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Trends at the Intersection of Eye Tracking, Machine Learning, Distance and Online Learning: A Bibliometric Analysis

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Abstract

In recent years, a considerable amount of scientific research has been conducted on eye tracking, distance/online learning and machine learning. However, there is no comprehensive bibliometric analysis study regarding the current situation in the intersection of these studies. In this study, the bibliometric analysis of scientific and academic articles (n = 8575) published in the last five years (2019-2023) in the context of eye tracking, distance education, online education and machine learning is discussed. During the data collection process, the data obtained from the Web of Science platform were classified on a yearly basis. Data obtained from the Web of Science platform were mapped, visualized and analyzed with VosViewer, pyBibx and Tableau software. According to the results of the research, the authors named "liu, sannyuya" and "liu, zhi" appeared as top two authors with 25 TLS and identified as the most prominent authors in this field. It was observed there occured identifiable networks of collaboration between different researchers. The works by Alqurashi (2019) (TLS = 31), Caskurlu (2021) (TLS = 29) and Accettone (2022) (TLS = 27) were more prominent as the result of citation analysis. The countries such as China, Singapore, Thailand, Philippines, Ethiopia, Bahrain United Arab Emirates, have become more prominent since 2021. Such as Nanyang Technol Univ. (Singapore) (TLS = 71), Monash Univ. (Australia) (TLS = 69), Cent China Normal Univ. (China) (TLS = 66), Chinese Acad Sci. (China) (TLS = 66), Zhejiang Univ. Organizations (China) (TLS = 57) were discovered as top organizations. While the keywords like online learning (TLS = 5185), education (TLS = 4012), students (TLS = 3391), performance (TLS = 3040), e-learning (TLS = 2934) were representing the general trends among the researchers, the trends with the phrases such as "natural language processing", "machine learning", "deep learning" and "sentiment analysis" started to be more visible and important among the researchers. However, no direct trend was found regarding "eye-tracking" in this

work. The reason behind this can be because of that there are not yet enough studies in the context of distance/online learning and machine learning benefiting from to eye-tracking, eye-tracking technologies or eye-tracking data. It was concluded that there is potential a gap in the literature on the subject of "eye-tracking" in the context of "distance/online learning", and "machine learning". Therefore, it is recommended to conduct a structured or systematic literature review in order to compare the methods and data types used in the studies and visualize the relations in more detail.

Keywords

Eye-Tracking, Machine Learning, Distance Learning, Online Learning, E-Learning, Bibliometric Analysis

1. Introduction

Eye tracking technologies have led to various developments in many scientific fields such as human-computer interaction, cognitive psychology and educational research in recent years [1]-[3]. These technologies essentially allow researchers to capture and analyze individuals' visual attention by monitoring their eye movements. By examining computer-aided models of eye movements, researchers can access important information about human visual perception, attention distribution, and cognitive processes in the brain. With the rapid development of computer and Internet technologies in recent years, accessing studies in scientific research fields has become easier for many researchers and followers via scientific journal databases such as Web of Science and Scopus. In addition, it has become possible to make future predictions regarding the studies carried out by means of bibliometric analyses [4]-[6]. This study focuses on the current status and possible future trends in the intersection of eye tracking distance education, online education and machine learning. In this context, firstly, the research problem is mentioned, and then important studies from the relevant literature are summarized. Following this, the methods used in the research are mentioned and the research results are discussed and listed in the context of the research questions.

2. Statement of Research Problem and Research Questions

Bibliometric analyses undoubtedly provide the researchers better insights in the scientific works on e-learning [7], mobile learning [8], instructional design [9], distance and higher education [10]. The studies especially in the fields like eye-tracking, distance and online learning and machine learning are rapidly produced since they benefit from many different branches of science and are gaining diversity, but bibliometric analyses shedding light on the intersection of these fields are still missing. And therefore, it seems very difficult to explore the current status of these studies and predict how these studies will evolve in the coming years. In this respect, this study focuses on the current status of the studies conducted in the

last five years period and what the future situation regarding the use of eye tracking technologies in context of distance and online learning and machine learning will look like. To test whether there was a previous bibliometric analysis on that context, a simple query was first made through the Web of Science database with the keywords "eye-tracking (All Fields) AND bibliometric analysis (All Fields)" on Web of Science platform in October 2023. And only 22 results were reached as a result of the query (See Table 1).

Table 1. Table for initial query results.

Author	Article Title	Source Title	Publication Year
[11]	Exploring contributors, collaborations, and research topics in educational technology: A joint analysis of mainstream conferences	Education And Information Technologies	2023
[12]	Neuromarketing coming of age: scientific mapping of 18 years of research in the field	Index Comunicacion	2023
[13]	Consumer neuroscience on branding and packaging: A review and future research agenda	International Journal Of Consumer Studies	2023
[14]	Global trends and hotspots in the digital therapeutics of autism spectrum disorders: a bibliometric analysis from 2002 to 2022	Frontiers In Psychiatry	2023
[15]	Comprehensive bibliometric research in neuroscience: focusing on ophthalmology	Frontiers In Neuroscience	2023
[16]	User Experience: A Bibliometric Review of the Literature	Ieee Access	2023
[17]	Roles and Research Trends of Neuroscience on Major Information Systems Journal: A Bibliometric and Content Analysis	Frontiers In Neuroscience	2022
[18]	Application of Neuroscience Tools in Building Construction: An Interdisciplinary Analysis	Frontiers In Neuroscience	2022
[19]	Discovering prominent themes of the application of eye tracking technology in marketing research	Cuadernos De Gestion	2022
[20]	Neuroscience research in consumer behavior: A review and future research agenda	International Journal Of Consumer Studies	2022
[21]	Expanding horizons of cross-linguistic research on reading: The Multilingual Eye-movement Corpus (MECO)	Behavior Research Methods	2022
[22]	Mapping Neuroscience in the Field of Education through a Bibliometric Analysis	Brain Sciences	2022
[23]	Dyslexia: A Bibliometric and Visualization Analysis	Frontiers In Public Health	2022
[24]	A Bibliometric Analysis and Visualization of the Use of Eye-Tracking Technologies for Vision Screening	2021 International Conference On E-Health And Bio-Engineering (Ehb 2021), 9th Edition	2021
[25]	Neuromarketing research in the last five years: a bibliometric analysis	Cogent Business & Management	2021

Continued

[26]	A Bibliometric Study on Eye-Tracking Research in Tourism	Tourism	2021
[27]	Mapping the Evolutions and Trends of Literature on Wayfinding in Indoor Environments	European Journal Of Investigation In Health Psychology And Education	2021
[2]	Research Trends of Human-Computer Interaction Studies in Construction Hazard Recognition: A Bibliometric Review	Sensors	2021
[28]	Planning an experiment in a virtual environment reality as a place of research on human behaviour using methods of neuroscience measurement - bibliometric analysis and methodological approach	Knowledge-Based And Intelligent Information & Engineering Systems (Kse 2021)	2021
[29]	An analysis of process-tracing research on consumer decision-making	Journal Of Business Research	2020
[30]	Landscapes and Emerging Trends of Virtual Reality in Recent 30 Years: a Bibliometric Analysis	Advanced & Trusted Computing	2018
[31]	Visualizing the Intellectual Structure of Eye Movement Research in Cartography	Isprs International Journal Of Geo-Information	2016

Considering the results, it was determined that a total of 13 studies were conducted in 2022 and 2023, which is more than half of the total studies conducted until 2023, which means that eye tracking and bibliometric analysis studies have accelerated in recent years and the number of the studies have increased. Although there is an increase in the number of studies in the context of eye-tracking and bibliometric analysis, when the titles and contents of the studies are examined, a very limited number of studies (n = 6) are addressing topics such as eye-tracking and education [11], reading [21], Dyslexia [23], Human-Computer Interaction [2], Virtual Reality [30]. However, it was observed that no bibliometric study was conducted yet in the context of distance education, online education and machine learning.

With this result, main assumption of the research was supported, and relevant research questions were later produced in the context of "eye-tracking, distance and online learning and machine learning", which is the focus and main subject of the research:

- RQ-1: Which authors are most prominent in this field, and are there identifiable networks of collaboration among different researchers?
- RQ-2: What are the most cited articles or authors in the intersection of eye-tracking, distance/online learning, and machine learning?
- RQ-3: Is there a geographical and organization concentration of research activity in these domains, and are there any emerging countries and organizations contributing significantly to this field?
- RQ-4: What are the publication trends in articles that address eye-tracking, distance/online learning, and machine learning? How have these trends evolved over the past five years?

3. Related Works

Eye-tracking technologies consist of advanced hardware and software compo-

nents to precisely measure and record data obtained from individuals' eye movements. The data collected includes many other information such as eye-movement metrics (e.g. fixation points, saccades, etc.) as well as other descriptive parameters such as frequencies and percentages. Eye-tracking techniques include some particular methods such electro-oculographic, scleral search coils, photo-oculography and pupil center to corneal-reflection [32]. These data points and techniques can provide researchers with important quantitative results that can be used to analyze visual behavior and draw meaningful conclusions about the cognitive processes underlying human perception. Eye-tracking technologies have received significant attention in educational research due to their potential to provide valuable insights into students' cognitive processes, attention allocation, and engagement [11] [22]. It is also well known that eye-tracking technologies have a very important place in distance and online education research, and in recent studies, the features might be categorized under particular subheadings. This literature review aims to summarize eye tracking applications in educational research, focusing on their benefits, limitations, and future directions.

3.1. Use of Eye Tracking Technologies in Understanding Attention and Cognitive Processes

The findings of subsequent research in the field of attention and cognitive processes, which is perhaps one of the areas where eye-tracking technologies are most frequently used, are discussed in this section. In this sense, [33] used Tobii and ClearView eye tracking and analysis tools to focus on individuals' differences in expertise in perceiving and interpreting complex, dynamic visual stimuli and in the process, it was found that, compared to novices, experts focused more on relevant aspects of the stimulus, used more heterogeneous task approaches, and used knowledge-based shortcuts. In a systematic analysis study on mathematics education and eye-tracking methodologies, [1] evaluated which areas and topics were addressed, how the method was used, and how eye movements were related to mathematical thinking and learning. In this context, 161 eye-tracking studies published between 1921 and 2018 were examined and showed that most of the studies were in the field of numbers and arithmetic, but many other areas of mathematics education research were also investigated.

3.2. Use of Eye Tracking Technologies in Evaluating Learning and Instructional Design

Another field where eye-tracking technologies are widely used is the field of learning and instructional design. [34] compared static signals, dynamic signals, and non-signal educational videos in a within-subject design. In this study, the eye movements of chemistry undergraduate students (n = 28) were tracked while watching educational videos about reaction mechanisms under different signal conditions. As a result, it was shown that dynamic signals helped students better focus their attention on relevant features of representations throughout almost the

entire video presentation, and dynamic signals increased retention performance while reducing external cognitive load.

