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Research Article

A Bibliometric Analysis of Laboratory Safety: Its Significance for the Discipline of Chemistry*

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Abstract – Laboratory safety is a multidisciplinary field of research that is highly significant for science education, and especially for the discipline of chemistry. This study addresses the developments, primary fields of study, and research tendencies related to the scope and application of laboratory safety in chemistry. The study utilized a survey research design from among descriptive methods and applied a bibliometric analysis technique. To this end, a total of 279 works published on laboratory safety between 1965 and 2024 and indexed in the Web of Science database were analyzed. The analyses encompassed 60 countries, 279 publications, 51 authors, and 43 subject categories. Findings were analyzed using VOSviewer via the bibliometric analysis method. According to the obtained results, the country with the highest number of relevant publications is the United States, the institution with the highest number of published articles is the University of California system, the journal with the highest number of articles is Journal of Chemical Education, and the researchers with the highest numbers of publications are Nancy L. Wayne and Xiaoyan Wang, followed by Imke Schröder, James H. Gibson, and Xinglong Jin. Although many researchers study the subject of laboratory safety, it is seen that the cooperation among authors is extremely weak. The most commonly used keywords were identified as "laboratory safety," "safety hazards," and "laboratory management."

Keywords: Bibliometric mapping, VOSviewer, laboratory safety, chemistry.

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Introduction

Laboratories, as environments of teaching and learning, are a fundamental part of science, technology, and engineering education at all levels. As chemistry is a branch of science based particularly heavily on laboratory research, emphasis must always be placed on laboratory safety in chemistry education (Hill, 2007).

While laboratories are the most effective spaces for putting theoretical knowledge into practice, they are also a complementary part of the discipline of chemistry. To reach the goals set for chemistry education, it is necessary to use laboratories effectively. Laboratory applications help students meaningfully and permanently structure the obtained knowledge, improve their psychomotor skills, use their hands effectively, and enhance their communication skills (Atasoy, 2002; Çepni et al., 1994; Hofstein & Lunetta, 2004; Morgil & Yılmaz, 2000). Previous studies have emphasized that laboratory work is significantly effective in the scientific success of students and helps students develop positive attitudes toward science (Hofstein et al., 2005).

A laboratory learning environment is a complicated learning environment. In this context, successful learning requires scientific reasoning, creativity and problem-solving, use of the affective domain, an understanding of the nature of science, meaningful and permanent structuring of obtained information, development of psychomotor skills, and unification and synchronization of the components of communication skills (Seery et al., 2018; Yılmaz, 2023).

Laboratory Safety

In all applications conducted in a laboratory environment, the most important point to keep in mind is safety. Safety measures taken during laboratory applications should not restrict the practical studies that are being undertaken; on the contrary, their purpose is to help conduct those studies safely (Morgil & Yılmaz, 2000; Yılmaz, 2015).

The US Chemical Safety and Hazard Investigation Board reported over 120 accidents occurring in university laboratories in the United States in the decade between 2001 and 2011, resulting in many injuries along with millions of dollars of damage. Other studies have revealed the occurrence of many high-profile accidents in laboratories, resulting in serious injuries and even death (Menard et al., 2020; Zhu et al., 2018). In Türkiye, the major reason of the laboratory accidents is the failure to apply the necessary safety measures (Akpullukcu, 2017; Tepe & Tekbıyık, 2019).

When the international literature is reviewed in terms of laboratory safety, we can see that subjects such as laboratory safety education (Meyer, 2017; Sigmann, 2018), laboratory safety culture (Ayi & Hon, 2018; Walters et al., 2017; Yoon, 2021), laboratory safety management (Weil, 2016; Zhu et al., 2018), laboratory risk assessment (Omidvari et al., 2015; Pluess et al., 2016), safety information (Agustian & Seery, 2017; Miller et al., 2000), laboratory hazard symbols (Wangdi & Tshomo, 2016), and chemical laboratory safety awareness, attitudes, and practices (Ayana et al., 2017) have been explored.

Bibliometric Analysis

This study used bibliometric analysis to provide a general view of the pioneering researchers, most prolific countries and institutions, and most commonly researched topics in the field of laboratory safety. Previous studies in the literature have highlighted the fact that bibliometric analysis is suitable for use in scientific research and that it helps scholars review the literature in a very short period of time (Block & Fisch, 2020; De Bellis, 2009; Gutierrez-Salcedo et al., 2017; Kurutkan & Orhan, 2018; McBurney & Novak, 2002).

Significance and Aim of the Study

Since laboratory safety is a vital and multidisciplinary field of research, studies on laboratory safety have rapidly increased over the last twenty years. However, in Türkiye, due to the low number of studies on laboratory safety, various accidents occur, especially in laboratory applications in middle school science classes, and such accidents may pose serious risks (Akpullukcu, 2017; Demir, 2016; Şener, 2018; Morgil & Yılmaz, 2000; Yılmaz, 2015). In 34 recorded laboratory or experiment accidents in Türkiye between 2001 and 2017, some serious incidents resulted in the loss of sight, burns, injuries, or poisoning (Tepe & Tekbıyık, 2019). In the studies conducted by Stuart and Toreki (2014) and Olewski and Snakard (2017), a total of 533 accidents were documented in three years, considering accidents occurring in school laboratories, and information on their severity was confirmed with relevant statistics. Among individuals working in laboratories of universities and other schools, 45% reported having an accident, and 73.7% of those cases were reported to be due to chemical substances (Nasrallah et al., 2022).

