Journal of Education for Sustainable Development Studies
J. Educ. Sustain. Dev. Stud.
2024, Vol. 1, No. 1, 28–40

Review Article

Global Trends Research and Application of Green Chemistry and Education: A Bibliometric Analysis (1994–2023)

Laurensia

Department of Chemistry Education, Universitas Negeri Jakarta, Indonesia

Abstract
In the field of education, it has also been implemented into the school curriculum. An assessment of how we analyze the current state and trends regarding research into the application of green chemistry and education by completing a thorough bibliometric study for the time period 1994–2023. Studies in this field focus on the language used in journal publications, the level of development, the author's keywords that are most often used, the journals that are often used as quotations, the most productive journal authors, the journals that influence researchers the most, which institutions are most productive, and which countries who is most active in research in this field. In the analysis section regarding bibliometric mapping, a total of 509 automatically selected peer-reviewed journals were obtained from data in Scopus. The results of the research show that: (1) manuscripts written in journals use English, (2) the top point publications in 2019 and 2020 were 51 papers, (3) green chemistry and education are the most frequently used keywords, (4) the work of (K., Alfonsi, Colberg J., Dunn P.J., Fevig T., Jennings S., Johnson T.A., Kleine H.P., et al. 2008), (J.H., Clark. 1999) as well as (M., Tobiszewski, Marć M., Gałuszka A., and Namieśnik J. 2015.) and (M., Tobiszewski, Marć M., Gałuszka A., and Namieśnik J. 2015.) is the most frequently cited document, (5) Yin J.; Goh T.-T.; Yang B.; Xiaobin Y., Nikou S.A.; Economides A.A., and Dessì D.; Fenu G.; Marras M.; Reforgiato Recupero D. is the most important author, (6) Journal Green Chemistry, and Journal Sustainability Switzerland are among the best journals, (7) University of Toronto, Universität Bremen, and University of York are among the top journals, and (8) Canada and Germany are the most important countries.

Keywords: Bibliometric mapping, education, green chemistry, Scopus

Laurensia
laurensiaumi73@gmail.com

Received
March 30, 2024
Accepted
May 17, 2024
Published
June 1, 2024

Citation: Laurensia. (2024). Global trends research and application of green chemistry and education: A bibliometric analysis (1994–2023). *Journal of Education for Sustainable Development Studies, 1*(1), 28–40.

1. INTRODUCTION

The Green Chemistry movement, which was first formulated in early 1990, was agreed upon by all countries in the world by issuing There are twelve principles of green chemistry, which are a reference for environmentally friendly production practices in industry. Among The relevance of employing technology to promote learning at higher education institutions around the world activities is well understood. Technology helps make innovative modules so that teachers can easily

work with them. Interestingly, module-based web has grown in popularity and is now used in many higher education institutions. Based on literature also said that web modules have utilized to boost student achievement in knowledge, skill, and creativity. Nowadays, web modules play a main function in facilitating student learning activities. Considering coronavirus has become a disaster and affects many sectors, one of them is education, which makes it difficult for communication between teachers and students.

1.1 Aim of the Study

The main research questions (RQ) proposed in The following are the findings of the current study:

RQ1: What language is used in publications from green chemistry and education in the field published from 1994 to 2023?
RQ2: From 1994 to 2023, how many publications in the field were published?
RQ3: Which keywords are most commonly used by writers of gamification applications in higher education?
RQ4: That top (10 Document) of most cited documents sources on green chemistry and education in higher education?
RQ5: Who are the most active authors and publishing sources on green chemistry and education in higher education? (top author)
RQ6: What is the collaboration network of authors on green chemistry and education in higher education
RQ7: Which institutions have provided the most publications in the last ten years?
RQ8: Which countries are the most productive publishing papers on m-learn green chemistry and education in higher education?

2. METHODS

2.1 Research Design

To be able to find out global trends in green chemistry and education applications, a systematic review was conducted. Within this scope, we take journal literature about green chemistry and educational applications in postsecondary education as research objects. For this purpose, scientific literature from the Scopus database from 1994–2023 has been selected. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were used in this analysis, to display an overall picture from the literature about green chemistry and education in higher education environments.