3.3. Use of Eye Tracking Technologies in Adaptive Learning Systems

With the increasing use of digital learning environments in recent years, the effects and contributions of adaptive learning systems to learning processes have become an important research area. With the addition of eye-tracking technologies, very detailed research is emerging in this field. For example, a study conducted by [35] investigated whether eye tracking could be used as a measure of the effectiveness of an e-learning material on reading. In the study, students' eye fixations were used as a noticing tool, and the results showed that there was a relationship between different competencies and fixation patterns.

3.4. Use of Eye Tracking Technologies in Distance and Online Learning Environments

The increasing tendency of educational institutions to use online and distance learning environments during the COVID-19 period brought to the fore the quality of learning processes in these environments and their effects on learners. Eye-tracking technologies have recently found an important place in such studies [3], for example, discussed the potential to transform traditional ways of teaching and learning in the classroom and the contributions of topics such as eye-tracking, data science, multi-modal learning analytics and artificial intelligence to this process. The research reported that to encourage and enhance the development of e-learning environments, methods such as collaborative and intelligent learning systems, plug-and-play devices and software modules, data science and learning analytics should be integrated into more processes in terms of student collaboration, participation and success. On the other hand, [36] investigated students' reactions and perceptions to the Learning Analytics Dashboard. In this study, an eye-tracking system was introduced into the research environment to measure students' eye movements, including eye fixations, saccades, and their subderivatives. The data was obtained by the data mining method produced by the eye tracking system, and as a result, it was revealed how the experiment involving eye-tracking technology contributed to the observation and measurement of students' reactions and the accumulation of knowledge.

Case studies with implementation of a particular software conducted in recent years also attract considerable attention. For instance, [37] focused on continuous monitoring of student engagement in the virtual classrooms and tested efficacy of the software, called *Stungage* which is processing collected data metrics such as fixation target, gazing, gaze energy similarity. The Stungage system analyzes students' facial video feeds during virtual classes to assess their visual attention and cognitive presence. The researchers reported that by identifying moments when students should focus on the presentation, the system evaluated their engagement

in real-time, achieving an F2-score of 0.88 in detecting engagement levels. Another work by [38] is about the tool, named as *VAAD*, which was developed to visualize and analyze eye movement data collected during learning sessions in online courses. By using an eye-tracker, it facilitates descriptive analyses of visual attention, helping identify learning patterns and differences among learners. Additionally, as mentioned by the researchers, *VAAD* includes a predictive module capable of anticipating learner activities during an e-learning session, offering valuable insights into online learning behaviors.

3.5. Use of Eye Tracking Technologies and AI/Machine Learning

In recent years, studies based on machine learning have been developing to process and cover many types of data (e.g. text, image, video, etc.). Data obtained from eye-tracking studies can also be processed with machine learning methods, and important and meaningful inferences are obtained from these data sets via future extraction and classification. For instance, in their study on eye-tracking and machine learning, [39] explored that the features such as pupil size, saccade, fixations, velocity, blink, pupil position, electrooculogram (EOG), and gaze point were among the biometric data that could be extracted from the eye-tracking data sets. [40] showed that eye-tracking data could be sued for identifying familiar users on the web. [41] reported that "eye tracking metrics play an important role in the classification of mental workload." (p. 1028). According to the research by [42], eye-tracking devices driven by AI and machine learning have the potential to revolutionize online education by giving teachers insightful knowledge about how students' cognitive processes and empowering them to enhance their lesson plans for better learning results.

3.6. Challenges in Integrating Eye-Tracking Technologies in Distance and Online Learning

The fact that eye-tracking technologies are becoming widespread in both conventional and online learning activities does not necessarily mean that they are always accessible technologies and applications without any technical pains. It is worth remembering that such technologies still have certain important technical challenges and barriers in terms of application and system integration. One of the most important difficulties is perhaps hardware and software cost constraints. Since the eye-tracking process requires specialized hardware and software equipment, it still requires a very costly integration. Limitations may arise due to webcam, which is a mandatory equipment for eye-tracking technologies. While webcam-based eye-tracking solutions are more accessible, they tend to be less accurate due to variations in camera quality, lighting, and angle. In terms of software, it is not uncommon to encounter more specific and specialized difficulties. Although software development processes are less time-consuming than in the past, accessing developers who are experts in eye-tracking or accelerating the process of becoming experts in this field is quite challenging. However, it may be inevitable that the

developed software will suffer from certain technical difficulties (e.g. data processing and latency) due to the existing technical infrastructure and software/library requirements. For example, continuous streaming of gaze data, particularly for cloud-based learning platforms, can consume large amounts of bandwidth. And also, processing eye-tracking data in real-time requires significant computational resources, which could introduce latency and affect responsiveness. Learning Platform integration of eye-tracking technologies is quite laborious and time-consuming. In this process, compatibility issues may arise. Many common Learning Management Systems (e.g., Moodle, Blackboard) are not built to support real-time eye-tracking data, which means they do not have standard packages for this kind of special tasks and therefore they require extensive modifications or plugin developments. There are also standardization challenges. There is still no universal framework or software integration workflows for integrating eye-tracking technologies with particular data processing workflows with existing educational software, which is making implementation highly complex and technical effort consuming. In addition to all these issues, there may also be data privacy and ethical concerns. For example, collecting and analyzing gaze data raises concerns about privacy, data security, and compliance with regulations (e.g., GDPR, CCPA). Processing of such personal data requires informed consent from both learners and teachers, as well as school administrators.

Supporting scientific studies have also been conducted regarding such difficulties and barriers. For instance, [43] discusses the promise of eye-tracking technology in education for understanding student information processing. However, it highlights challenges such as the potential inequality gap arising from differences in student participation and the need for personalized pedagogical interventions. Another study by [42] investigates the potential of AI-driven eye-tracking technology to improve online learning by monitoring students' attention and providing real-time feedback. It discusses challenges such as difficulties in capturing attention for the software algorithm, and limitations caused by working memory capacity and information processing speed, ethical considerations, integrating AI systems into existing educational platforms, and addressing the variability in students' environments and equipment.

4. Methods

In this study, bibliometric mapping, visualization and analysis methods were used to determine the current status and future trends regarding eye tracking technologies, distance, online education and machine learning. Bibliometric analysis is a quantitative research method widely used to examine patterns, trends, and relationships in scientific literature. This approach uses bibliographic data, such as publication records, citations, and co-authorship networks, to gain insight into various aspects of scholarly communication. With bibliometric analysis, special software and statistical techniques are used to analyze large data sets. One widely used analysis is co-authorship analysis, which examines patterns of collaboration

among authors. Another analysis is citation network analysis, which helps identify influential publications and key researchers in a field. In addition, it is possible to reveal the research productivity, impact and knowledge dissemination in a particular field, as well as the change between years and new emerging topics, through keyword analysis [4]-[6].

4.1. Data Collection and Nature of Research Data Set

The Web of Science (WoS) database was used to obtain bibliometric data. WoS is currently managed by Clarivate Analytics and is a very suitable platform for conducting bibliometric analysis with its rich content since 1950 and various data visualization tools it offers [44] [45]. The data collection process carried out within the scope of this research started in October 2023 and was completed in a total of two months. Academic articles published in the last five years period (2019-2023) were listed with the query tool on the WoS platform, and only academic articles were accessed. The actual content of the queries and the filters applied subsequently are shown in **Table 2**.

Table 2. Table for query setting on Web of Science.

Query	eye-tracking (All Fields) OR "eye tracking" (All Fields) AND "distance education" (All Fields) OR "distance learning" (All Fields) OR "e-learning" (All Fields) OR "online learning" (All Fields) OR "higher education" (All Fields) AND "machine learning" (Topic) AND "artificial intelligence" (Topic) OR "AI" (All Fields) OR "ML" (All Fields) AND "natural language processing" (Topic) OR "NLP" (All Fields)
Publication Years	2019 or 2020 or 2021 or 2022 or 2023
Document Type	Article
Web of Science Categories	Computer Science Artificial Intelligence or Education Educational Research or Computer Science Information Systems or Computer Science Interdisciplinary Applications or Computer Science Theory Methods or Computer Science Software Engineering or Education Scientific Disciplines or Social Sciences Interdisciplinary or Linguistics or Language Linguistics or Humanities Multidisciplinary
Citation Topics Meso	6.11 Education & Educational Research or 4.61 Artificial Intelligence & Machine Learning or 4.48 Knowledge Engineering & Representation or 6.69 Language & Linguistics or 4.47 Software Engineering or 4.284 Human Computer Interaction or 9.92 Statistical Methods or 4.182 Data Structures, Algorithms & Complexity
Citation Topics Micro	Self-regulated Learning or 4.48.672 Natural Language Processing or 6.11.333 Digital Learning or 6.11.1094 Medical Education or 4.61.145 Feature Selection or 6.11.295 Science Education or 4.48.817 Collaborative Filtering or 6.11.1395 Learning Styles or 6.11.190 Teacher Education or 6.11.1526 Computational Thinking or 4.47.410 Software Metrics or 4.48.1215 Information Visualization or 6.11.2332 Higher Education or 6.11.1889 Student Evaluation Of Teaching or 6.11.1544 Academic Development or 6.11.2525 Open Education Resources or 4.61.869 Clustering or 6.11.2357 Transformative Learning or 4.47.1111 Software Testing or 4.48.1522 Big Data or 6.11.2101 Critical Thinking or 9.92.332 Missing Data or 4.182.125 Graphs or 4.47.2069 Software Reliability or 4.182.1226 Computability
Query Date	October, 2023

A total of 8575 academic publications were reached with this query set created on WoS. It was found that the number of authors conducting research is more than 25,000 and the researchers came from 135 different countries. The number of institutions where the authors work is more than 8000. It was also explored that while 7591 publications had multiple authors, only 974 publications had articles with a single author (for further details see Figure 1). These data from the WoS platform were checked via PyBibX and it was observed that there were not missing or incorrectly formatted attributes. And since they were highly structured and clean in content, standardization and cleaning processes were not further applied.