There is one previous article on the bibliometric analysis of laboratory safety in the international literature, published by Yang et al. (2019). However, no such articles on this topic have been published in the Turkish literature to date. Thus, this study was undertaken to reveal the development of research conducted on laboratory safety; the most influential and

prolific authors, countries, and institutions; and trends in international cooperation. Safety is of the utmost priority in laboratory work. Accordingly, evaluating specific topics that require special attention in the field of laboratory safety with a holistic approach will shed light on avenues for future studies and is expected to contribute to both the overall body of literature and the individual work of researchers in this field.

Research Question

What is the bibliometric status of scientific studies conducted in the field of laboratory safety?

Method

Research Model

This study used a survey research design from among descriptive research methods. Bibliometric mapping was performed using VOSviewer and scientific studies in the field of laboratory safety were analyzed using the bibliometric analysis method. VOSviewer is an open-source bibliometric mapping program (www.neesjanvaneck.nl/vos/), and the possible analyses that can be performed with this software are shown in Table 1 (as cited by Arslan, 2022; Van Eck & Waltman, 2010, p. 536).

Data Collection

This study used the Web of Science (WoS) database. Specifically, data were obtained from the WoS Core Collection Database (https://clarivate.com/academia-government/scientific-and-academic-research/research-discovery-and-referencing/web-of-science/web-of-science-core-collection/), providing access to SCI-Expanded, SSCI, and ESCI citations. “Laboratory safety” and “safety in chemical laboratories” were used as keywords while searching the database. We found 1064 publications with the search phrase “laboratory safety” and 2945 publications with “safety in chemical laboratories.” The obtained publications were then reviewed in line with the inclusion/exclusion (filtering) criteria and the data pool for this study was created. All data were recorded on June 15, 2024, and a total of 279 publications were selected for inclusion in the study. Between 1965 and 2024, a total of 205 journal articles, 45 conference proceedings, 19 review articles, 8 meeting abstracts, and 2 early-access publications were obtained from different disciplines included the WoS categories. In the process of determining whether or not the publications found in the dataset were relevant within the scope of laboratory safety and its significance for the discipline of chemistry, the researchers reviewed the abstracts of all obtained publications.

Expert opinions were also collected regarding the publications obtained from the dataset and the data pool of the study was finalized in this way. The data collection process of the study is illustrated in Figure 1.

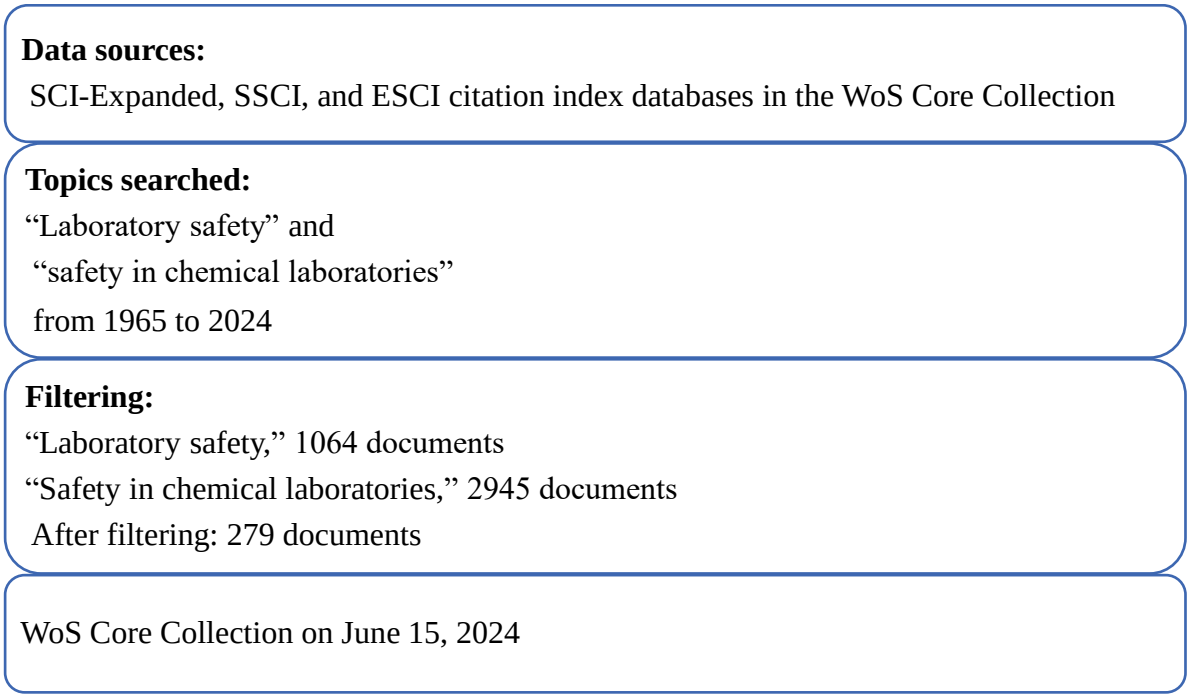

Figure 1 Data Collection Process

Data Analysis

The survey research design from among descriptive research methods was used to examine the data obtained in this study and a bibliometric analysis technique was applied. The distribution of the 279 publications obtained in the data collection process was analyzed by years, authors, journals, institutions, and countries. Bibliometric analysis was initially developed by Van Eck & Waltman (2010, as cited by Arslan, 2022). Science mapping and performance analyses, also known as citation analyses, were done using VOSviewer software. The analysis types and analysis units utilized with VOSviewer are explained in Table 1.

