A bibliometric review of laboratory safety in universities

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Abstract

With the frequent occurrence of accidents in universities, more and more studies on university laboratory safety have been carried out. The bibliometric method was introduced in the field of university laboratory safety to gain an overall review of the development in this field. A total of 219 publications on university laboratory safety were searched and screened from the database of Web of Science, which cover 44 countries or territories, 254 research institutions, 575 authors, 126 publication sources, and 70 subject categories. In this paper, the annual growth trend and the distribution of subject categories were analyzed by statistical description method. The most productive and influential countries, institutions, authors and their cooperation were identified from the cooperation networks mapped by VOSviewer. The citation and co-citation analysis was carried out to find out the core publications and publication sources in this field, and the research topics over time were obtained through terms co-occurrence network. The main results indicate that the university laboratory safety is a multidisciplinary research field. However, it's still a younger discipline and belonged to the minority research field compared with other safety domains, and there is an urgent need for researcher to come with topics and methods in this field.

1. Introduction

Laboratory is an important part of university teaching and scientific research, and it's an inherently dangerous work environment for learning and working, which is faced with various potential hazards including chemical, biological, and physical agents (Ayi and Hon, 2018). University laboratories are considered more dangerous than industrial laboratories due to the fact that the more relaxed safety management/culture and the lower safety investment in universities compared to industrial factories (Marendaz et al., 2013; Schröder et al., 2016b). A number of accidents in university laboratories resulting in laboratory students and staff suffering severe injuries or fatalities happened regularly, which have been reported globally. For example, three students who participated in the landfill leachate experiment were killed after an explosion happened in the laboratory of Beijing Jiaotong University on December 26, 2018 (Chinadaily, 2018). A postdoc fellow lost an arm in a lab explosion accident at the University of Hawaii while she was mixing carbon dioxide, hydrogen, and oxygen from separate cylinders to produce a bacterial growth medium on March 16, 2016 (Trager, 2017). A research assistant was killed by a lab fire accident while working with a pyrophoric chemical at the University of California, Los Angeles (UCLA) on December 29, 2008, and this accident prompted a quickly and comprehensive reform of laboratory safety in UCLA (Gibson et al., 2014).

Recent years, major accidents in university laboratories have occurred frequently, and more and more universities realize that laboratory safety must be at top priorities. In order to reduce the occurrence of laboratory accidents in universities, a large number of studies on university laboratory safety have been published and these studies are mainly divided into four aspects: laboratory safety education (Fivizzani, 2016; Meyer, 2017; Sigmann, 2018); laboratory safety culture (Ayi and Hon, 2018; Walters et al., 2017; Wu et al., 2007); laboratory safety management (Olewski and Snakard, 2017; Weil, 2016; Zhu et al., 2018) and laboratory risk assessment (Omidvari et al., 2015; Pluess et al., 2016; Shariff and Norazahar, 2012). Literature review is an effective and fast way to understand a research field, however, there is no comprehensive review on the laboratory safety in university laboratories to our knowledge. Bibliometric analysis is a technique that can provide a macroscopic overview of a large number of literature, and it can be used to identify and quantify cooperation relationship, co-citation similarity, main research topics, and research trends in a research domain

(van Nunen et al., 2018; Zou et al., 2018). Recent years, bibliometric methods have been introduced in some sub-domains of safety, such as construction safety (Jin et al., 2019), road safety (Zou et al., 2018), safety culture (van Nunen et al., 2018) and domino effects (Li et al., 2017). Furthermore, bibliometric analysis also used to assess the topic maps and output distributions of six core safety journals (Li and Hale, 2016), to identify the knowledge communication among core safety science journals (Li and Hale, 2015), and to make the links among process safety, environmental protection, and industry 4.0 (Gobbo et al., 2018). Therefore, it's also meaningful and significant to analyze the overview research on university laboratory safety using bibliometric method.

The present work aims to introduce the bibliometric method into the field of university laboratory safety, and to evaluate overall research situation based on publication records retrieved from Web of Science (WOS). VOSviewer, a freely available computer program (van Eck and Waltman, 2010), are used to map and visualize the following research networks: the cooperation relationship based on countries, institutions, and authors; the co-citation similarity based on publication sources; and the research topics based on terms co-occurrence. Furthermore, the annual distribution trends and the subject categories of publications also have been discussed by the descriptive method. The results can be used to identify the most influential authors, the most productive countries and institutions, the most cited publications and journals, and the hot topics and research trend of university laboratory safety.

2. Methodology

2.1. Data source

The data used in this study were retrieved from the SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH and ESCI citation index databases in the WOS Core Collection on January 9, 2019. The retrieval topic was "university laboratory safety", and the timespan was "from 1955 to 2018" based the earliest time in KU Leuven database. Initially, a total of 1283 documents were retrieved, but not all the retrieved documents were related to laboratory safety in universities due to the fact that the retrieval topic was searched in the titles, the abstracts and keywords of publications. For example, although within the retrieved documents of university laboratory safety, the paper was focused on the coal dust at a longwall mining (Arya et al., 2018), thus further manual screening process was carried

out to remove the documents which were not related to the topic of university laboratory safety. Finally, 219 publications related to the university laboratory safety were identified, and the full records and cited references of the 219 selected documents were exported as plain text for the further bibliometric analysis.

Six document types were identified, and the most productive document type was articles (141), which accounted for 64.384% of the total documents. The second and third largest document types were proceeding papers (44; 20.091%) and meeting abstracts (30; 13.699%) respectively, which indicated that conferences and meetings also made a significant contribution to the research of university laboratory safety. Furthermore, others with less contributions were editorial materials (5; 2.283%), reviews (5; 2.283%) and news items (1; 0.457%). As for publishing language, English is undoubtedly the most widely language, and 205 documents were written in English accounted for almost 93.607% due to the fact that English is the most popular academic language (Liu et al., 2012). Other seven publishing languages included Chinese (4), Spanish (4), French (2), Japanese (1), Polish (1), Portuguese (1) and Turkish (1).