A large number of the studies accessed according to WoS categories were identified as Educational Research (n = 4331), Computer Science Information Systems (n = 1338) and Computer Science Artificial Intelligence (n = 1328) (see Figure 2). This indicated that consistent and accurate results were reached with the created query set and filters applied. The authors who produced the most works

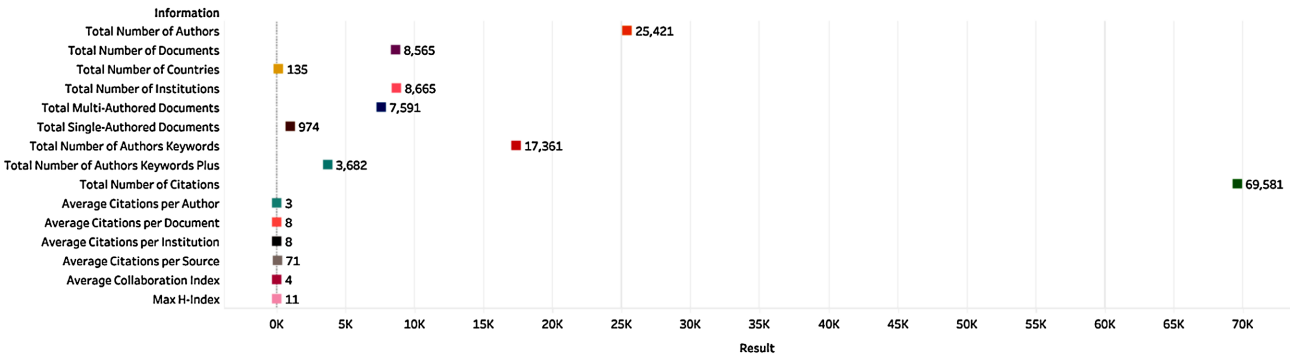

Figure 1. Query results in numbers.

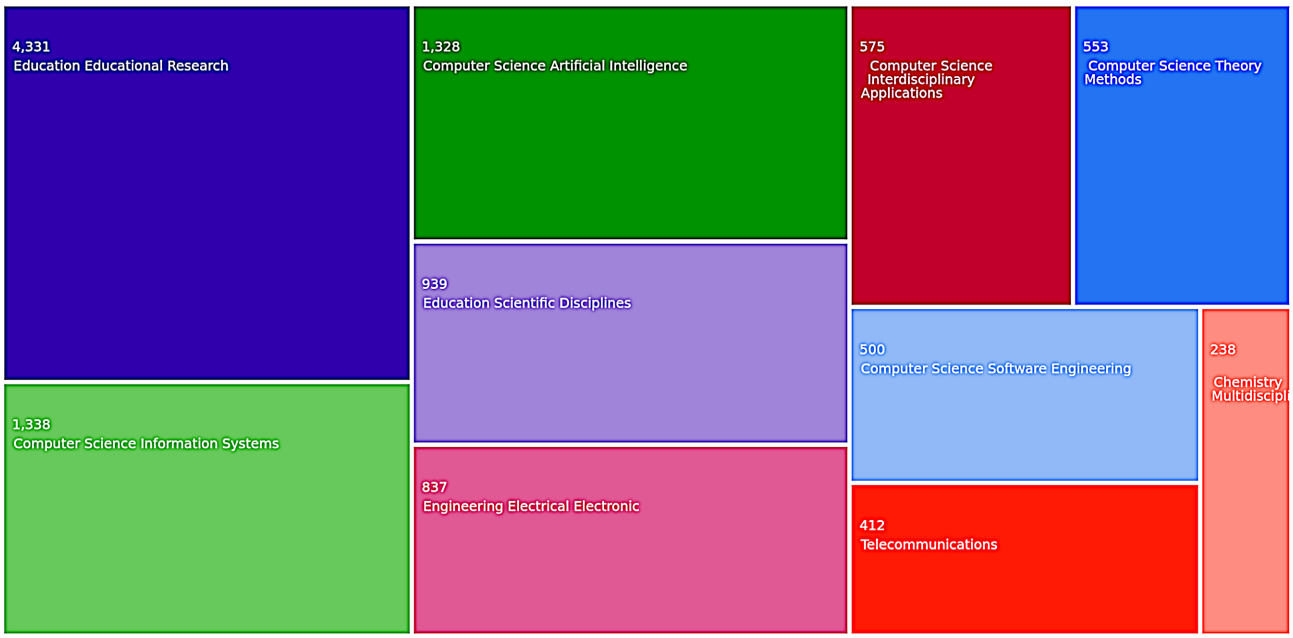

Figure 2. Distribution of WoS categories.

in this field were also identified and the author named, Y. Zhang, ranked first with over 35 works (see Figure 3). When the countries where research was conducted on this subject were listed, it was observed that most of the published works were produced in the USA (n = 1735), China (n = 1468) and Australia (n = 462) (see Figure 4). It was also determined that the citation values of the examined data set reached the highest level in 2022 (n = more than 26,000) (see Figure 5).

4.2. Data Visualization and Analysis

VOSviewer [46], pyBibx [47] and Tableau [48] software were used in the mapping,

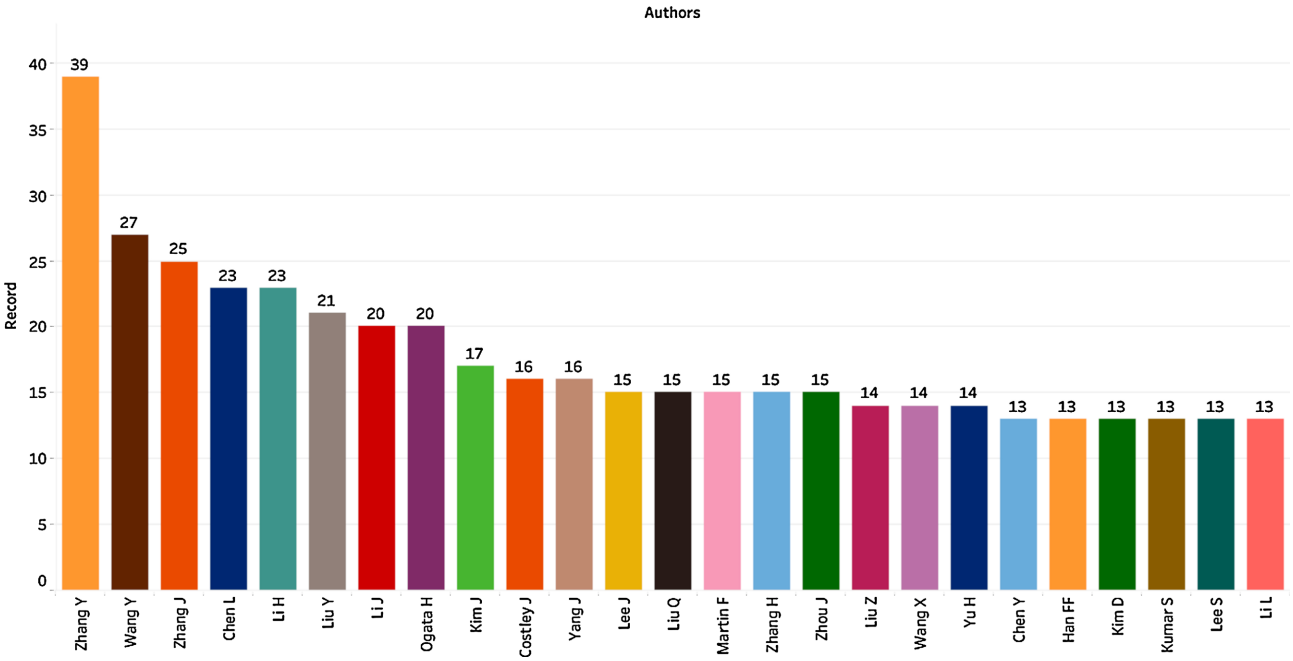

Figure 3. Distribution of authors.

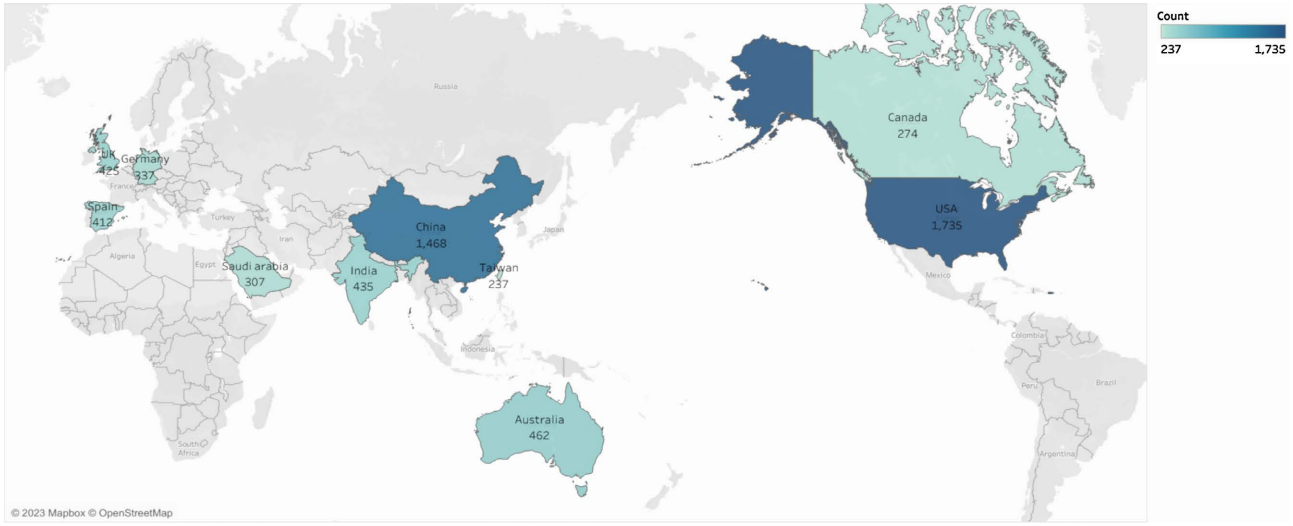

Figure 4. Distribution of top 10 countries (Map by Tableau).

visualization and analysis of the data obtained. VOSviewer and pyBibx software have been developed for bibliometric analysis and are frequently used in this field. First of all, analysis types, analysis units and analysis parameters for mapping and network visualization to be done with VOSviewer software were determined as shown in Table 3. Co-authorship, Co-occurrence and citation analysis types were determined for this study. A word cloud was created with the pyBibx software and the development of the topics discussed in the articles was displayed. The visualizations were then recorded and discussed and examined in the findings section.