Table 1 Types and Units of Analysis Available with VOSviewer Mapping

Type of analysis	Unit of analysis
Bibliographic-coupling	Documents, sources, authors, organizations, countries
Co-citation	Cited references, cited sources, cited authors
Co-authorship	Authors, organizations, countries
Co-occurrence	Author keywords
Citation	Documents, sources, authors, organizations, countries

In the present study, co-citation, co-authorship, co-occurrence, and citation analyses were performed.

Findings

The findings of this study are categorized into two sections: descriptive findings and bibliographic findings.

Descriptive Findings

Concerning laboratory safety in the discipline of chemistry, the distribution of the 279 relevant publications obtained from the WoS database up to June 2024 was evaluated based on years, on authors with the highest numbers of publications, on journals with the highest numbers of articles, and on countries and institutions with the highest numbers of publications.

The distribution of articles according to years is presented in Figure 2. Considering the distribution of articles by years, it is seen that 10 articles between 1965 and 1980, 13 articles between 1988 and 1999, and 10 articles between 2002 and 2007 were published on laboratory safety in chemistry education. Furthermore, there was no increase in the number of articles published until 2009, but there were 7 articles published in 2010 and the highest numbers of articles were published between 2021 and 2023. The increase in the number of publications is an indicator of the importance of the field of laboratory safety at every level of education.

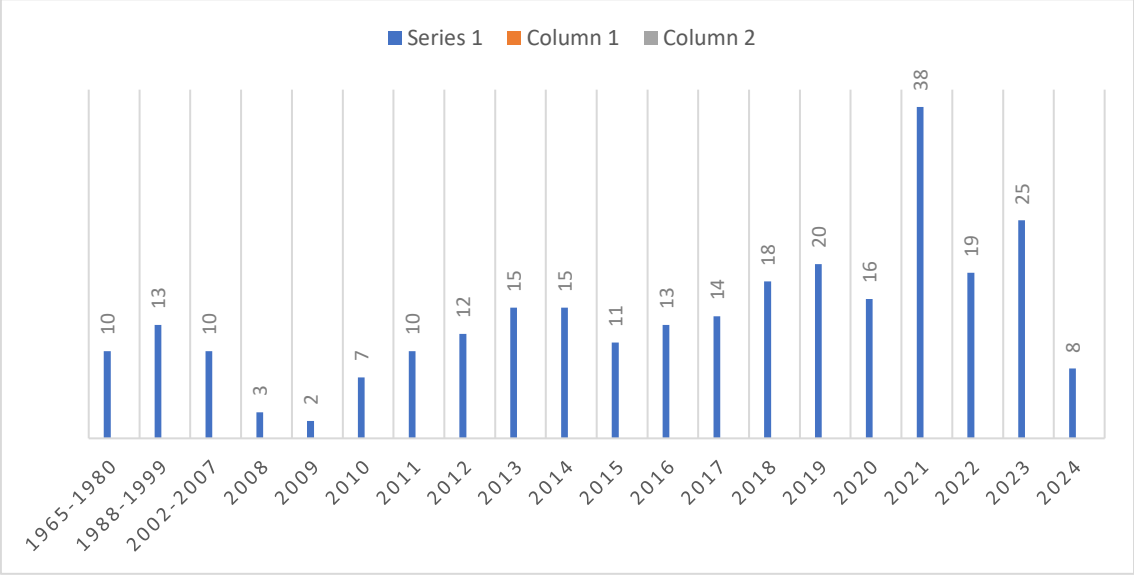

Figure 2 Yearly Distribution (1965-2024)

The names of the five researchers who published the highest numbers of articles in this field are given in Table 2. The researcher with the most publications in this field was Nancy L. Wayne, followed by Xiaoyan Wang, Imke Schröder, James H. Gibson, and Xinglong Jin.

Table 2 The Five Researchers with the Highest Numbers of Articles

Author's name	Number of article
Nancy L. Wayne	6
Xiaoyan Wang	6
Imke Schröeder	5
James H. Gibson	5
Xinglong Jin	5

The names of the eight journals with the highest numbers of articles in this field are given in Table 3. The five journals that published the highest numbers of relevant articles were found to be Journal of Chemical Education, Journal of Chemical Health and Safety, ACT Chemical Health Safety, Abstracts of Papers of the American Chemical Society, and Safety Science.

Table 3 The Eight Journals with the Highest Numbers of Articles

Journal	Number of article
Journal of Chemical Education	52
Journal of Chemical Health Safety	37
ACT Chemical Health Safety	23
Abstracts of Papers of the American Chemical Society	8
Safety Science	7
Process Safety Progress	7
Journal of Loss Prevention in the Process Industries	6
ACS Symposium Series	5

The countries with the highest numbers of publications in this field of research are given in Table 4. The remaining countries (39 countries with a total of 41 articles) were all countries with 3 or fewer relevant publications. Considering the distribution of publications based on countries, the United States had the most, followed by China, Brazil, England, and South Korea.

Table 4 Countries with the Highest Numbers of Publications

Country	Number of article	Country	Number of article
USA	104	Germany	6
China	35	Spain	6
Brazil	11	Switzerland	6
Canada	10	Taiwan	5
England	8	Thailand	5
South Korea	8	Slovakia	4
France	7	India	4
Malaysia	7	Other countries (n=39)	41
Türkiye	7		

The names of the 13 institutions with the highest numbers of publications are given in Table 5. The institution with the most relevant publications was the University of California system, followed by University of California-Los Angeles, the American Chemical Society, Ecole Polytechnique Federale de Lausanne, and Swiss Federal Institutes of Technology Domain.