The entire method for carrying out bibliometrics is illustrated in Figure 1, the PRISMA protocol was used. That important step is implemented in order to zoom out refraction and write a clear report on the results of its findings clear and trustworthy. This is highly recommended by Mc Burney and Novak, They both suggested that to explore research trends over several years, bibliometric analysis methods could be used. Bibliometric methods analysis provides systematic data that can describe a quantitative publication to help researchers determine the direction of trends and research patterns.

2.2 Data Collection

This research takes document data from the Scopus database on the internet at https://www.scopus.com/ on Thursday, September 14, 2023. Advanced data search is used for search strings including keyword combinations in conjunction with AND and OR. This is the command to follow: Heading-ABS-Key ((“green chemistry*”) additionally (“education” OR “green chemistry” OR “education*”

additionally LIMIT-TO (DOCTYPE, “ar”) is used. Any set of characters is replaced with the asterisk sign (*) to broaden the search. For instance, green chemistry* will discover chemical catalysis principles of green chemistry, etc. Articles meeting the inclusion requirements are those whose titles, abstracts, or keywords contain at least one of the keywords.

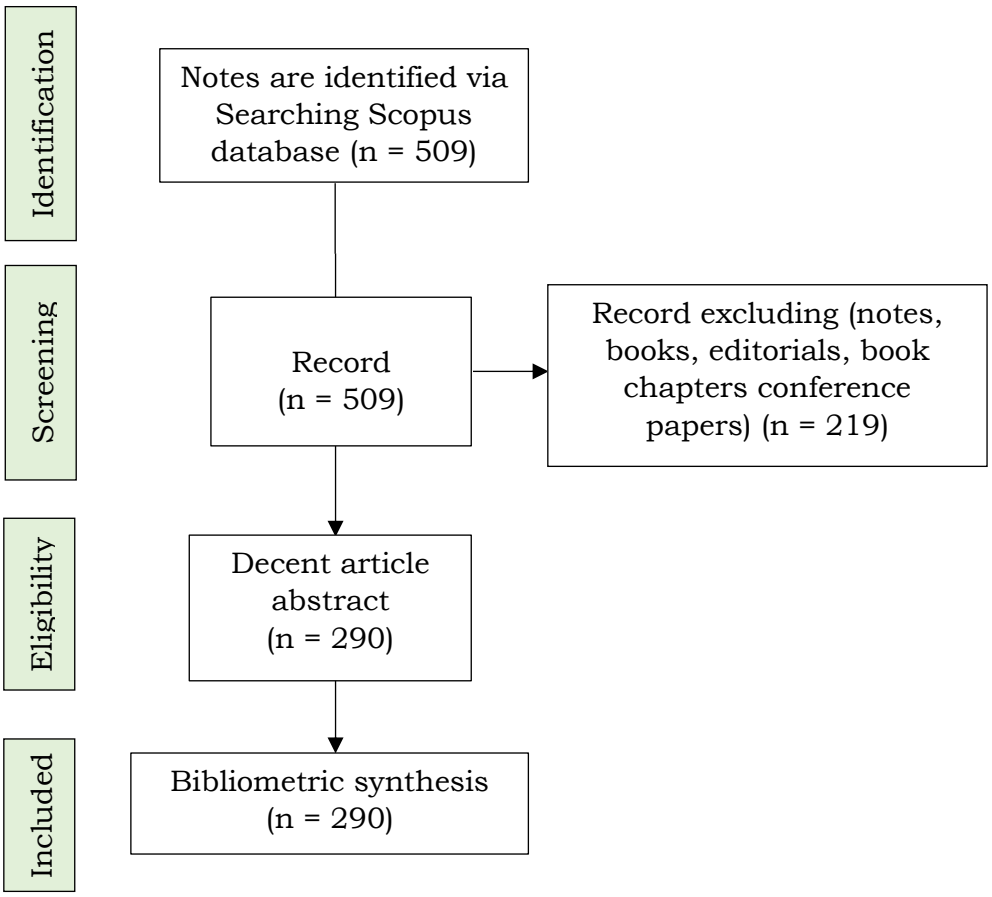

Figure 1. PRISMA Flowchart

Changeable what is studied is the language used in publications, the year of publication of the document under study, the keywords used, documents that are cited by many people, authors who are frequently quoted, active journals, productive journals, and productive countries. Frequency is taken out for every variable. The index is quantitatively studied to map trends in this field by searching for H-index.