2.2. Bibliometric analysis

In the present work, the main method is based on the bibliometric analysis software: VOSviewer which developed by van Eck and Waltman from Leiden University (van Eck and Waltman, 2010). VOSviewer uses the visualization of similarities mapping technique (Van Eck and Waltman, 2007), and creates distance based on visualizations of networks where the distances among nodes show the level of closeness among them. Furthermore, VOSviewer is especially useful for displaying bibliometric maps contain maps containing at least 100 items in an easy-to-understand way (van Eck and Waltman, 2010), and it can be used to analysis the co-authorship, terms co-occurrence, and co-citation similarity. Based on the above advantages, VOSviewer has been widely used in the bibliometric analysis of other safety domain (Gobbo et al., 2018; Jin et al., 2019; Li and Hale, 2015, 2016; Li et al., 2017; van Nunen et al., 2018; Zou et al., 2018).

3. Results and discussions

3.1. Yearly distribution and growth trend

The number of publications is a vital indicator to measure the development trend of a research domain. The research level and future development trend can be easy inferred by analyzing the number of publications over time (van Nunen et al., 2018; Zou et al., 2018). Fig. 1 presents the number and cumulative number of publications on university laboratory safety by year. It can be seen from Fig. 1 that there are less than 6 publications per year on this topic until 2010 (especially before 2000, less than 3 publications per year), which indicate that there is an initial stage for university laboratory safety research and the laboratory safety had not been taken seriously in universities. From 2010 to 2013, there is a stable and significant growth in the number of publications, due to the death of a researcher at UCLA on the last months of 2008 was attracted unprecedented and widespread attention from both the mainstream and industry media, as well as from research institutions across the nation (Gibson et al., 2014), and more and more researchers carried out the research about the laboratory safety in universities from then on. However, the most significant increase in the number of publications was is 2016. Furthermore, the cumulative number of publications approximately follows a linear growth which is consistent with the growth trend of the publications in six core safety journals (Li and Hale, 2016). However, compared with the number of publications in other sub-domains of safety (such as safety culture, road safety and construction safety) (Jin et al., 2019; van Nunen et al., 2018; Zou et al., 2018), university laboratory safety still belongs to the preliminary research stages, and there is still much room for development.

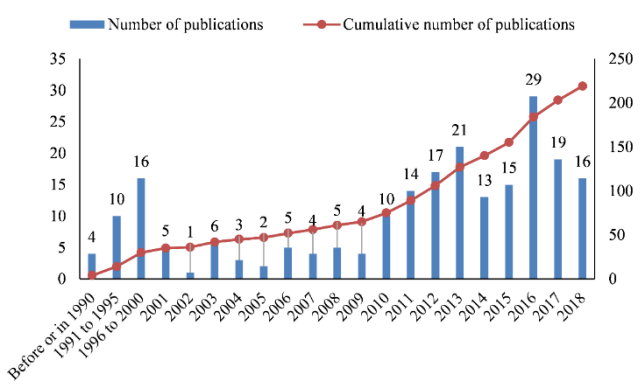

Fig. 1. Number and cumulative number of publications on university laboratory safety by year.

3.2. Cooperation network analysis

3.2.1. Distribution of countries and territories.

219 retrieved documents on university laboratory safety come from 44 different countries or territories, and Table 1 summarizes the productive countries or territories that have contributed more than 4 publications. Furthermore, 17 countries or territories published 2 or 3 documents, and other 18 countries or territories produced only one publication. As consistent with the research results in other safety domains, USA is the country with the largest number of publications accounting for more than fifty percent, and China ranks second as one of the emerging science forces (Zou et al., 2018). The number of publications on university laboratory safety may be linked to the economic level of countries (or territories) and the frequencies of laboratory accidents in universities. As can be seen from Table 1, although USA has the highest number of total citations, its average citation per document is only 2.83 that is far behind Germany (21.4), Taiwan (11.29) and Switzerland (9.6). The above results indicate that the documents published by Germany, Taiwan and Switzerland attracted more attention on university laboratory safety.

Fig. 2 represents the cooperation network among countries and territories which was plotted by VOSviewer. The size of the label and the circle is determined by the number of publications in each country or territory, and the thickness of lines between two nodes represents the strength of cooperation among countries or territories. The colours represent the collaboration clusters. As shown in Fig. 2 and the last column of Table 1, the publications of most countries or territories (28) without cooperating with others. Even though some countries or territories cooperated with others (such as cooperation between USA and Qatar, Ireland), the number of publications among them is very limited, and all collaborative publications among countries or territories are less than 3. Furthermore, there is a significant geographically correlated trend among cooperative countries, such as mainland of China and Taiwan; UK, Germany, Norwary and Denmark; Belgium and the Netherlands. Therefore, it can be concluded that there is a serious regional imbalance in university laboratory safety research, and the cooperation among countries and territories is still at a very low level on this topic.

Table 1

Countries or territories published more than 4 publications on university laboratory safety.

Rank	Country/Territory	Quantity	Percentage	Citation	Avg. citation	Total link
1	USA	110	50.228%	311	2.83	3
2	China	14	6.393%	2	0.14	1
3	Taiwan	7	3.196%	79	11.29	1
4	Spain	7	3.196%	9	1.29	0
5	Germany	5	2.283%	107	21.4	1
6	Switzerland	5	2.283%	48	9.6	1

7	UK	5	2.283%	30	6	1
8	Turkey	5	2.283%	8	1.6	0
9	Indonesia	4	1.826%	0	0	0

Avg. citation denotes the average number of citation of a document; Total link represents the number of documents cooperating with other countries or territories.

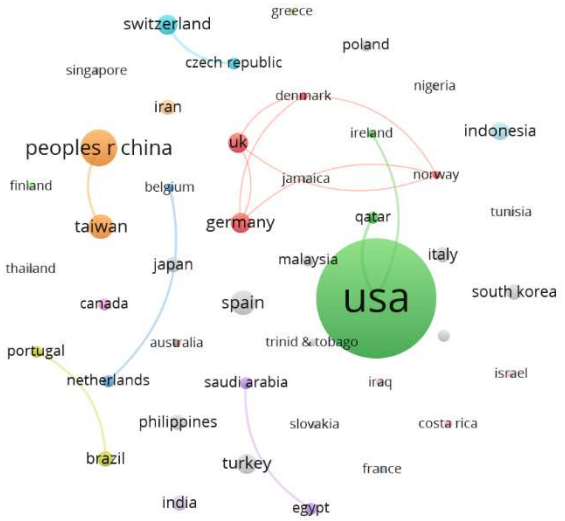

Fig. 2. Countries or territories cooperation network on university laboratory safety.