Table 5 The 13 Institutions with the Numbers of Articles

Institutions	Number of article
University of California system	10
University of California-Los Angeles	8
American Chemical Society	5
Ecole Polytechnique Federale de Lausanne	5
Swiss Federal Institutes of Technology Domain	5
Tianjin University of Technology	5
University of North Carolina	5
Battelle Memorial Institute	4
United States Department of Energy (DOE)	4
University System of Ohio	4
KU Leuven	3
Wittenberg University	2
Abant Izzet Baysal University	1

Bibliographic Findings

Co-authorship results

In the analysis of co-authorship in the field of laboratory safety in chemistry education, a network map was created to identify the authors with the most links, representing the most cooperation (Minimum number of publications of an author: 1; Minimum number of citations of an author: 1; Number of authors to be selected: 630; Clusters: 3; Links: 49; Total link strength: 61). In Figure 3, three different colors and types of nodes are apparent. Each color represents clusters of authors who conduct research on similar topics. On the other hand, the lines represent cooperation between authors. Visualizing the relationship between authorship and co-authorship in the field of laboratory safety helps reveal the most prolific authors. The most prolific authors were accordingly found to be Nancy L. Wayne (6 publications), James H. Gibson (5 publications), and Imke Schröder (4 publications), who are shown with blue nodes in Figure 3 together with their cooperation with other authors.

Although many scientists have studied laboratory safety, the cooperation among authors in this field is notably weak.

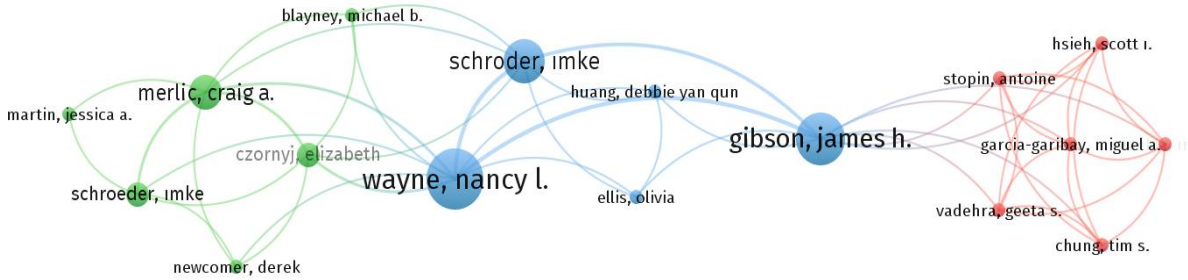

Figure 3 Network Visualization Map of Co-Authorship

Citations of authors

To visualize the network of citations in this field, a network map was created (Minimum number of documents of an author: 1; Minimum number of citations of an author: 1; of 775 authors, 582 met these thresholds; Clusters: 15; Links: 2908; Total link strength: 3310). Generally speaking, the most prolific authors and well-known research groups contribute greatly to science and to the work of other researchers, and this is also reflected in the numbers of citations that their publications receive. Therefore, the citation map given in Figure 4 was created. The most cited authors were found to be James H. Gibson (160 citations), Nancy L. Wayne (143 citations), Imke Schröder (121 citations), and A.D. Menard and J.F. Trant (108 citations).