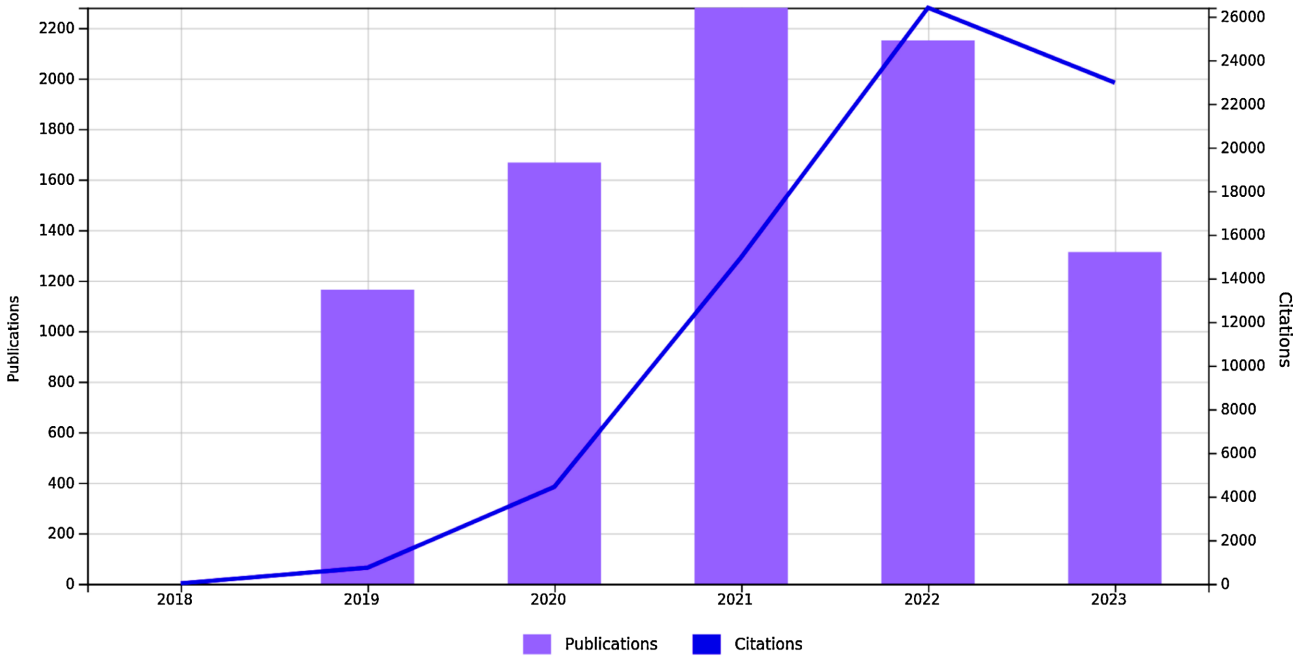

Figure 5. Citation rates within years.

Table 3. Settings for data analysis in VOSviewer.

	Type of Analysis	Unit of Analysis	Minimum Number of Documents of an Author/Organization/Country /Keyword/Citation	Minimum Number of Citations of an Author/Organization /Country	Number of Results Meeting the Threshold
1.	Co-authorship	Authors	5	5	255
2.	Co-authorship	Organizations	10	10	329
3.	Co-authorship	Countries	5	5	97
4.	Co-occurrence	All Keywords	25	---	342
5.	Citation	Documents	0	---	8,575

4.3. Limitations

This study and the results explored are limited to the bibliometric data set (n = 8575) obtained from the WoS platform in October 2023 by applying certain que-

ries and filters. Within the scope of the study, only scientific articles published in the five-year period (2019-2023) were examined.

5. Findings

In this part of the study, the findings obtained as a result of data mapping and visualization were discussed. The results associated with the research questions and the analysis and discussions regarding the results were included in the discussion section.

RQ-1: Which authors are most prominent in this field, and are there identifiable networks of collaboration among different researchers?

For this question, Co-Authorship-Authors analysis was carried out with VOSviewer. For this analysis, the minimum number of documents and citations value was determined as 5, and a total of 255 results were obtained for these parameters. With these results, Document, Citation and Total Link Strength (TLS) scores were calculated by VOSviewer. As a result of the analysis, the authors named "liu, sannyuya" (number of documents = 12 and number of citations = 376) and "liu, zhi" (number of documents = 11 and number of citations = 191) were listed as the top two authors with the 25 TLS score. The authors such as "yang, zongkai" (number of documents = 9 and number of citations = 109) and "ogata, hiroaki" (number of documents = 20 and number of citations = 188) were ranked as third and fourth authors with 22 and 21 TLS scores (see Figure 6). Regarding the network visualization created with VOSviewer, it was visualized that there occurred 6 clusters in total with the given parameters. The Co-authorship network in the middle of the visualization indicated the authors such as "liu, sannyuya", "liu, zhi", "peng, xian" and "yang, zongkai" with most frequent collaborations (see Figure 7).

RQ-2: What are the most cited authors and articles in the intersection of eye-tracking, distance/online learning, and machine learning?

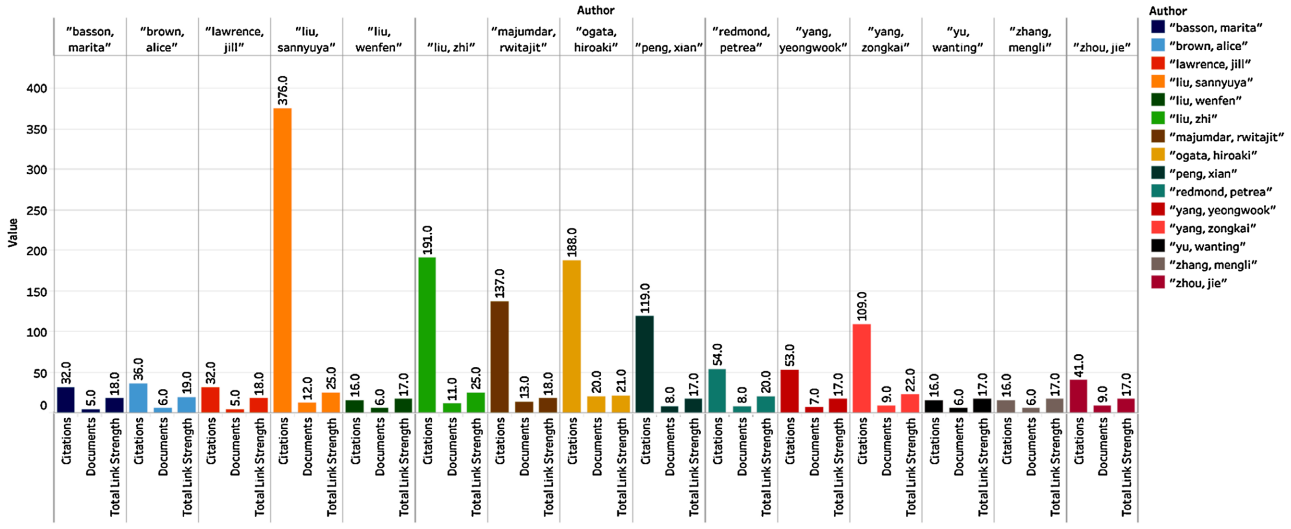

Figure 6. Distribution of top 15 authors with higher TLS scores.

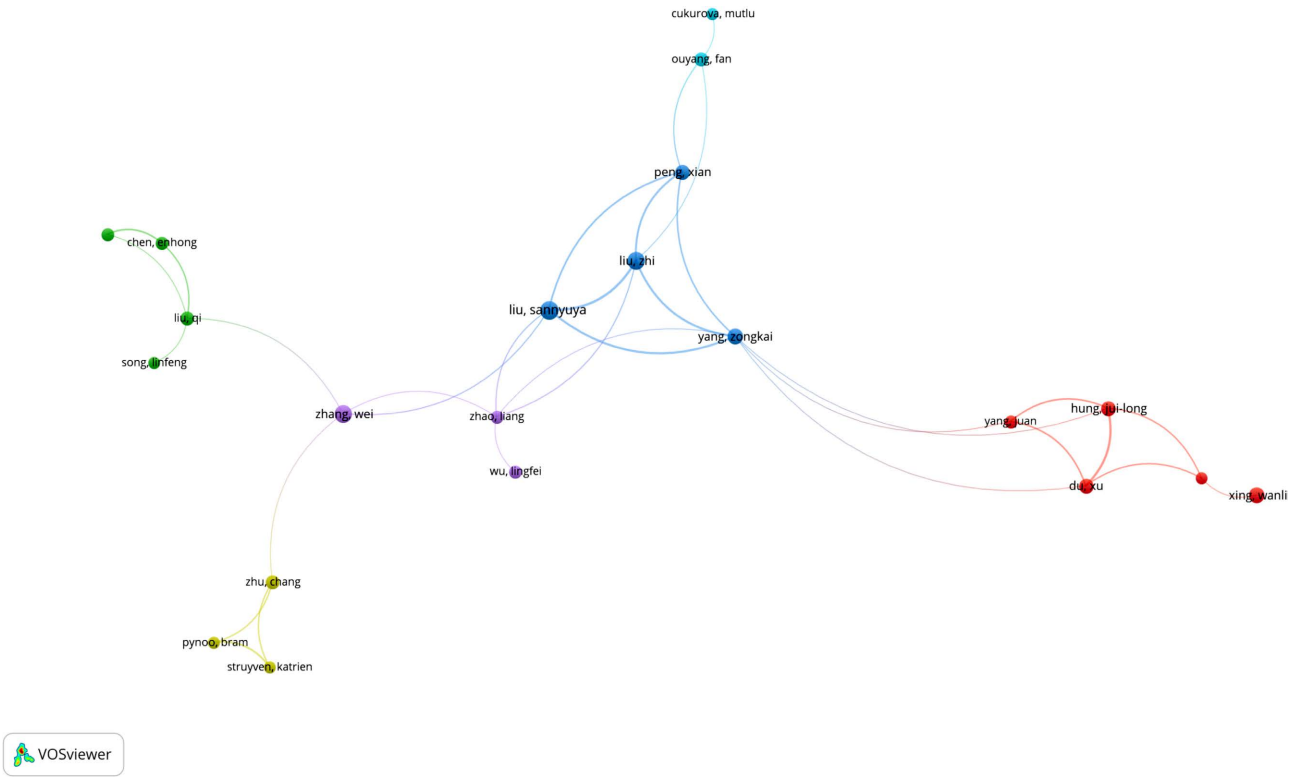

Figure 7. Network visualization for co-authorship (Weights = TLS score).

Regarding this question, citation-documents analysis was performed with VOSviewer and the minimum number of citations of documents parameter was applied as 0 and 8575 results were obtained in order to visualize all possible networks. With this, network visualization has been achieved. As a result, it was observed that 25 clusters were formed in total, and it was determined that authors and articles such as Alqurashi (2019) (TLS = 31), Caskurlu (2021) (TLS = 29) and Accettone (2022) (TLS = 27) were more prominent in the analysis (See **Figure 8**). With the given parameters, the network visualization showed that there occurred at least two clusters (cluster 22 and 23), which solely focused on eye-tracking studies (See **Figure 9**). It was also observed that three (Chiu, 2022; Khalil et al., 2020; Simmons & Mistry, 2023) out of top ten authors and articles three of the most cited articles were on COVID-19, which proved that the works on Covid 19 and distance or online learning dominated this intersection when compared to the studies (See **Table 4**).

RQ-3: Is there a geographical and organization concentration of research activity in these domains, and are there any emerging countries and organizations contributing significantly to this field?