3.2.2. Distribution of research institutions

Table 2

Institutions published more than 3 documents on university laboratory safety.

Rank	Institutions	Country/ Territory	Quantity	Citation	Avg. citation	Total link
1	University of California Los Angeles	USA	7	127	18.14	5
2	Battelle Memorial Institute	USA	6	8	1.33	2
3	Ecole Polytechnique Federale de Lausanne	Switzerland	5	48	9.6	3
4	Cornell University	USA	4	9	2.25	2
5	Hungkuang University	Taiwan	4	67	16.75	3
6	Iowa state university	USA	4	0	0	1
7	University of Illinois	USA	4	5	1.25	1
8	Duke University	USA	3	8	2.67	2
9	Princeton University	USA	3	111	37	3
10	Texas Tech University	USA	3	7	2.33	2
11	University of California San Diego	USA	3	1	0.33	0
12	West Virginia University	USA	3	0	0	0
13	Wittenberg University	USA	3	9	3	3

Total link represents the number of documents cooperating with other institutions.

Through the analysis of the publications and cooperation relationship of research institutions, the most productive and influential institutions on university laboratory safety. 254 research institutions contributed 217 documents (2 documents lack of institutional information), and the institutions which published more than 3 documents on this topic are listed in Table 2. As can be seen from the table, UCLA is the most productive and influential university whether in the number of documents, total citations, and total links, due to the fact that UCLA have put laboratory safety at an

unprecedented high level since the laboratory accident occurred at 2008 (Gibson et al., 2014), and founded the University of California Center for Laboratory Safety (UCCLS) which organized laboratory safety workshop to discuss and improve laboratory safety every two years (Czornyj et al., 2018; Gibson and Wayne, 2013; Schröder et al., 2016a). In terms of total citations and the average citations, Princetion University, Hungkuang University and Ecole Polytechnique Federale de Lausanne also attracted a lot of attention from scholars in this field. Furthermore, 11 out of the top 13 institutions which published more than 3 documents are from USA, and the result indicates that USA has an overwhelming advantage in this topic, which is consistent with the results of section 3.2.1.

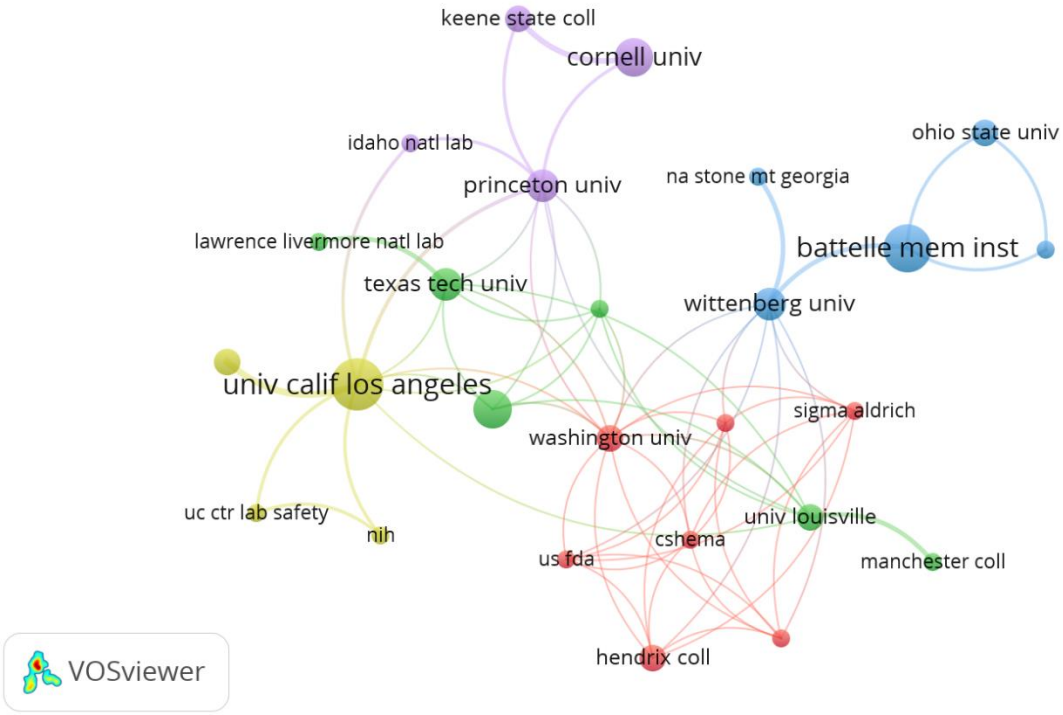

Fig. 3. Institutions cooperation network on university laboratory safety.

The institutions cooperation network on university laboratory safety is shown in Fig. 3, where the node denotes each institution, the colours represent the clusters of institutions, and the lines represent the strength of cooperation among institutions. Institutions that did not cooperate with others or small clusters were removed from the cooperation network. It can be seen from Fig. 3 that all the research institutions in the cooperation network are from the USA, which indicates that the cooperation between institutions is mainly within their own countries or territories, and the cores of clusters in the network are mainly the most productive institutions listed in table 2 (such as UCLA, Battelle Memorial Institute, Princeton University, and Texas Tech University). Furthermore, it should

be noted that some institutions from other countries also cooperated with each other, but they were removed from the network due to these clusters are too small compared with the cooperation among the institutions from the USA. Finally, in terms of the thickness of lines in the network, we can conclude that the cooperation among the institutions is too limited, and the largest cooperation institution (UCLA) only published 5 cooperative documents, and other institutions published no more than 3 cooperative documents.

3.2.3. Authors and co-authorship relationship

Analyzing the number of publications and citations of authors, and mapping the co-authorship relationship have great significance to identify the most productive authors and the most renowned research groups on university laboratory safety. Those information is helpful for researchers to seek cooperation with other authors and to learn from the research trend on this topic. There are 575 authors from the retrieved 219 documents on the topic of university laboratory safety. Out of those 546 authors (94.957%) published only one document, and 31 authors contributed only 2 publications. 8 authors contributed more than 3 publications, and the most productive author is Hill, R. H. who published 7 papers. It can be concluded that although many scholars carried out the research on university laboratory safety. Almost 95% authors contributed very limited publications, and the number of productive authors and their publications is still very small.