2.3 Data Analysis

There is no specific period in the search process. Bibliometric analysis includes documents published throughout the year. The interesting thing that was found was that The initial manuscript was released in 1994. Consequently, data collection In this investigation, time was from 1994– 2023 with an interval of 29 years. Following the first search, a total of 509 documents were obtained from 1994 to 2023 (including print media). The type of document in this review is determined as an article in a journal article. Books, book chapters, theses, editorials, corrections, and correspondence were all among document kinds that were subsequently eliminated from the research. To eliminate this, we ran a Scopus filter. 219 unrelated publications, such as editorials, commentaries, and reviews of books. After removing

any works unrelated to the study's goals, a total of 290 article abstracts were assessed for eligibility.

From all example articles, each piece of data containing citation details, keywords, abstract, and bibliographic data were downloaded. The file is then uploaded to the viewer for the Visualization of Similarities (VOS).

3. RESULTS

3.1 The Language Used In Publications

As previously mentioned, the analysis's conclusions of 509 documentaries regarding the application of green chemistry and education during the research time frame were carried out. Every scientific research has been published in English in 100% of cases.

3.2 Annual Production of Green Chemistry and Education

To answer query RQ2, we displayed the yearly production of science in the fields of green chemistry and education. The findings indicate that there is a variation in the quantity of publications over time. It is seen that 2019 and 2020 held the greatest quantity of publications, and 2007 possessed the least amount of green chemistry and education publications. However, in the last 3 years, the number of articles seems to have increased, as depicted in Figure 2, research on the application of green chemistry and education seems to have started in 1994 even though there is only 1 article by Illman Deborah L. He became the first paper of note that year. He researched how Chemists Contemplated Reforms Organic Chemistry Curriculum.

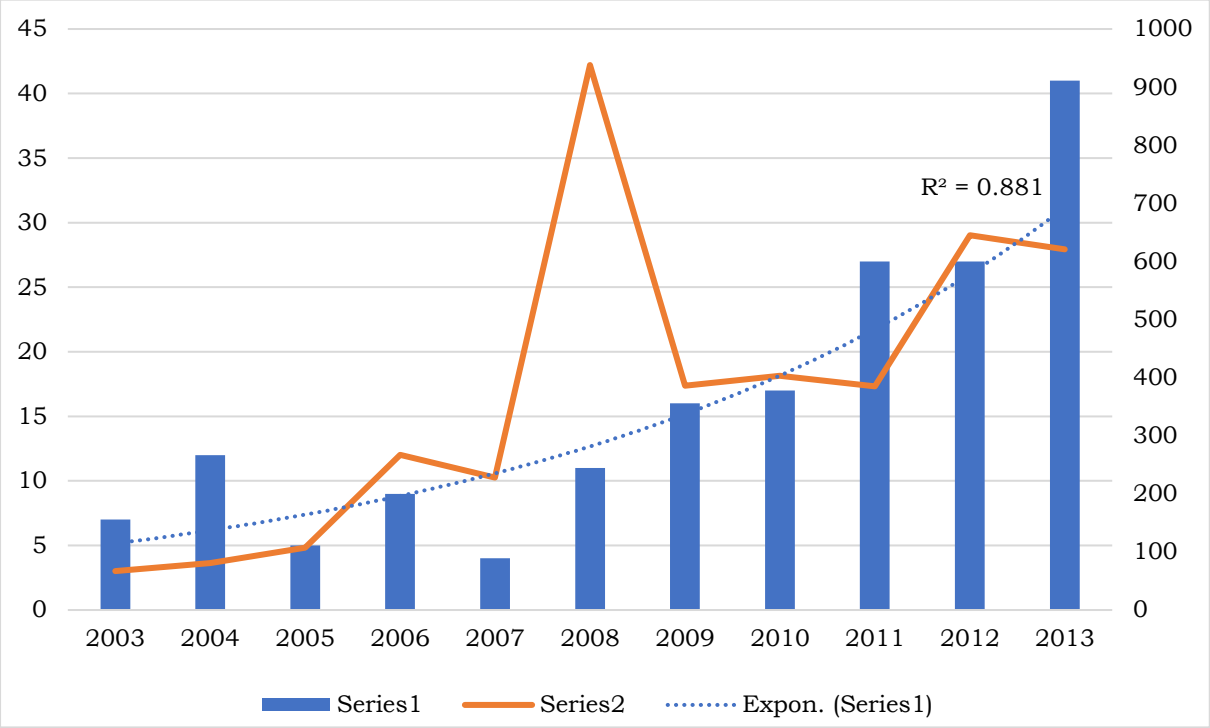

Figure 2. Evolution of Publication and Citation (2003–2023)