In the context of this question, first co-author and country and then co-author organization visualizations were performed with VOSviewer. It was visualized that the countries such as USA (TLS = 757), China (TLS = 739), England (TLS = 452), Australia (TLS = 410) and Germany (TLS = 308) were the top 5 countries with higher concentration of research activity (See **Figure 10**). In the density

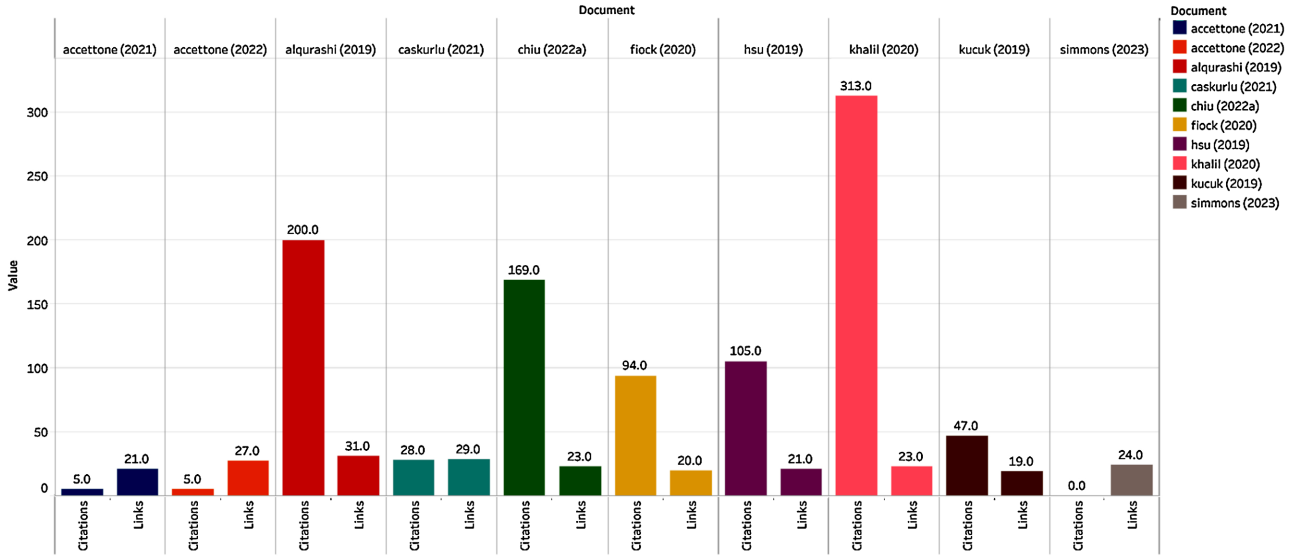

Figure 8. Distribution of top 10 authors and articles with higher TLS scores.

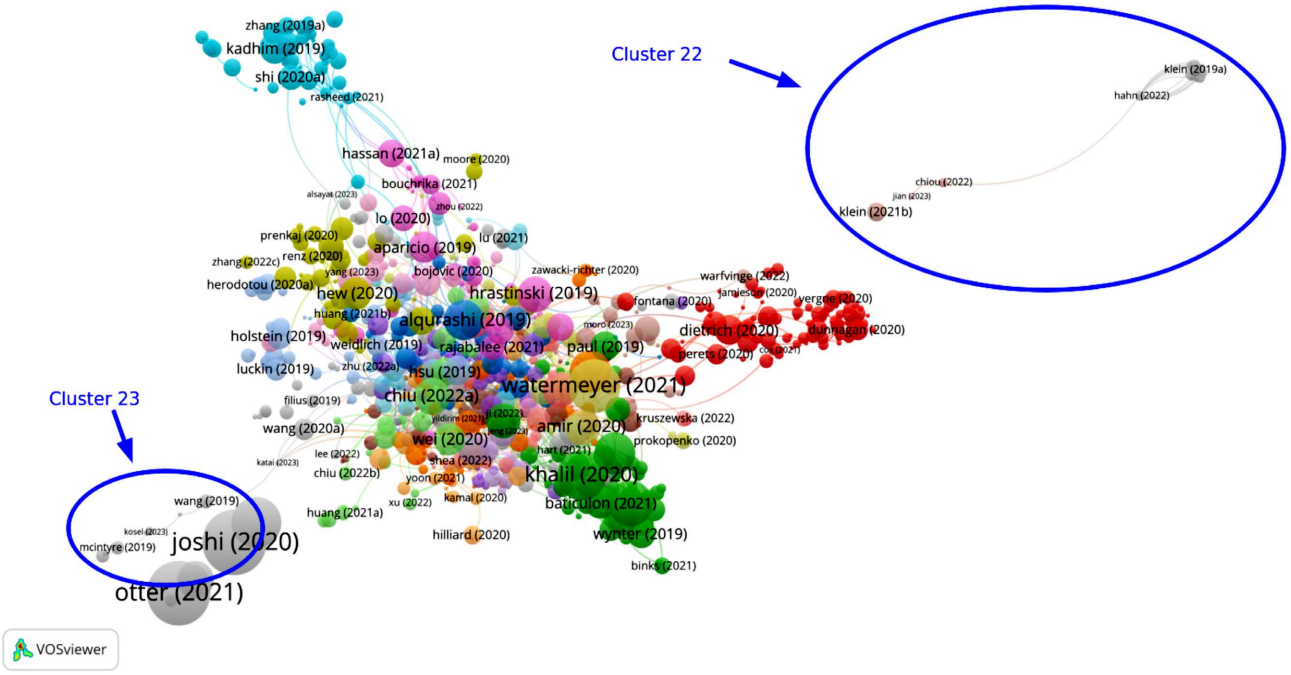

Figure 9. Network visualization of citation-document analysis (Weights: citations and number of the selected documents: 1000).

Table 4. List of the top 10 documents.

Author/ Document	Article Title	Source Title	Year	Citations	TLS
[49]	Predicting student satisfaction and perceived learning within online learning environments	Distance Education	2019	200	31
[50]	The qualitative evidence behind the factors impacting online learning experiences as informed by the community of inquiry framework: A thematic synthesis	Computers & Education	2021	28	29

Continued

[51]	Student Perceptions of Remote Chemistry Laboratory Delivery Models	Journal Of Chemical Education	2022	5	27
[52]	A Snapshot of Chemistry Teaching and Learning Practices in UK Higher Education as It Emerges from the COVID-19 Pandemic	Journal Of Chemical Education	2023	0	24
[53]	Applying the self-determination theory (SDT) to explain student engagement in online learning during the COVID-19 pandemic	Journal Of Research On Technology In Education	2022	169	23
[54]	The sudden transition to synchronized online learning during the COVID-19 pandemic in Saudi Arabia: a qualitative study exploring medical students' perspectives	Bmc Medical Education	2020	313	23
[55]	Reexamining the impact of self-determination theory on learning outcomes in the online learning environment	Education And Information Technologies	2019	105	21
[56]	Student Perceptions of Remote Chemistry Lecture Delivery Methods	Journal Of Chemical Education	2021	5	21
[57]	Designing a Community of Inquiry in Online Courses	International Review Of Research In Open And Distributed Learning	2020	94	20
[58]	A Structural Equation Model of Predictors of Online Learners' Engagement and Satisfaction	Online Learning	2019	47	19

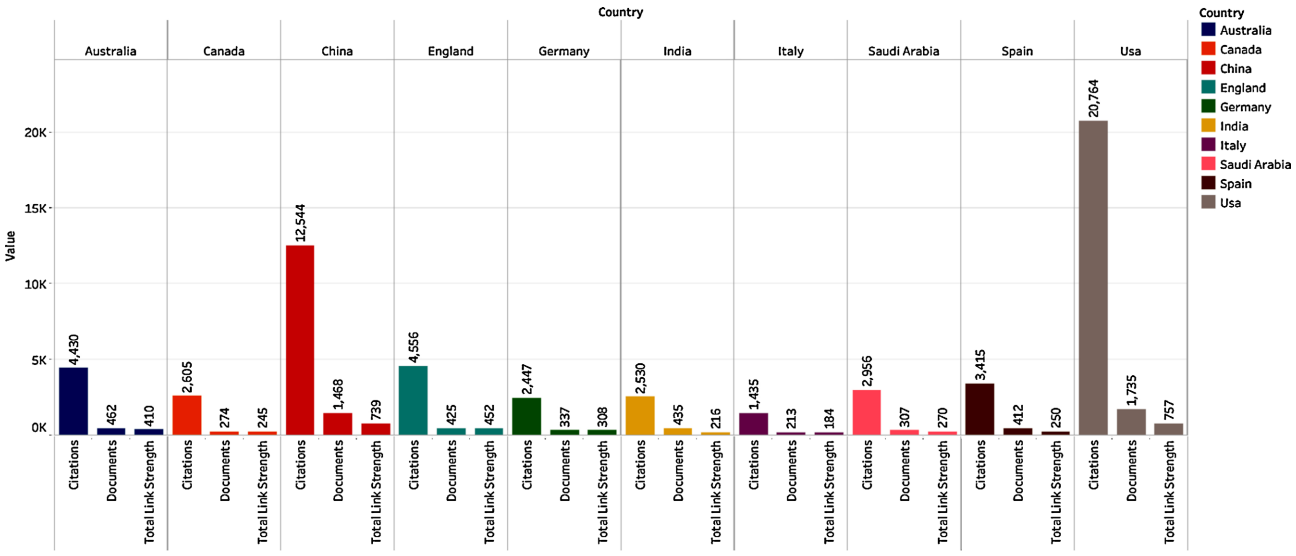

Figure 10. Distribution of top 10 countries with higher TLS scores.

visualization, 9 clusters in total appeared and it was explored that the countries such as Iceland, Colombia, Argentina, Peru, Tunisia and North Macedonia were highly differentiated from the rest of the countries, and more importantly, the countries are basically divided on the east-west axis. (See **Figure 11**). The overlay visualization applied later showed that some countries, especially China, Singapore, Thailand, Philippines, Ethiopia, Bahrain United Arab Emirates, have become more prominent since 2021 (See **Figure 12**). The co-authors-organizations analysis applied later also revealed similar results and Nanyang Technol