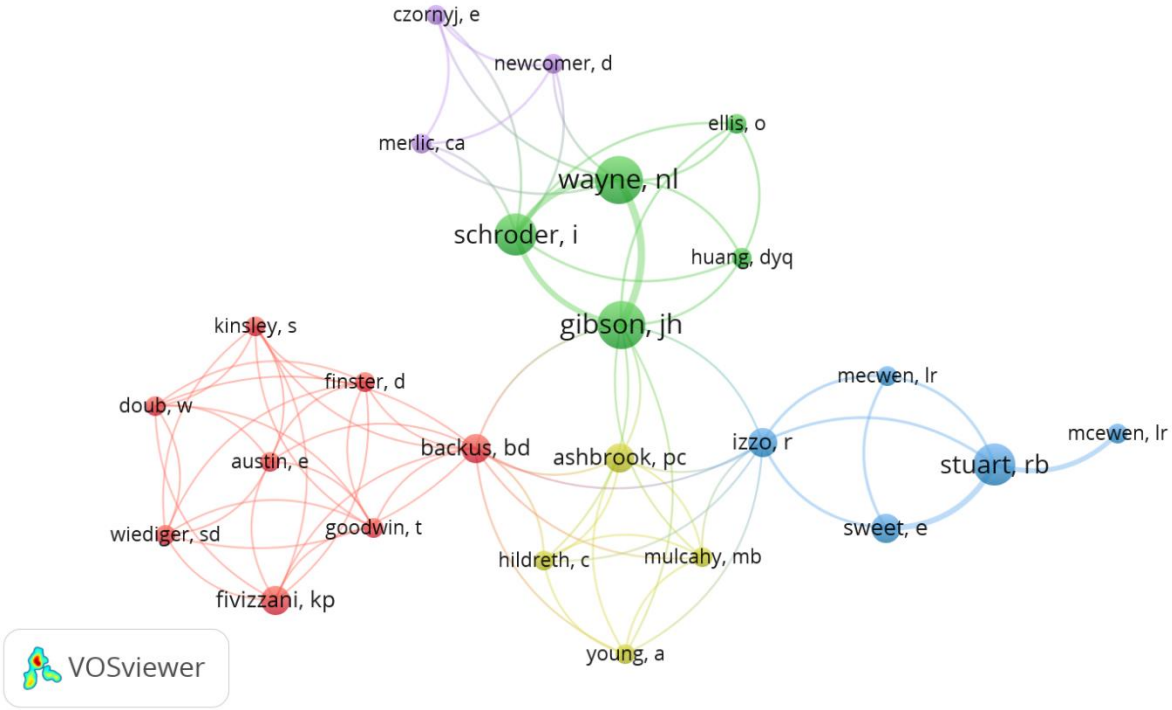

Fig. 4. Co-authorship network on university laboratory safety.

Fig. 4 presents the co-authorship on university laboratory safety using VOSviewer, where the node denotes the author, the colours represent the clusters of authors with similar research topics, and the lines represent the strength of cooperation among authors. It should be noted that the small clusters that were not connected to each other were removed from the network, and 25 authors (divided into 5 clusters) were included in the network after the screening process. As can be observed in Fig. 4, Gibson, J.H. (UCLA; 5 publications), Wayne. N.L. (UCLA; 5 publications) and Schroder, I. (UCLA; 5 publications) published more cooperative documents compared with other authors in the green clusters, and they are all from UCLA which is consistent with the result that UCLA is the most productive institution on university laboratory safety. Stuart, R. from Keene State Coll published 4 documents is the most productive author in the blue cluster, and other authors in the 5 clusters published less than 2 documents. It can be concluded from the above analysis that the cooperation among the authors on university laboratory safety is still weak in the number of publications.

3.3. Citation and Co-citation network analysis

3.3.1. Document citation and co-citation analysis

Table 3

The top 10 most cited documents on university laboratory safety.

Article	Journal	Country/ Territory	Citation	Avg. citations per year	COS
Morley et al., 2008	Review of Scientific Instruments	USA	106	8.83	0
Schmid et al., 2007	Journal of Hospital Infection	Germany	64	4.92	1
Wu et al., 2007	Journal of Safety Research	Taiwan	53	4.08	8
Groso et al., 2010	Particle and Fibre Toxicology	Switzerland	32	3.20	2
Hoffmann et al., 2013	Journal of Occupational Medicine and Toxicology	Germany	24	3.43	0
Di Raddo, 2006	Journal of Chemical Education	USA	17	1.21	5
Alaimo et al., 2010	Journal of Chemical Education	USA	15	1.50	5
Seal and Karn, 2014	Safety Science	USA	14	2.33	0
McGarry et al., 2013	Journal of Chemical Education	USA	14	2.00	4
Billiet et al., 1991	Laboratory Medicine	USA	14	0.48	0

Avg. citations per year denotes the average number of citations per year per publication; COS (Citation of references) represents the number of times cited by the 219 retrieved documents on university laboratory safety.

Citation analysis is an effective way to measure the impact and quality of a publication by looking at the number of times that publication has been cited by other work, and to identify the most important publications in a research field. As for the field of university laboratory safety, a total of 219 retrieved documents were cited 728 times by 642 publications covering 425 different publication

sources, and the top 10 most cited documents which accounting for 48.489% of total citation are listed in Table 3. As shown in Table 3, the most cited and the highest average cited paper is the *"GaInSn usage in the research laboratory"* (Morley et al., 2008). However, this paper was not cited by the retrieved publications on the topic of university laboratory safety, and the reason may be that it focused on the distinctive narrow topic of how to use the GaInSn in university laboratory safely. Furthermore, the paper *"Safety climate in university and college laboratories: impact of organizational and individual factors"* (Wu et al., 2007) has been cited 8 times by the retrieved 219 publications, which is the most cited document on university laboratory safety, and this may be because safety climate is closely related to the research on university laboratory safety.