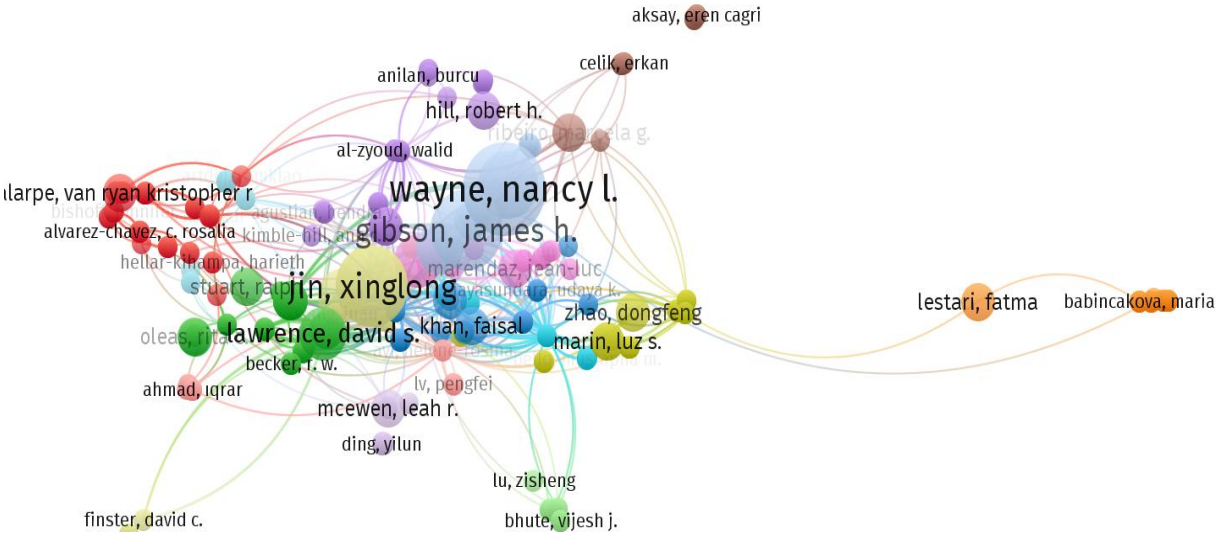

Figure 4 Network Visualization Map of Citations

Table 6 The Five Most Frequently Cited Documents on Laboratory Safety

Article	Journal	Country	Citation	Average per year
Menard, A.D. and Trant, JF A (2020) review and critique of academic lab. safety research	Nature Chemistry	Canada	109	21.8
Agustian, H. Y and Seery, M.K (2017). Reasserting the role of pre-laboratory activities in chemistry education: a proposed framework for their design	Chemistry Education Research And Practice	England	90	11.25
Yang, YF , Reniers, G , Chen, Guohua and Goerlandt, F (2019). A bibliometric review of laboratory safety in universities	Safety Science	China Belgium Netherlands Canada	77	12.83
Schröder, I, Huang, DYQ Ellis, O, Gibson, JH, Wayne, NL.(2016) Laboratory safety attitudes and practices: A comparison of academic, government, and industry researchers	Journal Of Chemical Health & Safety	USA	75	8.33
Walters, AUC; Lawrence, W; Jalsa, NK (2017). Chemical laboratory safety awareness, attitudes and practices of tertiary students	Safety Science	Univ. West Indie	64	8

Citation analysis is crucial in determining the effect and quality of a published article. Looking at Table 6, the most frequently cited publication is “A review and critique of academic lab safety research” by Menard and Trant (2020). This article also has the highest annual number of citations. In this work, Menard and Trant (2020) revealed that many high-profile accidents resulting in serious injuries and death in academic laboratories around the world occurred in the last decade. Furthermore, they suggested that laboratory safety policies have still not been improved even after such incidents, and they defined the research questions to be asked to minimize serious academic laboratory accidents in the future and highlighted the need for determined leadership in this area. This article has been cited 109 times to date.

Co-citations of references

The co-citation map of reference analysis is given in Figure 5. This analysis was conducted to evaluate the interaction among studies done on laboratory safety and the publications with co-citations (Minimum number of citations of cited references: 3; of 6295 cited references, 204 met the threshold; Clusters: 7; Links: 6364).

Nodes of the same color represent the same cluster comprising articles on similar topics. The size of each node signifies the number of citations an article has received, and the thickness of each line reflects the number of co-citations received by two articles in other

publications. The article by Schröder (2016) published in *Journal of Chemical Health & Safety* is included among the green nodes in Figure 5, having the highest number of links (504) and 32 co-citations. The article by Menard and Trant (2020) published in *Nature Chemistry* is included among the blue nodes with 486 links and 32 co-citations.