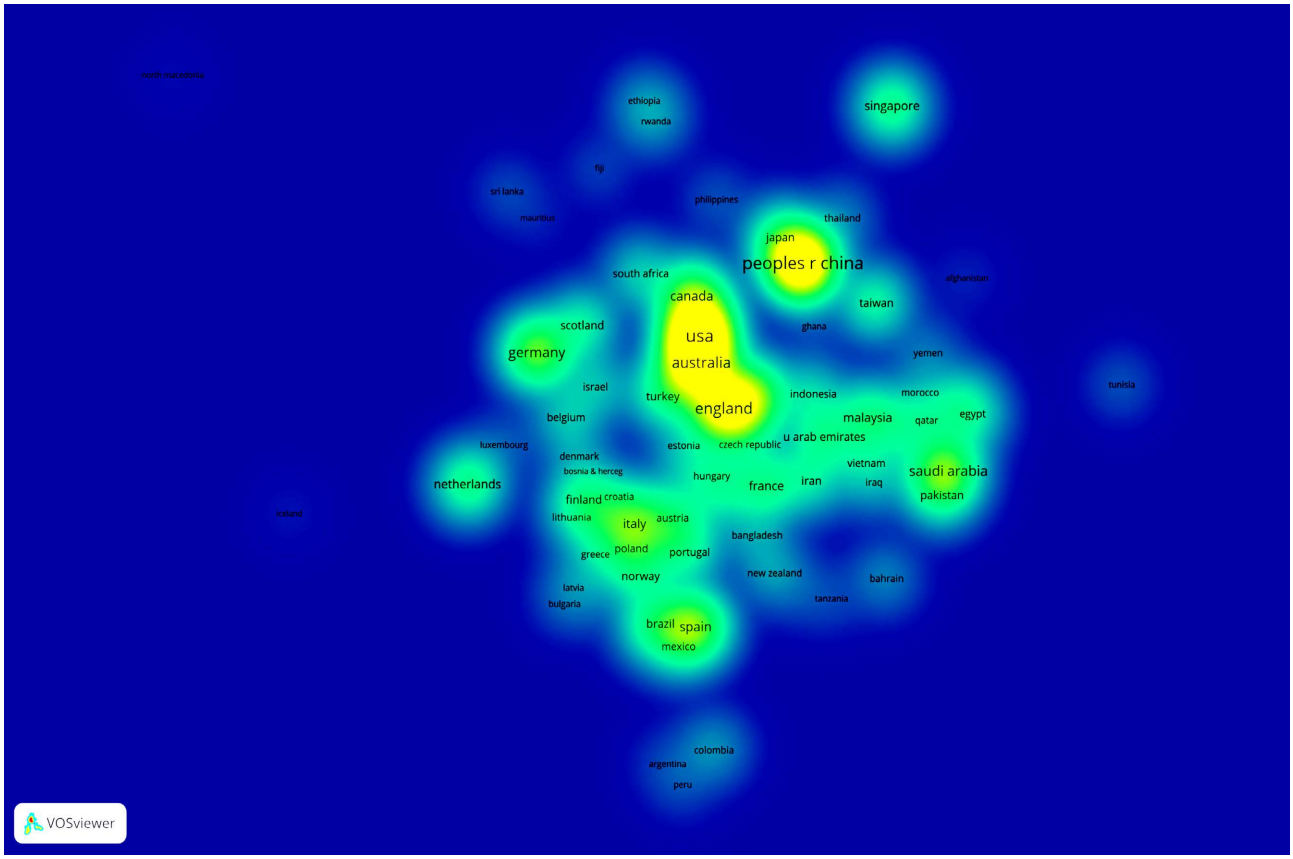

Figure 11. Density visualization of co-author - country analysis (Weights: TLS).

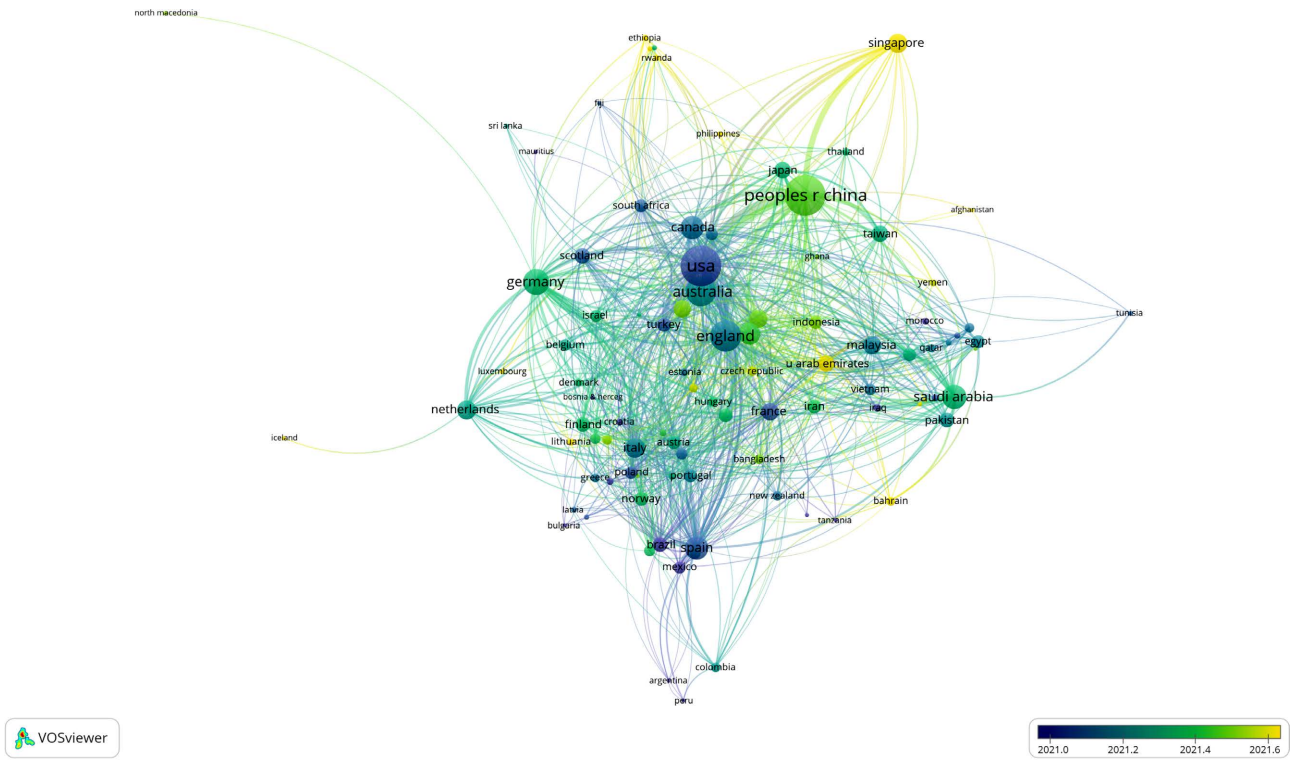

Figure 12. Overlay visualization of co-author - country analysis (Weights: TLS and Scores: average publication year).

Univ. (Singapore) (TLS = 71), Monash Univ. (Australia) (TLS = 69), Cent China Normal Univ. (China) (TLS = 66), Chinese Acad Sci. (China) (TLS = 66), Zhejiang Univ. Organizations such as (China) (TLS = 57) made up the top 5 organizations (See Figure 13). And the organizations such as Beijing Normal Univ., Tencent Ai Lab, Univ. Edinburgh, Chinese Univ. Hong Kong, King Abdulaziz Univ. and Saarland Uni. were identified as emerging organizations (See Figure 14).

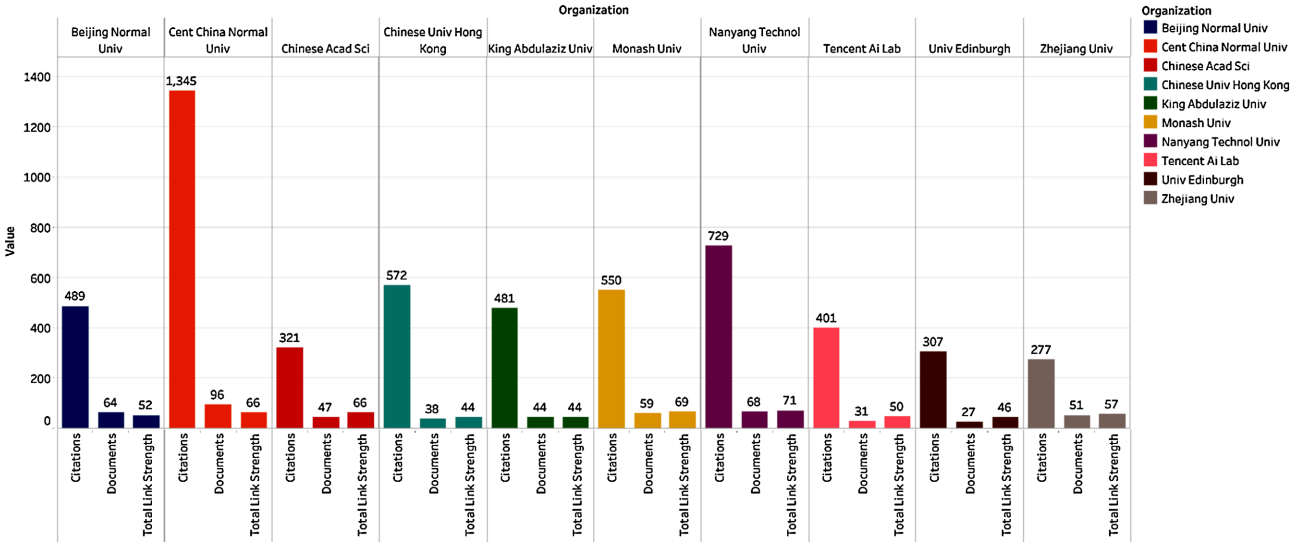

Figure 13. Distribution of top 10 organizations with higher TLS scores.

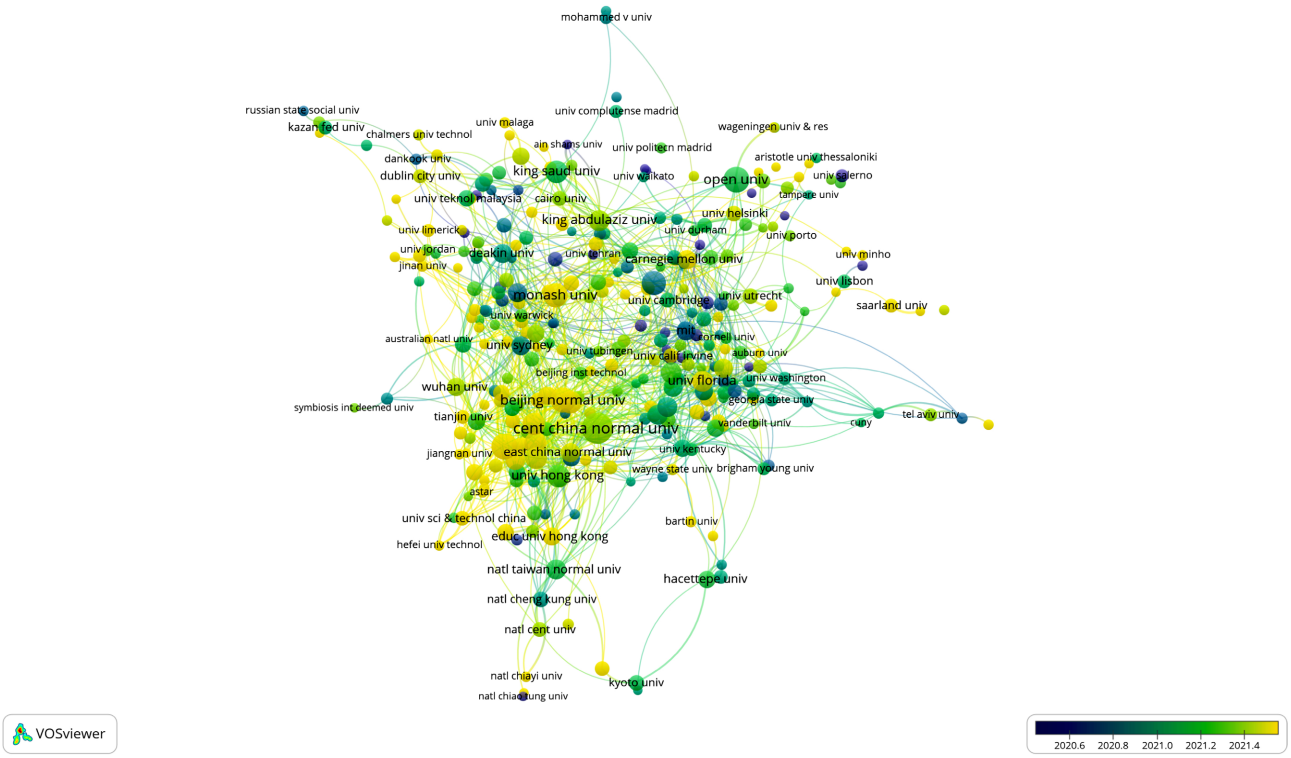

Figure 14. Overlay visualization of co-author - organization analysis (Weights: documents and Scores: average publication year).

