процесів викладання різних інженерних дисциплін шляхом впровадження інноваційних, інтерактивних та захоплюючих навчальних середовищ для надання студентам можливості опановувати сучасні навички, необхідні для досягнення успіху в технологічному ландшафті, що швидко розвивається.

У цій статті за допомогою бібліометричного аналізу з метою визначення ключових тенденцій, викликів і можливостей досліджується використання Метапростору в інженерній освіті. У дослідженні проаналізовано бібліографічні мережі та статистичні дані з використанням сучасних інструментів, таких як Publish or Perish та VOSviewer, для складання карти наукового ландшафту. Бібліометричний аналіз надає кількісне уявлення про дослідницькі тенденції, кількість цитувань та авторитетність авторів, що представлено у вигляді таблиць та графіків для кращої візуалізації. Ця стаття має на меті поглибити наше розуміння того, як цифрові та імерсивні технології змінюють освітні практики та підвищують залученість студентів, їх мотивацію та результати навчання. Аналіз показав важливість постійних досліджень та регулярних інвестицій у Метапростір як життєво важливий ресурс для сучасної освіти, особливо в інженерних дисциплінах, які успішно розвиваються завдяки інтерактивному та практичному навчальному середовищу. Представлене дослідження, незважаючи на певні обмеження, закладає важливий фундамент для уявлення того, як Метапростір може трансформувати інженерну освіту. Після ретельного аналізу та окреслення сучасного ландшафту автори роблять висновки, які можуть бути орієнтиром для подальших досліджень.

Ключові слова: Метапростір; інженерна освіта; віртуальна реальність; розширена реальність; бібліометричний аналіз; VOSviwers.