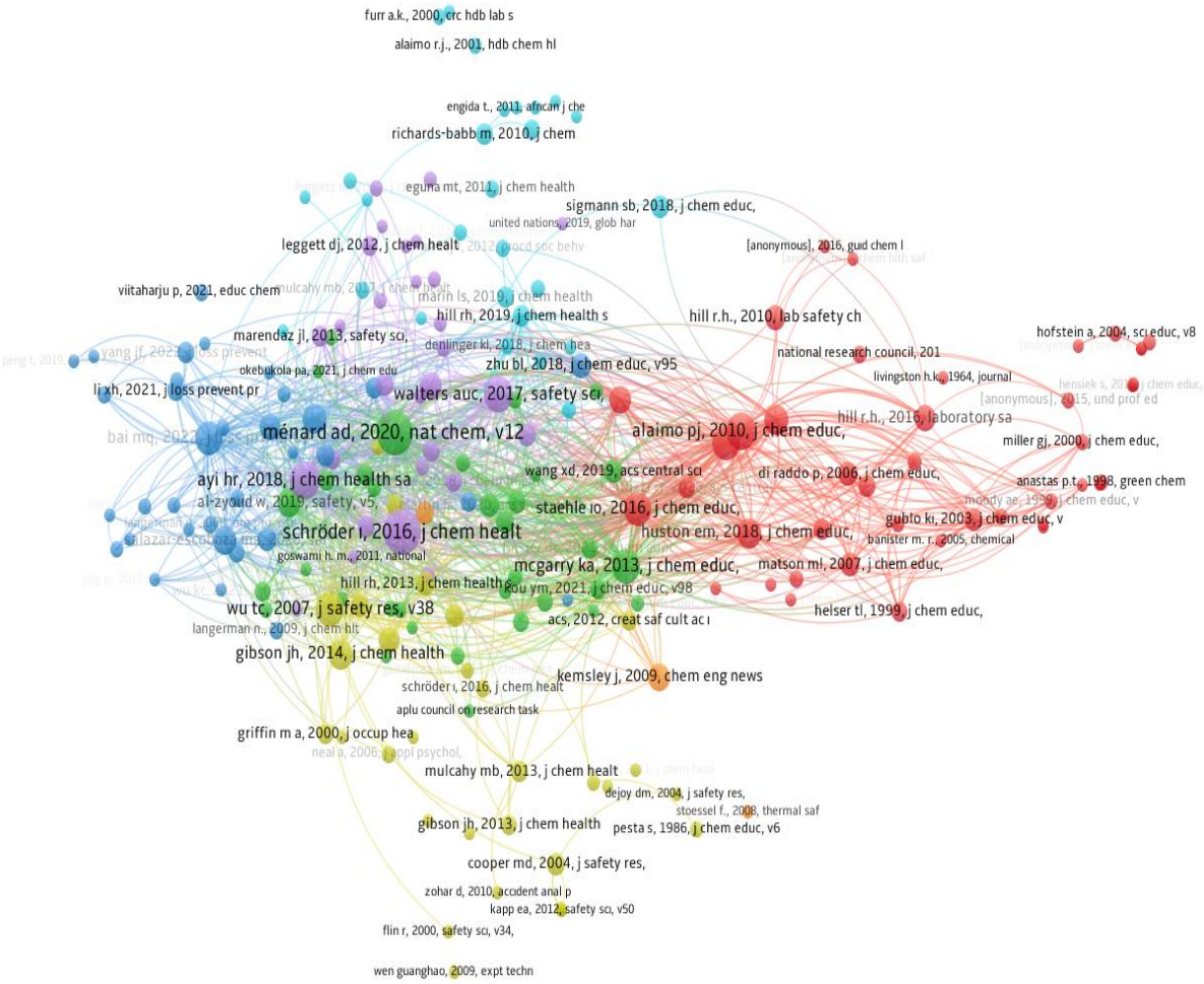

Figure 5 Network Visualization Map of Co-citations

Citations by countries

Analysis was also conducted to evaluate the numbers of citations of different countries, and the results are shown in Figure 6 (Minimum number of publications of a country: 1; Minimum number of citations of a country: 1; of 60 countries, all 60 met these thresholds; Clusters: 14, Links: 159, Total link strength: 489). As seen in Figure 6, the countries with the highest numbers of citations are the United States with 1104 citations (99 publications), Canada with 286 citations (10 publications), and China with 244 citations (35 publications).

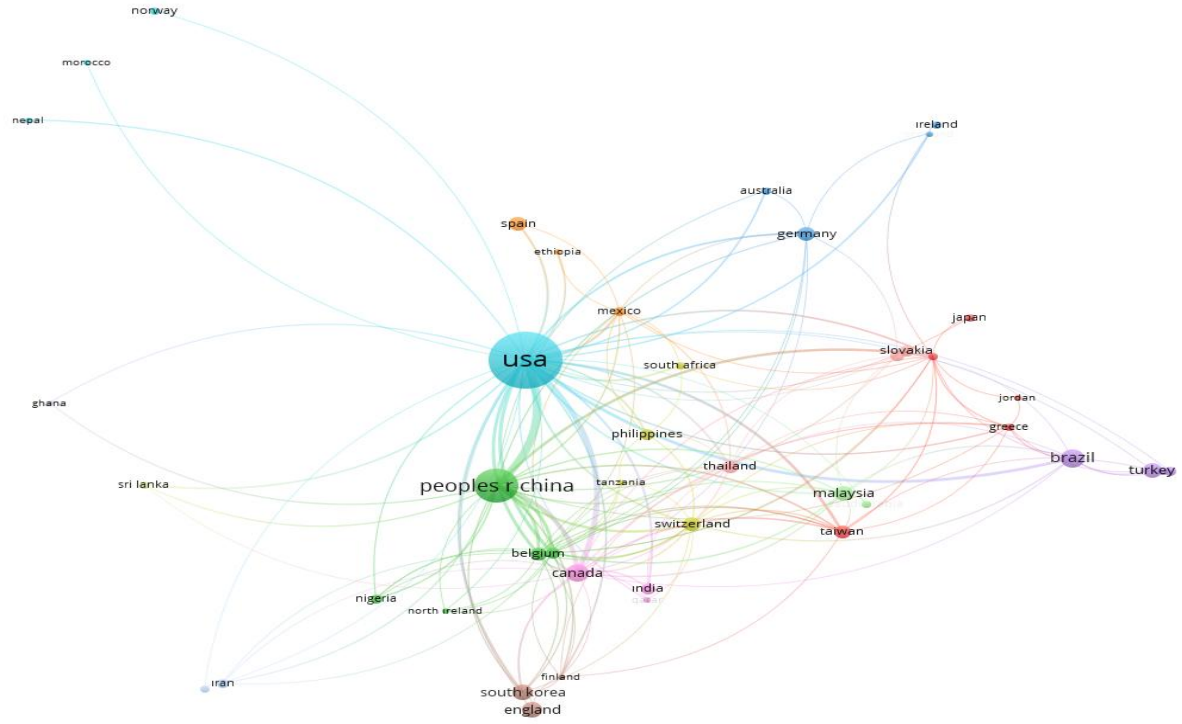

Figure 6 Network Visualization Map of Citations by Countries

Citations by institutions

Analysis was conducted to evaluate the numbers of citations of different institutions (Minimum number of publications of an institution: 1; Minimum number of citations of an institution: 1; of 361 organizations, 285 met these thresholds; Clusters: 18; Links: 973; Total link strength: 1115). The colors in Figure 7 represent clusters of institutions and the lines represent the strength of cooperation among institutions. The most prolific institutions were found to be the University of California-Los Angeles with 180 citations (7 publications), Dow Chemical Co. with 118 citations (3 publications), the University of Minnesota with 110 citations (3 publications), Delft University of Technology with 109 citations (3 publications), and the University of Windsor with 108 citations (1 publication).