RQ-4: What are the publication trends in articles that address eye-tracking, distance/online learning, and machine learning? How have these trends evolved over the past five years?

Considering this question, to gain a general insight into the trends emerging in the research, a word cloud was first created with keywords. Word cloud provided general information, albeit limited, and sized the prominent words according to their frequency. Accordingly, the words that stand out are words such as "learning", "online", "education", "language", "distance", "student" and "covid" (See Figure 15). Then, co-occurrence - all keywords analysis was carried out with VOSviewer. The words like online learning (TLS = 5185), education (TLS = 4012), students (TLS = 3391), performance (TLS = 3040), e-learning (TLS = 2934) appeared as the most frequently occurred keywords produced in the articles (See Figure 16). As a result of the overlay visualization, 5 clusters were identified in total and it was clarified that the keywords such as "natural language processing",

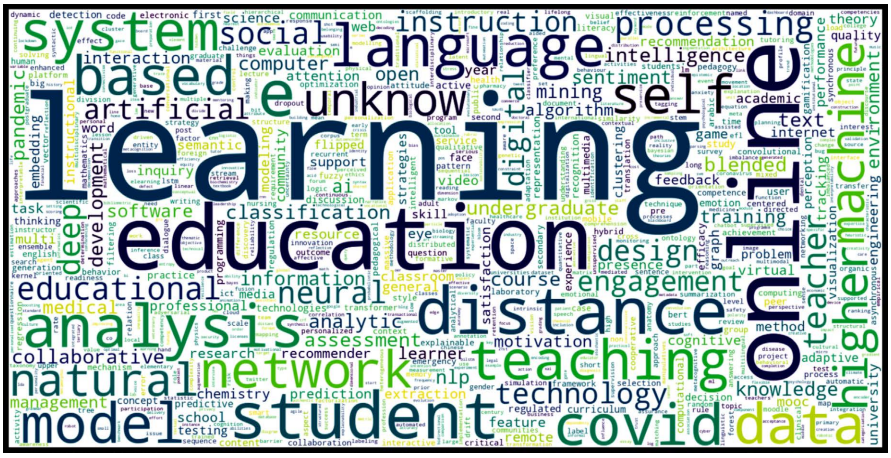

Figure 15. Word cloud for key words.

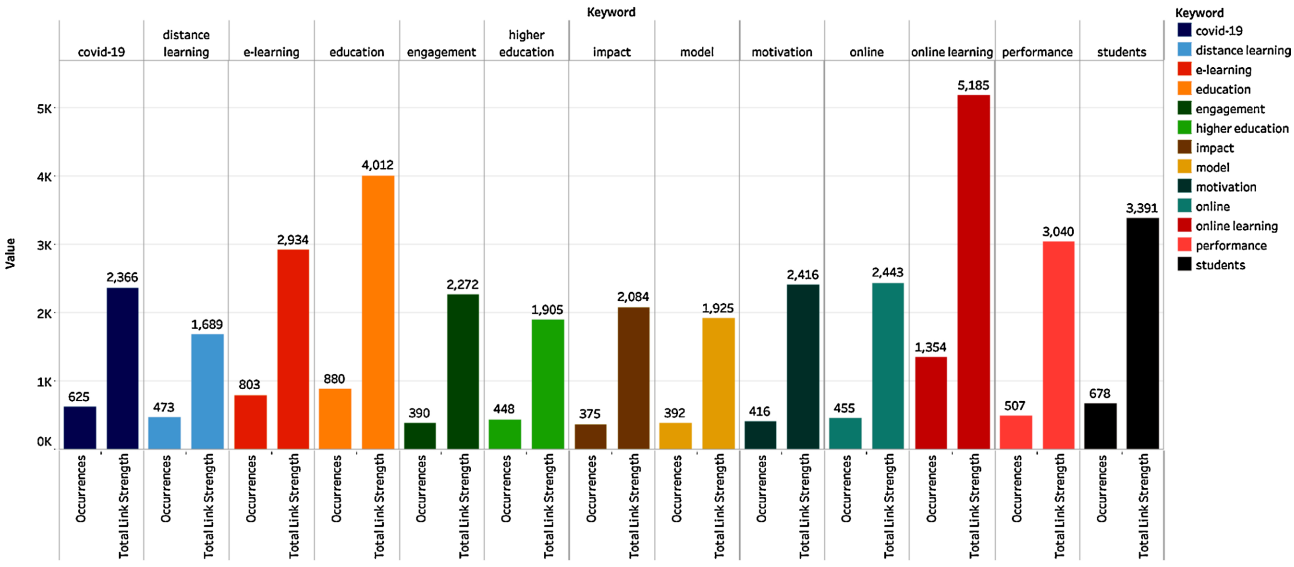

Figure 16. Distribution of top 10 key words with higher TLS scores.

"machine learning", "classification", "feature selection", "recommender system" started to be more visible and important among the researchers. It was also observed that the key word "eye-tracking" was linked with the words such as "attention", "cognitive load" and "performance" (See Figure 17).

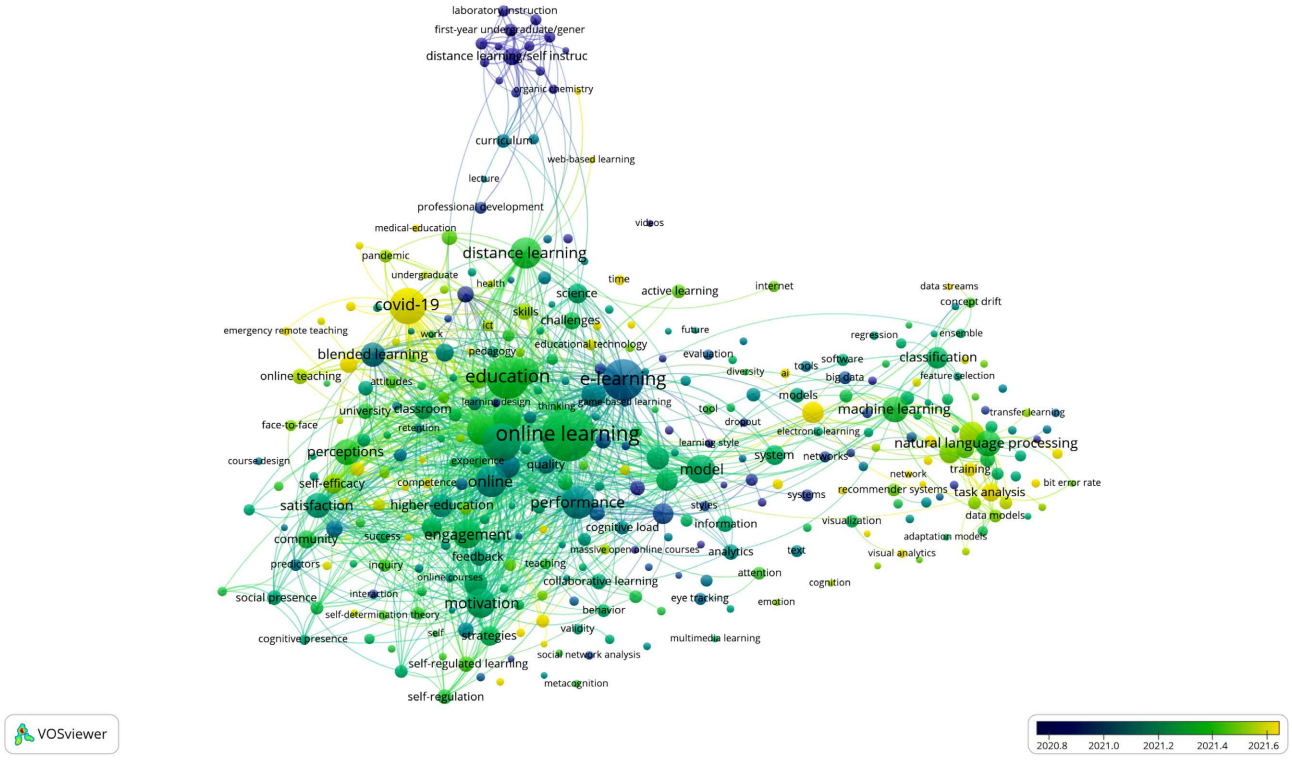

Figure 17. Overlay visualization of co-occurence - all keywords analysis (Weights: occurrence and Scores: average publication year).

Then, n-grams were examined with pyBibX software and Trigrams were accordingly visualized. Meaningful results were reached in the analysis, such that keywords such as "face to face" (f = 50), "self-determination theory" (f = 29), "cognitive load theory" (f = 26), "pedagogical content knowledge" (f = 25), "higher education students" (f = 23), "higher education online" (f = 21), and "open online courses" (f = 21) were identified as the most frequently used words. And it was also observed that among these words, there occurred a word, "support vector machines", which is frequently used in machine learning (See Figure 18). Although these results gave some limited insights about the researchers' trends, this did not give more information on trends and evolution of the trends. Therefore, the analysis was continued with pyBibX to detect and visualize a more detailed insights with trends, based on authors' keywords. As a result of the evolution analysis, the change in trends over the years was determined as in Figure 19. According to the results of this analysis, there occurred some trends that had been constantly researched by researchers for five years, and "blended learning", "online learning", "higher education" and "e-learning" can be given as examples for these trends. Apart from these, it constantly maintained its importance among re-

searchers on topics such as "machine learning" and "deep learning" for last five years. In addition, this analysis also showed that since 2020, "Covid-19" has entered the field of interest of researchers and constituted a significant part of the research. However, the topics of "Artificial Intelligence" and "Natural Language Processing" attracted more attention among researchers since 2021 and began to become a new trend. As of 2023, "Sentiment Analysis" has begun to become the focus of more attention among researchers. With the given entity parameter (value = 10) and analysis only with the authors' key words, no direct trend was found regarding "eye-tracking" (See Figure 19).