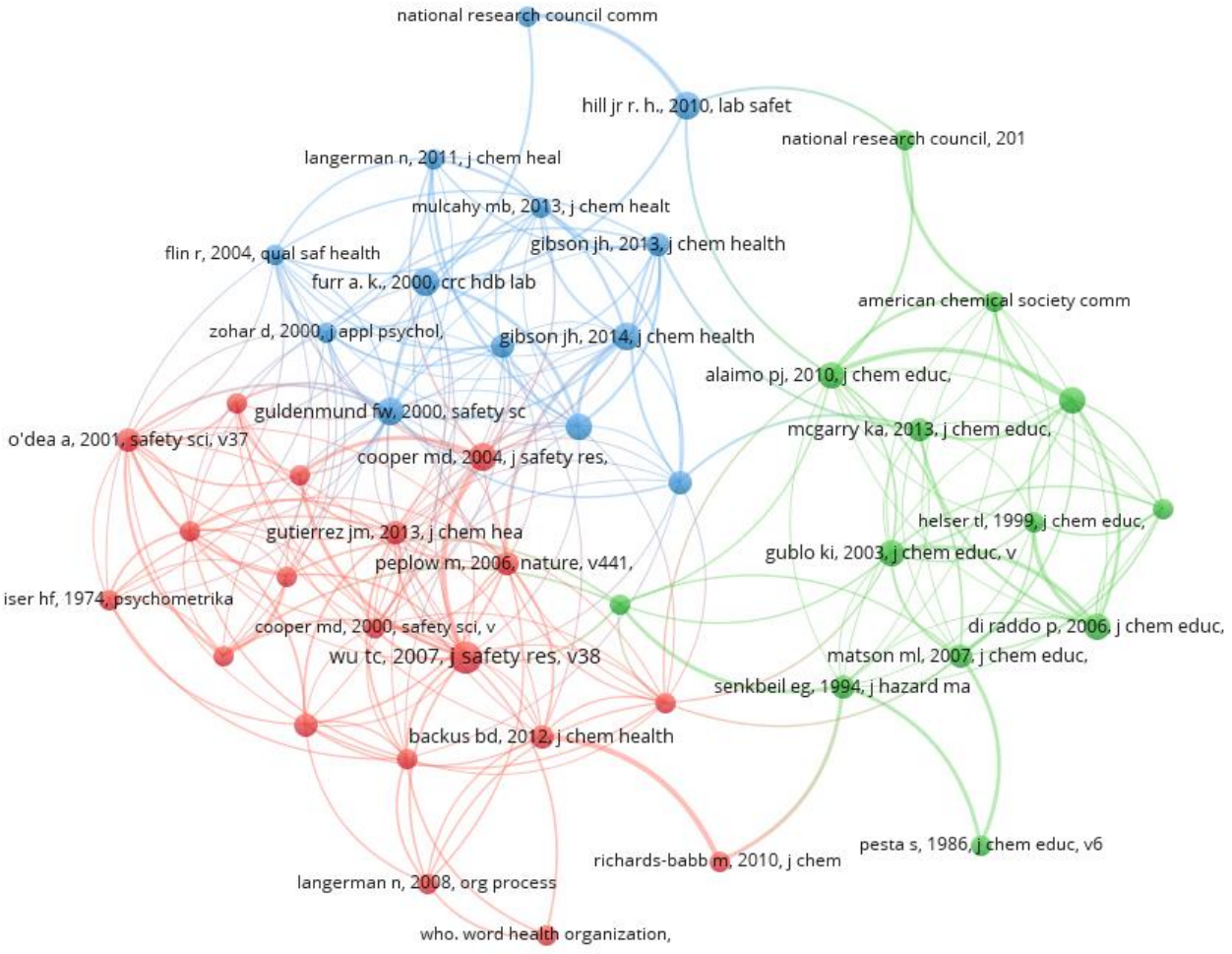

Fig. 5. Co-citation map of references that were cited more than 3 times by publications on university laboratory safety.

Co-citation analysis of documents can be used to determine the core publications on university laboratory safety, and to assess the interaction between documents that have been cited together by the publications on this topic. There are a total of 3119 references cited by the 219 retrieved

publications on university laboratory safety, and out of those 175 references were cited more than 2 times and 48 references were cited more than 3 times. Fig 5 shows the co-citation map of references that were cited more than 3 times by the publications on university laboratory safety using VOSviewer, and 3 references that not connected to others were excluded from the network. The size of the circle represents the number of citations received by the documents and the thickness of lines denotes the times of two documents have been cited together by other publications. The circles with the same colour represent a same cluster with a similar topic. As can be seen from Fig. 5, 45 references in the network are divided into three clusters according to the co-citation relationship. The red cluster mainly focus on laboratory safety culture or climate, and the paper *"Safety climate in university and college laboratories: impact of organizational and individual factors"* (Wu et al., 2007) has the largest links (22) and citations (8) can be considered as the core of this cluster. The topic of the green cluster is laboratory safety education, and the paper *"Laboratory safety course in the chemistry curriculum"* (Senkbeil, 1994) is the most important publication due to the largest links (12) in this cluster. The blue cluster is mainly related to laboratory risk assessment and safety management, and the paper *"The nature of safety culture: a review of theory and research"* (Guldenmund, 2000) has the largest links (22) and citations (6) in the cluster can be considered as the core of this cluster.

3.3.2. Distribution and co-citation analysis of publication sources

Table 4

Publication sources that published more than 3 documents on university laboratory safety.

Rank	Source Title	Quantity	Percentage	COSEJ
1	Journal of Chemical Health and Safety	45	20.548%	71
2	Abstracts of Papers of the American Chemical Society	29	13.242%	1
3	Journal of Chemical Education	12	5.479%	197
4	Safety Science	8	3.653%	74
5	Journal of Loss Prevention in the Process Industries	6	2.740%	23
6	Health Physics	6	2.740%	8
7	Procedia Social and Behavioral Sciences	4	1.826%	2
8	Process Safety Progress	3	1.370%	12

COSEJ (Citation of references each source) represents the number of times each source cited by the 219 retrieved documents on university laboratory safety.