We can see the evolution of publication and citation of green chemistry and education from 2003 to 2023 from the following data. Over the last twenty years, it has been seen that the quantity of citations and publications has increased, as

shown in Figure 2 meaning that as the years go by, readers tend to follow more or look for information about green chemistry and education. This can be understood by seeing that the highest rates were in 2008, 2012, and 2013. In that year California passed two legislation aimed at encouraging green chemistry programs, namely by introducing the Green Chemistry Initiative for California. According to one of these statutes, the California Department of Toxic Substances Control (DTSC) must create new regulations to identify substances that could be harmful to the environment or public health and to encourage the substitution of safer chemicals for those that are more dangerous.

The resulting regulations became operative in 2013, marking the beginning of the Safer Consumer Products Program of the DTSC. Then in 2019 and 2020, the number of articles increased to 51 and the cut also increased again, this is because in 2019 the newly approved Supplement on Professional Training by the Committee on Professional Training (CPT) "Green Chemistry in the Curriculum" encourages the teaching of green chemistry in undergraduate courses. A systems thinking approach, which examines the life cycle of each component involved in a chemical process, makes safer technologies possible to design. Green chemistry employs systems thinking techniques that may help predict and prevent unexpected repercussions from emerging chemical compounds examine the instruction strategies that have occurred employed in order to assist green chemistry learning (GCL) and green chemistry education (GCE) to determine appropriate pedagogical techniques for College students and pre-service teachers are being taught and learning about green chemistry (Eila-Jeronen, 2020).

The trend of researchers and observers of green chemistry issues has increased in the last 20 years as can be seen from the trendline graph which has a figure of 0.88. This makes it possible that in the years to come research on green chemistry and education will be researched more frequently and become a trend in itself, especially in many countries this green chemistry has been widely included in the education curriculum in secondary schools. As is the case in Indonesia, with the independent curriculum in chemistry subjects in class.

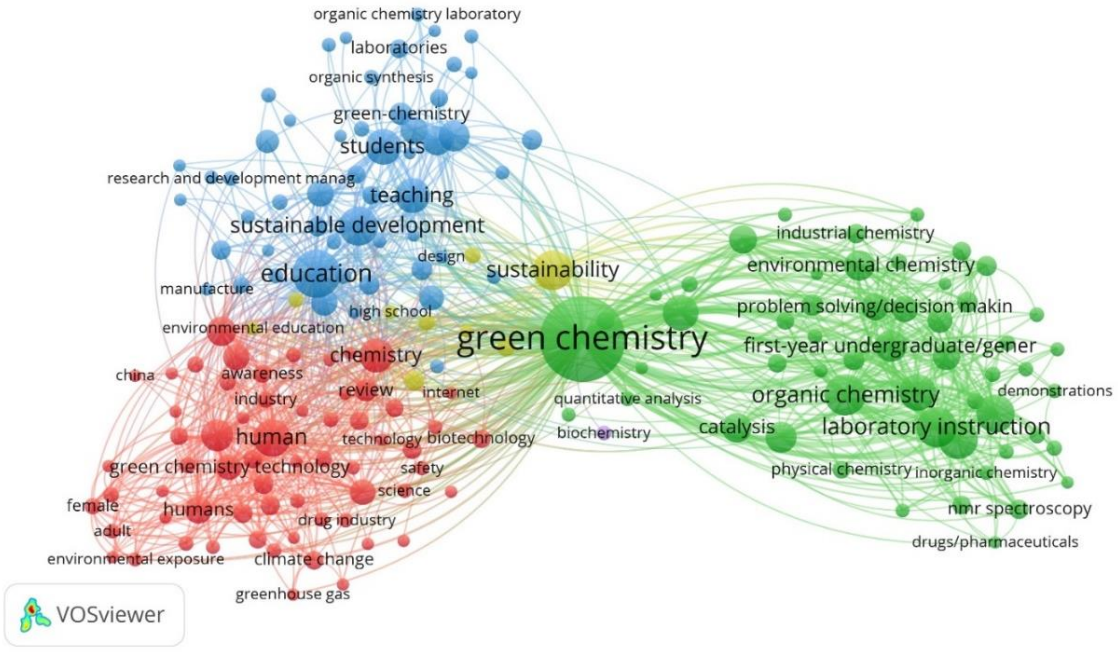

Figure 3. Co-Occurrence with All Key

3.3 Most Frequently Searched Keywords

To answer question RQ3, we can see from this picture we can interpret that the search trend in data-based journals or articles on Scopus is about green chemistry which is associated with laboratory instruction, organic chemistry problem-solving, and the chemical industry. Other keywords that are no less important are green chemistry, technology, human and education, sustainable development related to students, and green chemistry learning (see Figure 3).