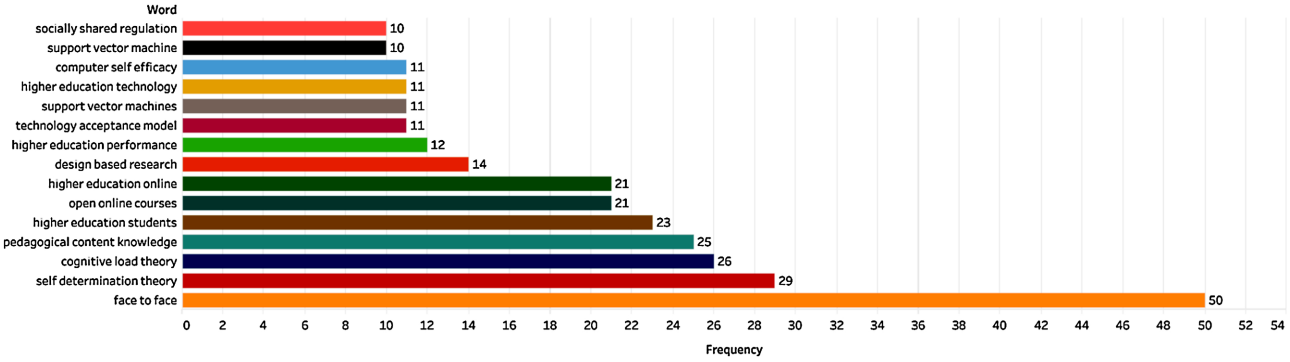

Figure 18. Distribution of trigrams.

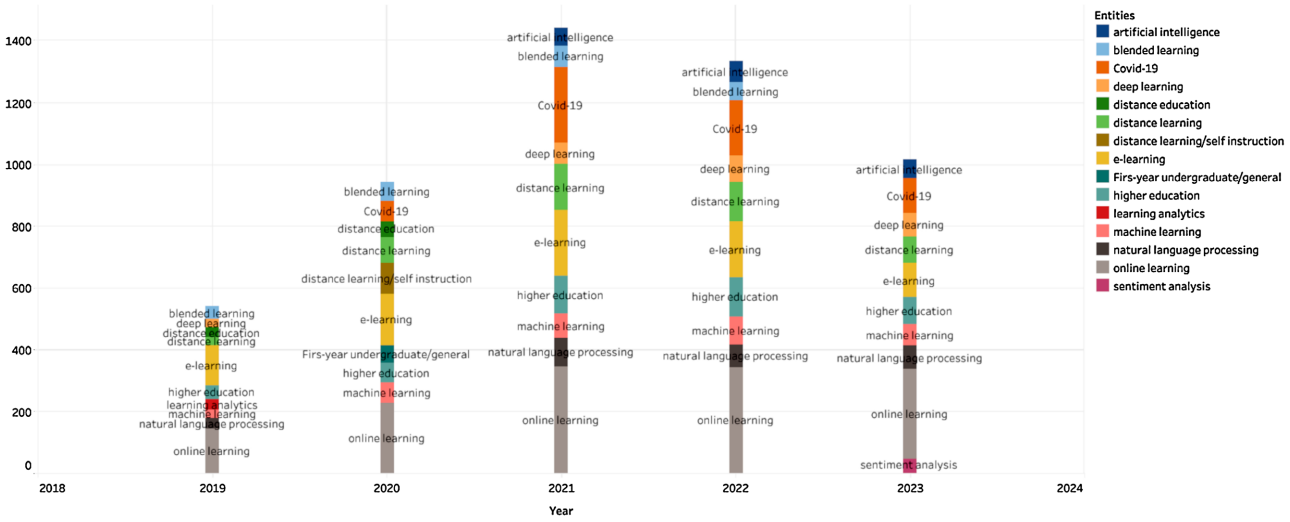

Figure 19. Evolution of trends within years (Total number of entities: 10 and Analysis: authors' key words).

6. Discussion

Eye-tracking studies are studies that require a lot of human and computer effort, time, financial support and well-established technical infrastructures. In addition, it can be very difficult to carry out such studies without personnel specialized in eye-tracking. Nevertheless, according to [59] there are still a lot of advantages that eye-tracking technology can bring to e-learning. For example, it can support personalized and adaptive learning [60], as demonstrated by the

adaptive e-learning system [32], which can infer certain emotions from the learner and respond appropriately. When eye tracking is used in e-learning, learners tend to be more motivated and pay closer attention to the learning interface and eventually some abilities such as reading ability [61], response processes and adaptive problem-solving [62] can be detected. The data obtained from eye-tracking studies can be easily used for different purposes, and machine learning-based classifications or artificial intelligence for purpose of determination of students' performance are also exercised with these data [41] [63]. Thanks to all these advantages, eye-tracking can offer opportunities and possibilities that researchers can easily apply in fields of study such as distance/online learning and machine learning.

As a result, a collaboration and network in terms of co-authorship was found among the authors. However, this seems a limited collaboration and when we look at the countries of the authors and the institutions they work in, it is seen that they collaborate most with the authors in their own region or neighboring countries. Although regional concentrations were observed, it was indicated that western countries form clusters mostly among western countries and eastern countries form clusters mostly among themselves. This means that the countries that conduct scientific studies on these issues partially conduct international studies. As understood from keyword analysis, although words such as "natural language processing", "machine learning", "sentiment analysis" have become more visible and turned into trends in recent years, it is estimated that it is too early to say that these topics have a more significant relationship with "eye-tracking". Compared to other topics, the subject of eye-tracking has not yet evolved into a more dominant position regarding distance/online learning and machine learning. As of now, at the intersection of these issues, topics such as COVID-19 as one of the dominant subjects in the last three years, engagement, performance, come to the fore, and eye tracking is mostly linked to the issue of attention and performance. The reason behind this can be because of that there are not yet enough studies in the context of distance/online learning and machine learning benefiting from eye-tracking technologies or eye-tracking data. In other words, it is presumed that there is a research gap in the relevant literature on this subject or context. The frequency of the keywords also supports this situation, in that only 78 studies included "eye-tracking" in their title (See **Figure 20**).

It is regarded that subjects such as eye tracking, distance/online learning, and machine learning are interdisciplinary and that more detailed studies with more data are needed to determine to what extent these fields use each other's methods, particularly eye-tracking, and to what extent they interact. Although topics such as machine learning and artificial intelligence have been in close contact with distance/online learning as a trend in recent years, how much eye tracking or eye-tracking technologies and methods are used in the field of distance/online learning remains a question that still needs to be answered.

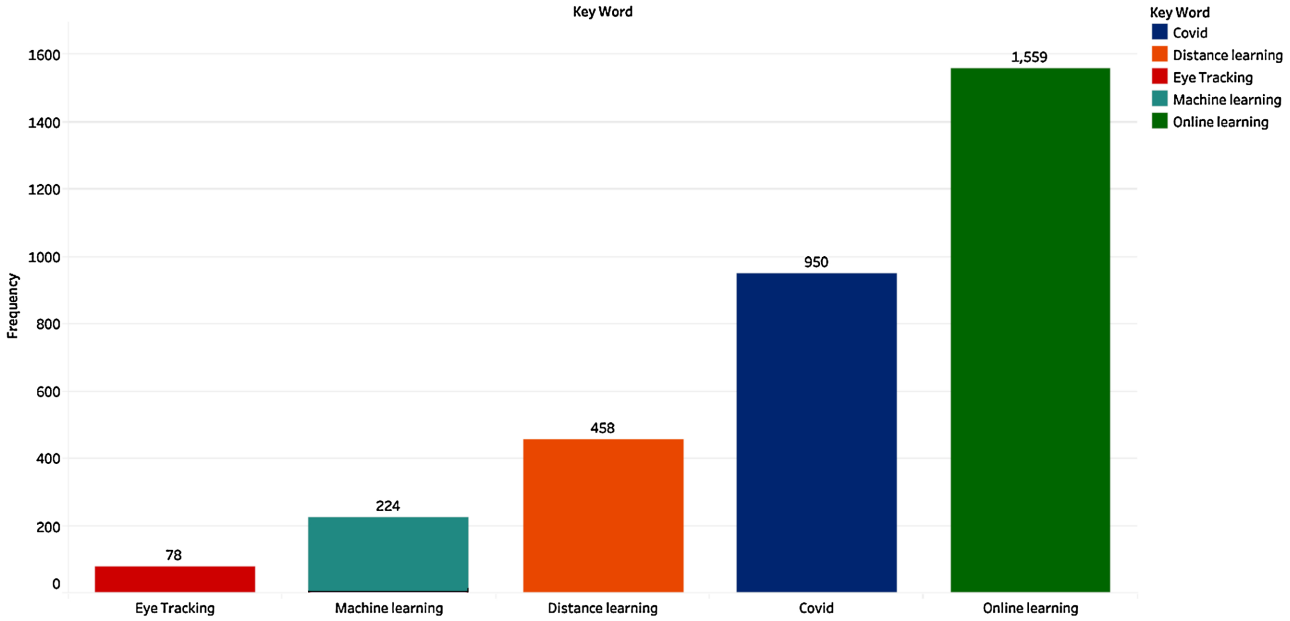

Figure 20. Frequency of keywords in the titles.

7. Conclusion and Recommendation

In this work, a comprehensive bibliometric analysis study regarding the current situation in the intersection of these studies was conducted. The bibliometric analysis of scientific and academic articles published in the last five years (2019-2023) in the context of eye tracking, distance education, online education and machine learning was carried out and discussed. The data-set obtained from the WoS platform was mapped, visualized and analyzed with VosViewer and pyBibx software. It is observed that while eye tracking is a promising field of study that can be used in different parts of the development during the distance education process, it is not yet widely used in this field. Since these types of studies require an interdisciplinary study, they are very difficult to carry out with a single perspective and infrastructure without technical support. It seems that there is still a potential gap in the literature on the subject of "eye-tracking" in the context of "distance/online learning", and "machine learning". Data sets containing more scientific publications from different sources (e.g. Scopus, etc.) are needed to better detect the interdisciplinary interaction in eye-tracking and other mentioned fields and to provide a more understandable prediction and insight, though. In this regard, it is recommended to conduct a structured or systematic literature review in order to compare the methods and data types used in the studies and visualize the relations in more detail.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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