Publication sources analysis is a useful method to identify the core journals related to university laboratory safety, and it is of great significance for researchers to search literature and choose a suitable journal to publish their research on this topic. Based on the retrieved results, 219 documents retrieved from 126 publication sources, and the information of publication sources that published

more than 3 documents on university laboratory safety has been listed in Table 4. As can be seen from Table 4, The *Journal of Chemical Health and Safety* (45) is the most productive source on university laboratory safety, followed are the *Abstracts of Papers of the American Chemical Society* (29) and the *Journal of Chemical Education* (12). In terms of the cited times of each source by the 219 retrieved documents, the *Journal of Chemical Education* (197) ranks the first, followed are the *Safety Science* and the *Journal of Chemical Health and Safety* (61).

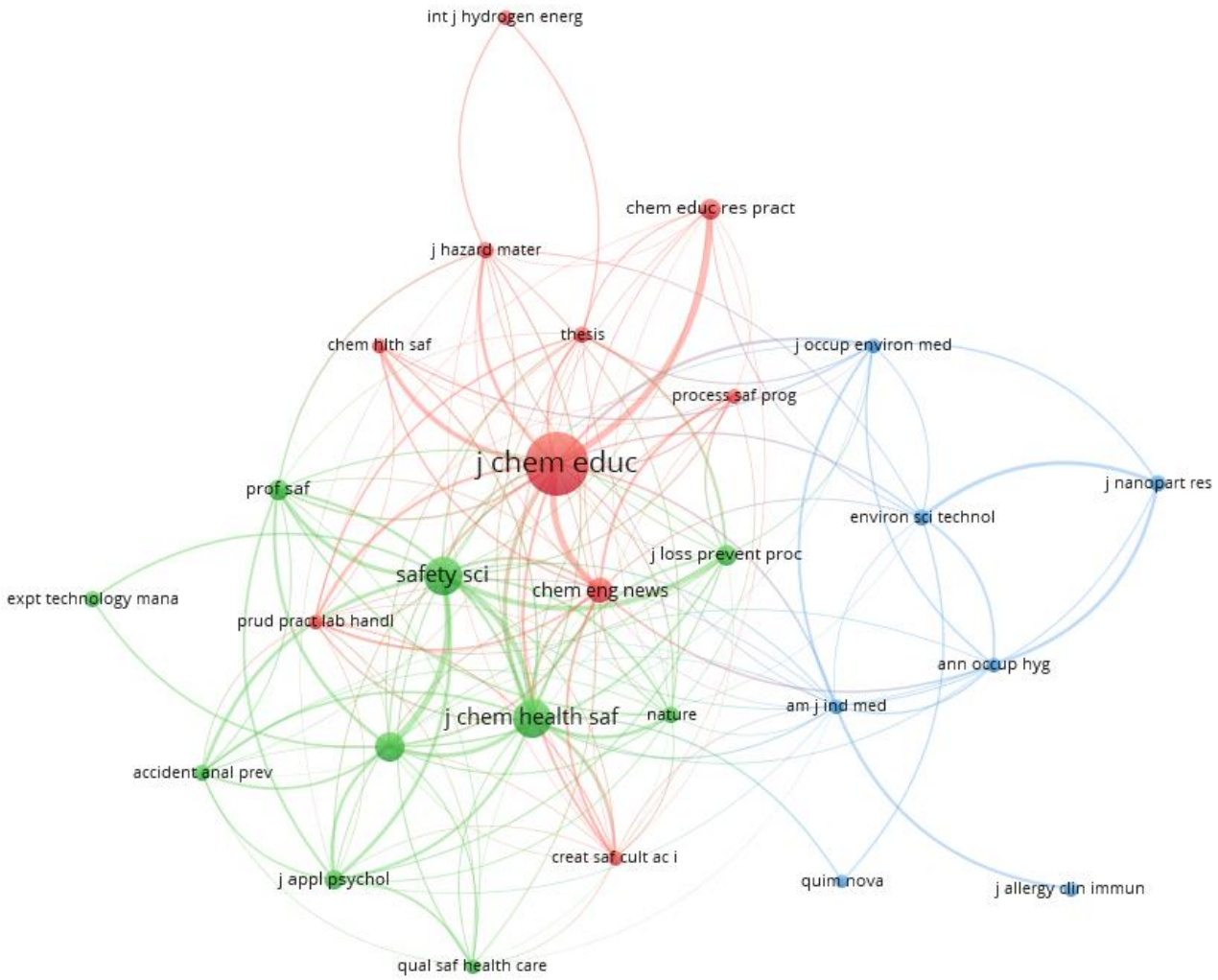

Fig. 6. Co-citation map of publication sources that were cited more than 10 times by publications on university laboratory safety.

Co-citation analysis of publication sources aims to identify the most influential publication sources that are cited by the publications on university laboratory safety, and to reveal their co-citation relationship by analyzing two publication sources were citied together in the same publications on this topic. The more two publication sources are cited together, the stronger co-citation relationship between them. There are 2032 publication sources cited by the 219 retrieved publications, and 27

sources were cited more than10 times. Fig. 6 shows the co-citation map of publication sources that were cited more than 10 times by publications on university laboratory safety using VOSviewer. The size of the circle represents the number of citations received by the publication sources and the circles with the same colour represent a same cluster with strongly relevance. The thickness of links denotes the times of two sources had been cited together by other publications, and the number of links represents the number of sources co-cited with other sources. As can be seen from Fig. 6, the *"Journal of Chemical Education"* ranks first both in the number of links (19) and citations (197) in the red cluster that is related to safety education. In the green cluster which focused on safety science and technology, the *"Safety Science"* is the most highly cited journal (74), but the *"Journal of Chemical Health and Safety"* is the strongest correlation with other sources (22 links). Compared with the red and green clusters, the blue cluster focussed on environment and occupational health is much smaller w.r.t. the number of citations and links, and the *"American Journal of Industrial Medicine"* can be considered as the core journal due to the largest number of links (17).