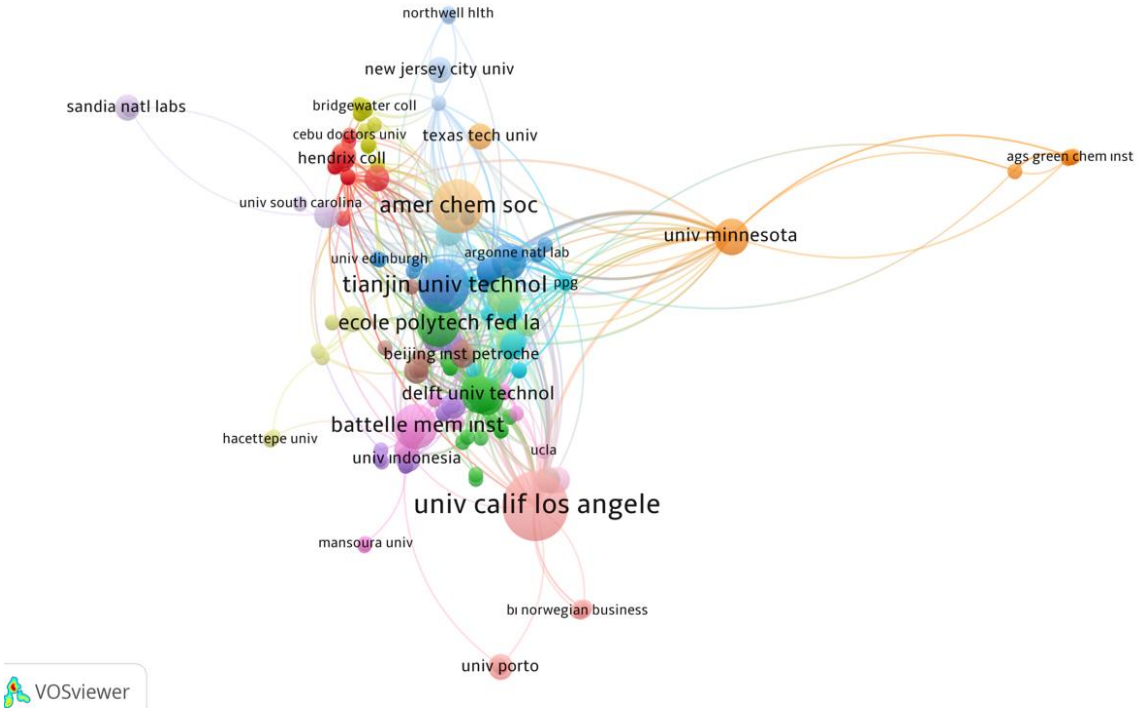

Figure 7 Network Visualization Map of Institutional Cooperation

Keyword analysis (co-occurrence of authors)

The network structure obtained for the co-occurrence of authors according to keywords is presented in Figure 8 (Minimum number of occurrences of keywords: 1; of 572 keywords, all 572 met the threshold; Clusters: 33; Links: 1680; Total link strength: 2067). The most frequently used keywords were “laboratory safety” (37 occurrences), “safety hazards” (24 occurrences), “laboratory management” (23 occurrences), “safety” (18 occurrences), “laboratory instruction” (14 occurrences), and “risk assessment” (11 occurrences).

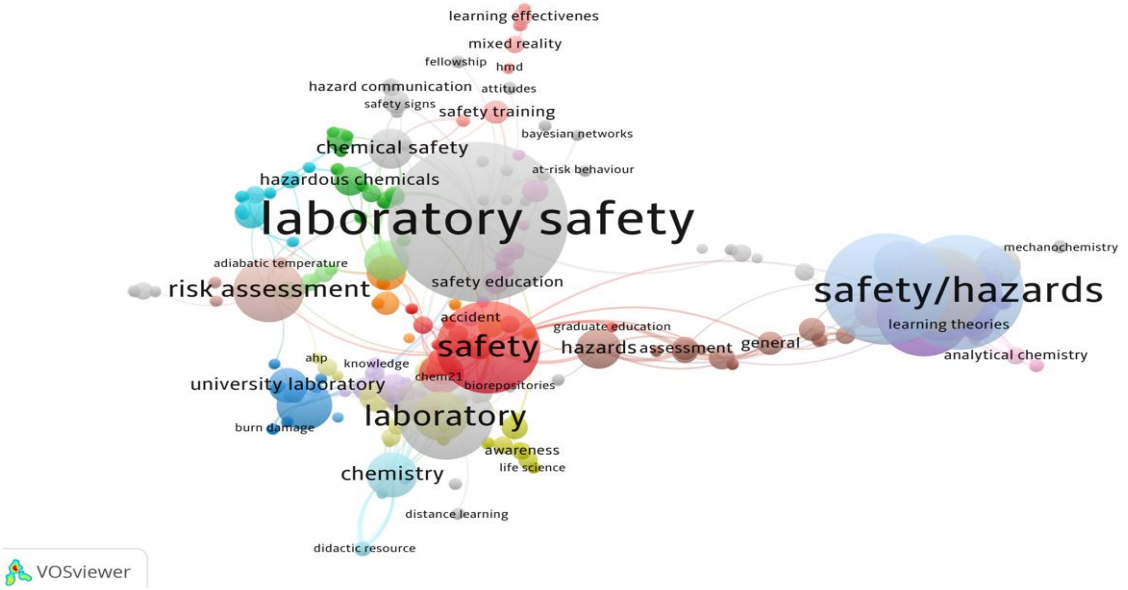

Figure 8 Network Visualization Map of Keywords Co-Occurring Among Authors

Conclusions and Suggestions

In this study, bibliometric analysis was conducted due to the multidisciplinary nature of laboratory safety and its significance in chemistry education. Safety is of the utmost importance in laboratory work. The findings obtained in this study were evaluated with a holistic approach. The results of the analysis are expected to guide future studies, contribute to the literature, and help other researchers.