3.4. Temporal evolution of terms co-occurrence network

The keywords, titles, and abstracts can be used to infer the themes and trends of a specific research field. However, in the field of university laboratory safety, 110 out of 219 retrieved publications are lack of author keywords, and it may result in inaccurate results. Thus, in the present work, the co-occurrence analysis of terms which were extracted from the title and abstract of a publication using VOSviewer based on the natural language processing algorithms, is used to study the themes and trends of university laboratory safety. Setting the minimum occurrence of terms at 10 in VOSviewer, 85 out of 4581 terms were initially considered. Terms that were a subset of university laboratory safety such as "laboratory safety", "university laboratory", and "university" were excluded. Terms with a general meaning such as "research", "paper", and "year", were also removed. Terms with a similar meaning such as "accident" and "incident", were merged. Finally, 70 terms were considered in the terms co-occurrence network. The top 10 most frequently occurring terms were: "Student (73)", "Practice (49)", "Program (46)", "System (44)", "Environment (42)", "Accident (39)", "Level (37)", "management (37)", "assessment (36)" and "health (36)".

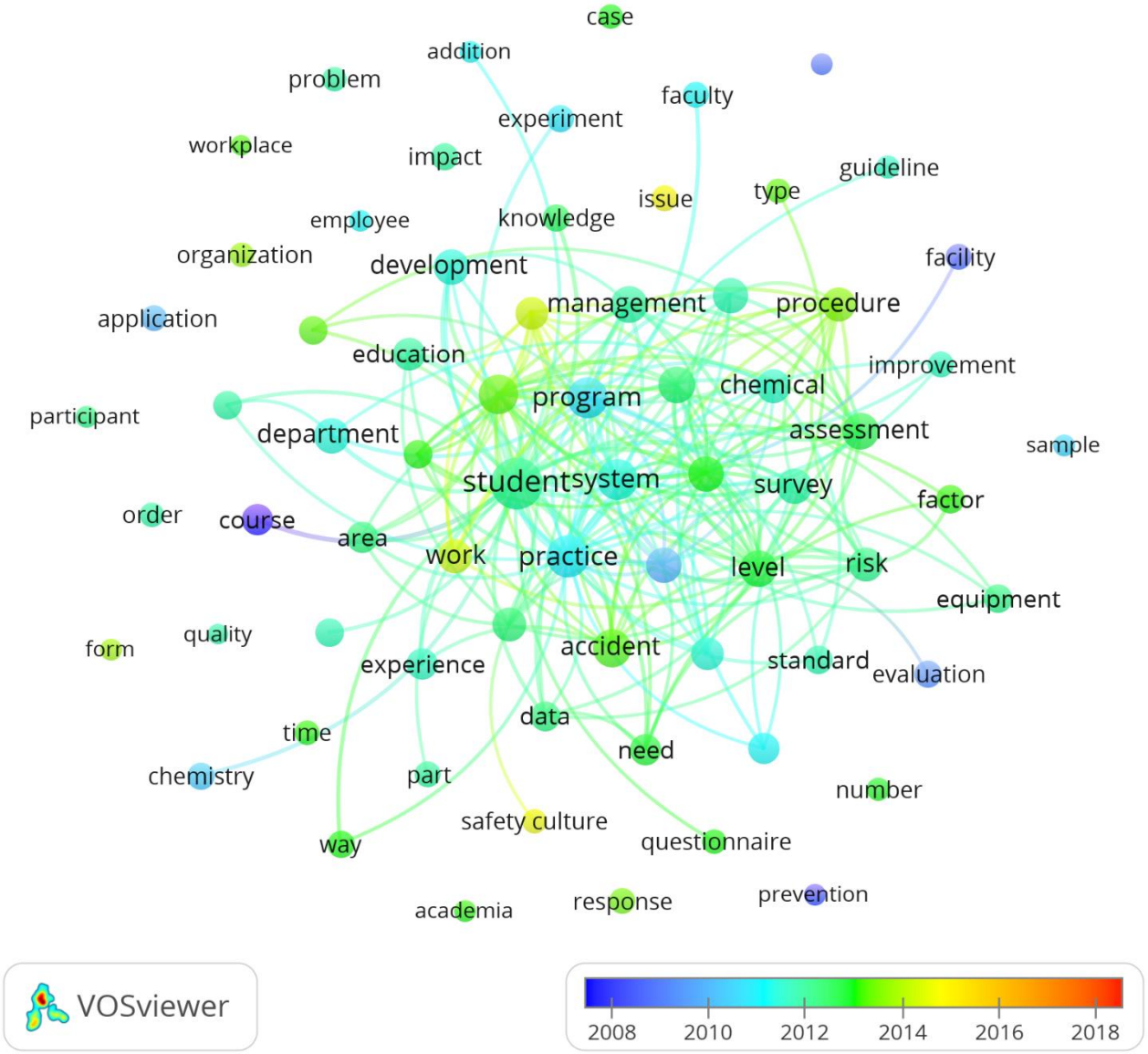

Fig. 7. Terms co-occurrence network of university laboratory safety with time information.

Fig. 7 indicates the co-occurrence network of terms with time information using VOSviewer. Temporal variation in research themes can be obtained from the average publication year of various terms which denotes the average publication year of the documents in which a term occurs. In Fig. 7, the size of the circle represents the occurrence frequency of the individual term. The colour of the circle denotes the average publication year of a term, and the purple circles indicate the terms most occurred around 2008, and the red circles mean the terms most occurred around 2018. The links between two terms represent two terms occurred in the same publication, and the thickness of the links represents the times of two terms occurred together. In order to make the picture clear, only the top 200 strongest links were displayed in Fig. 7, and the terms without links don't mean that they

didn't occurred together with other terms. As can be seen from Fig. 7, there were total 11 terms (such as course, prevention, facility, training, chemistry, experiment, and occupational safety) before 2010 which can be considered as the early stage of the research on university laboratory safety based on the results of section 3.1. The main topic can be concluded that laboratory safety course/training and facilities were the principal measures to guarantee the occupational safety related to chemistry experiment in university laboratory during this period. A total of 40 terms were mentioned 1080 times around 2011 and 2012 which shows there were a rapid improvement in the field of university laboratory safety, and the main popular terms were: student, practice, system, management, level, assessment, hazard, survey, chemical, risk, education, faculty, employee, etc. These terms indicate that the researchers started to pay attention to the education of students and employees, to identify hazard and assess risks, and to build safety management system in university laboratory from 2011 to 2012. There were 19 terms appeared 420 times from 2013 to 2014, and the main terms were: environment, accident, process, industry, response, safety culture, work/workplace, and organization, etc. These terms indicate that the research on safety cultures, experiences of industrial laboratory, and environment of workplace in university laboratory were emerging at that time. However, there were no new terms appeared from 2015. It can be concluded that no new research topic or method has appeared in the past 5 years, and there is an urgent need for new research topics and methods in this field.