This study examined 279 publications on the subject of laboratory safety. The documents reviewed were obtained using the WoS database and bibliometric analysis was performed. Considering the research on laboratory safety to date, the first publications appeared in 1965 and no increase in number was observed until 2009. In 2011, the number of annual publications increased and the highest numbers of studies were conducted between 2021 and 2023. The increase in the number of publications is an indicator of the importance of the field of laboratory safety at every level of education. Since the scope and applications of laboratory safety cover a wide spectrum, there are many different possible directions for advancements in this field. Yang et al. (2019) also stated that this area of research is quite young and open for improvement.

Reviewing the distribution of publications on laboratory safety according to authors, the most prolific researchers were found to be Nancy L. Wayne and Xiaoyan Wang, each with 6 articles, and Imke Schröder, James H. Gibson, and Xinglong Jin, each with 5 articles.

The institutions with the highest numbers of publications in the field of laboratory safety were found to be the University of California system and University of California-Los Angeles. Looking at the distribution of publications by institutions in Türkiye, the institutions with the highest numbers of publications in this field are Hacettepe University and Abant İzzet Baysal University.

The countries with the highest numbers of publications and the highest concentration of research were found to be the United States and China. These were followed by Brazil and Canada. On the other hand, in total, 7 relevant articles were published in Türkiye. It was thus found that the United States is considerably successful in terms of the number of publications and citations in this field, followed by China. Yang et al. (2019) emphasized that China's rise in this field of research should be taken into account.

It is of considerable value to identify publication and citation counts, and co-authorship relations among researchers studying laboratory safety to improve this area of

study and help researchers acquire new information. When such information is available, we can identify the most productive researchers in laboratory safety. The contributions and the influence of specific researchers in a field constitute an essential indicator for the development of that field. The authors with the highest numbers of citations in the field of laboratory safety are James H. Gibson (160 citations), Nancy L. Wayne (143 citations), Imke Schröder (121 citations), and A.D. Menard and J.F. Trant (108 citations). When the network structure of the relationships among researchers who published co-authored articles in this field was examined, it was found that cooperation was concentrated around Nancy L. Wayne, James H. Gibson, and Imke Schröder.

The article published by Schröder (2016) in Journal of Chemical Health & Safety was cited 32 times, the article published by Menard and Trant (2020) in Nature Chemistry was cited 32 times, and the article published by Alaimo et al, 2010 in Journal of Chemical Education was cited 31 times. Additionally, these journals are among the most influential journals in the field.

Overall, the analysis conducted in this study showed that cooperation among authors in the field of laboratory safety is relatively weak. Yang et al. (2019) also reported that cooperation between countries, institutions, and authors is very low in this field.

Looking at the co-occurrence of keywords among the analyzed publications, the most frequently used keywords were “laboratory safety” (37 occurrences), “safety hazards” (24 occurrences), “laboratory management” (23 occurrences), “safety” (18 occurrences), “laboratory instruction” (14 occurrences), and “risk assessment” (11 occurrences).

This study examined laboratory safety in the context of the discipline of chemistry, and it was limited to studies indexed in the WoS database. Databases such as Google Scholar, ERIC, and SCOPUS were excluded from analysis. This study could be repeated using different databases. Conducting further bibliometric analyses of laboratory safety in science education could provide significant contributions to the field. In addition, the conduct and interpretation of bibliometric analysis studies by scientists who are experts in laboratory safety will make a great contribution to the field.

Compliance with Ethical Standards

Disclosure of potential conflicts of interest

No conflict of interest.

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No payments have been received from any institution/person for this study.

CRediT author statement

The researchers took full responsibility for the research.

Research involving human participants and/or animals

This article did not involve human participants and/or animals.

Laboratuvar Güvenliğinin Bibliyometrik Analizi: Kimya Disiplini için Önemi

Özet:

Laboratuvar güvenliği fen eğitimi ve özellikle kimya disiplini için oldukça önemli ve multidisipliner bir araştırma alanıdır. Bu çalışmada, kimya disiplininde laboratuvar güvenliğinin kapsamına ve uygulanmasına ilişkin gelişmeler, odak çalışma alanları ve eğilimler incelenmiştir. Araştırmada, betimsel yöntemlerden tarama modeli kullanılmış ve bibliyometrik analiz tekniği uygulanmıştır. Bu amaç kapsamında, 1965 ve 2024 yılları arasında laboratuvar güvenliği alanında Web of Science (WoS) Veri Tabanı'nda yayınlanan toplam 279 makale incelenmiştir. İncelemelerde 60 ülke, 279 araştırma, 51 yazar ve 43 konu kategorisi bulunmaktadır. Bulgular, VOSviewer ile bibliyometrik analiz yöntemi ile analiz edilmiştir. Elde edilen bulgulara göre ; araştırma alanı ile ilgili en fazla yayın yapılan ülkenin Amerika Birleşik Devletleri(ABD) olduğu, en fazla makale yayınlayan kurum University of California System , en fazla makale yayınlanan dergi Journal of Chemical Education, en fazla çalışma yapan araştırmacı Nancy L. Wayne ve Xiaoyan Wang olduğu ve bu araştırmacıları, Imke Schröeder, James H. Gibson ve Xinglong Jin izlediği tespit edilmiştir. Laboratuvar güvenliği konusunda çok sayıda bilim insanı araştırma yapmış olsa da yazarlar arasında işbirliğinin son derece zayıf olduğu saptanmıştır. En fazla kullanılan anahtar kelimeler laboratory safety, safety hazards laboratory management olduğu belirlenmiştir.

Anahtar Kelimeler: Bibliyometrik analiz, VOSviewer, laboratuvar güvenliği, kimya disiplini.

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