3.5. Distribution of documents in subject categories

Every journal covered by WOS Core Collection is assigned to at least one subject categories which represent a particular research area. Every record in WOS contains the subject category of its source publication, and 219 retrieved publications on university laboratory safety belong to 70 subject categories. Of these 70 subject categories, 11 subject categories included only one document, 14 subject categories contained only two publications, and 9 subject categories published 3 documents. The subject categories published more than 4 documents were presented in Fig. 8. The most productive subject category on university laboratory safety was *"Public, Environmental & Occupational Health"* with 70 publications, followed by *"Chemistry, Multidisciplinary"* with 46 publications and *"Education, Scientific Disciplines"* with 20 publications. It can be seen from Fig. 8

that there were 4 subject categories (with 37 publications) related to engineering, 3 subject categories (with 81 publications) belong to environmental domain, 2 subject categories (with 59 publications) contained chemistry or chemical, and 2 subject categories (with 35 publications) related to education. Thus, it can be concluded that the research domain of university laboratory safety covered a wide variety of themes and disciplines. The most popular themes were environment, occupational health, chemistry or chemical, education and engineering. Furthermore, it also covered nuclear science, management science, social science and medicine.

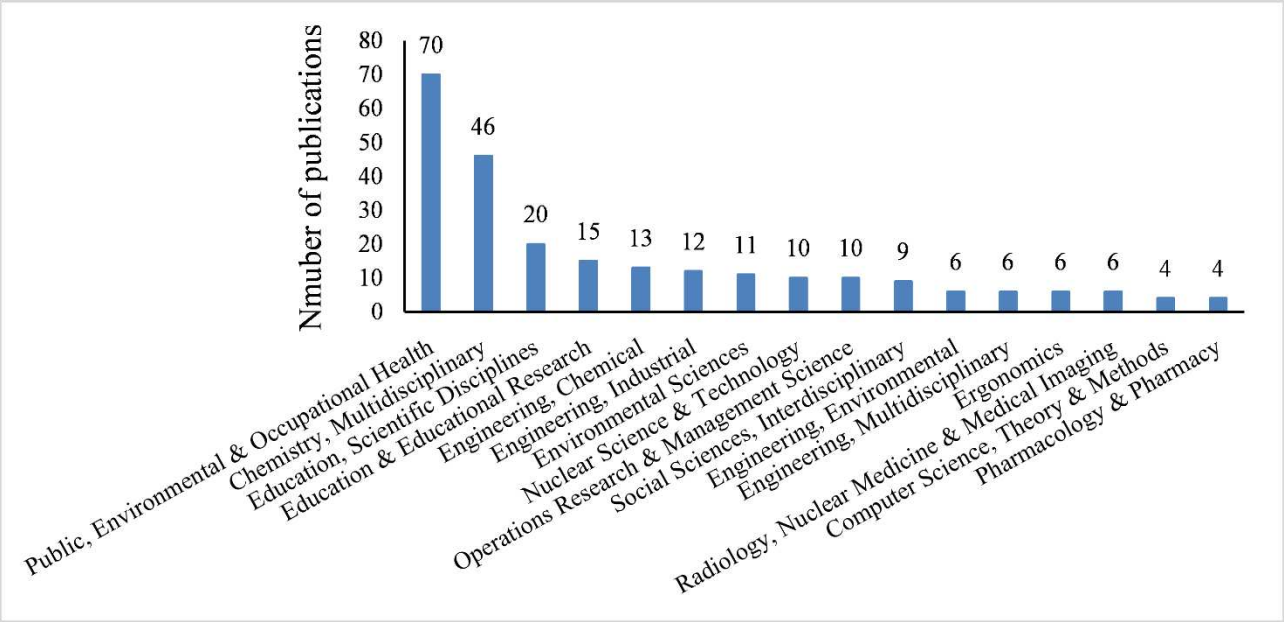

Fig. 8. The subject categories with more than 4 publications on university laboratory safety.

4. Conclusions

In this paper, 219 publications related to the university laboratory safety were retrieved and screened from WOS Core Collection database, and the bibliometric analysis of this field was carried out based on the above publications. In terms of the publications over year, although the number of publications in university laboratory safety increased linearly since 2010, this field is still a younger discipline and belonged to the minority research field when compared with the publications of other safety-related areas (such as safety culture, road safety and construction safety).

In the field of university laboratory safety, USA has overwhelming advantages in the number of publications, of total citations, and of most productive institutions. However, the publications of Germany, Taiwan and Switzerland were much more popular in this field, w.r.t. the average citation

per publication. UCLA is the most productive and influential university whether in the number of documents, total citations, and cooperative institutions. Princetion University, Hungkuang University and Ecole Polytechnique Federale de Lausanne also attracted a lot of attention from scholars in this field in terms of the total citations and the average citations. There are 575 authors from the retrieved 219 documents on the topic of university laboratory safety, but almost 95% authors contributed only one publication. The most productive author is Hill, R. H. who published 7 papers. Gibson, J.H., Wayne. N.L. and Schroder, I. from UCLA published the most cooperative documents (5 publications) compared with other authors. It should be noted that the cooperation among countries/territories, institutions, and authors is still at a very low level in this field, and the cooperation among different institutions is mainly within their own countries or territories.

As for the citation and co-citation analysis of documents and publication sources, the most cited and the highest average cited paper is Morley et al., 2008, and Czornyj et al., 2018 is the most cited document by the publications on university laboratory safety. Furthermore, Morley et al., 2008, Senkbeil, 1994 and Guldenmund, 2000 are the core publications of their respective clusters. The *Journal of Chemical Health and Safety* is the most productive source on university laboratory safety, and the documents published in the *Journal of Chemical Education* were the most cited by the publications on university laboratory safety. The university laboratory safety is a multidisciplinary research field. However, no new research topic or method appeared since 2015, and there is an urgent need for researcher to come with topics and methods in this field.

Acknowledgement

This study was supported by the National Key R&D Program of China (2016YFC0801500), the National Natural Science Foundation of China (21576102), and China Scholarship Council (201806150064).

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