3.4 The Most Frequently Cited Papers

In response to query RQ4, the documents with the most citations have been identified, and are displayed in Table 1. The papers with the highest frequency are included in this table of citations between papers on the utilization of green chemistry and education since 1994. Note that The magnitude of the impact is influenced by the amount of citations.

Table 1. Top 10 Most Cited Documents

Authors	Title	Source	Cites
(K., et al. 2008, K., et al. 2008)	Green chemistry tools to influence a medicinal chemistry and research chemistry-based organization	Green Chemistry	884
(J.H. 1999)Clark J.H.	Green chemistry: Challenges and opportunities	Green Chemistry	788
(M., et al. 2015)	Green chemistry metrics with special reference to green analytical chemistry	Molecules	275
(T.-L., et al. 2020)	Implementation of green chemistry principles in the circular economy system towards sustainable development goals: Challenges and perspectives	Science of the Total Environment	188
(J.H., 2006)	Green chemistry: Today (and tomorrow)	Green Chemistry	186
(M.P. and M.R. 2009)	Toward a new U.S. chemicals policy: Rebuilding the foundation to advance new science, green chemistry, and environmental health	Environmental Health Perspectives	168
(J., L. and M.J. 2007)	New trends for design towards sustainability in chemical engineering: Green engineering	Chemical Engineering Journal	157
(R.K., S. and S. 2012)	Preparation of gold nanoparticles using tea: A green chemistry experiment	Journal of Chemical Education	121
(P., et al. 2017)	Sustainable chemistry: How to produce better and more from less?	Green Chemistry	109
(J.D., C., et al., 2020)	The Green Print: Advancement of Environmental Sustainability in Healthcare	Resources, Conservation, and Recycling	90

From Table 1, we can see that the two most cited articles are about the application of green chemistry instruments to impact medicinal chemistry and related studies to green chemistry as challenges and opportunities.

In 2020, if viewed on an annual scale, on average, one article was found that was most cited, regarding the Challenges and perspectives for implementing green chemistry concepts in a circular economy system to achieve sustainable development goals. This is to the trend in that year, research interest has become widespread among researchers about the application of green chemistry (T.-L., et al. 2020).

3.5 Most Productive Authors

Regarding research question RQ5, Table 2 provides details on the top 10 productive writers who have published the most about the use of green chemistry and education in higher education. It should be mentioned that a measure of productivity is the quantity or number of publications.

Table 2. The Number Of Publications By The Top Ten Authors

Author	Organization	Nation	N	H-index
Dicks, A.P.	University of Toronto	Canada	18	19
Eilks, I.	Universität Bremen	Germany	13	27
Clark, J.H	University of York	England	10	93
Zuin, V. G	Leuphana Universität Lüneburg	Germany	7	20
Mahaffy, P.G.	King's University,	Canada	7	17
Hurst, G.A.	University of York	UK	7	14
Bastin, L.D.	Widener University	US	7	8
Wissinger, J.E.	University of Minnesota Twin Cities	US	6	12
Warner, J.C.	Monash University	Australia	6	18
Pagliaro	Istituto Per Lo Studio Dei Materiali Nanostrutturati, Rome	Italy	6	55

From the data analyzed, it can be seen that the authors with the most publications are Dicks, A.P. with 18 articles, followed by Eilks, I with 13 articles, and Clark, J.H. with 10 articles. The following authors are Zuin, V. G., Mahaffy, P.G, Hurst, G.A, and Bastin, L.D, each of whom has 6 articles. The remaining writers among the best ten are Wissinger, J.E, Warner, J.C, and Pagliaro, with 6 works. Figure 4 also analyzes the most productive authors based on the h-index. The productivity and influence of research articles published in the Scopus database are gauged by the H-index.

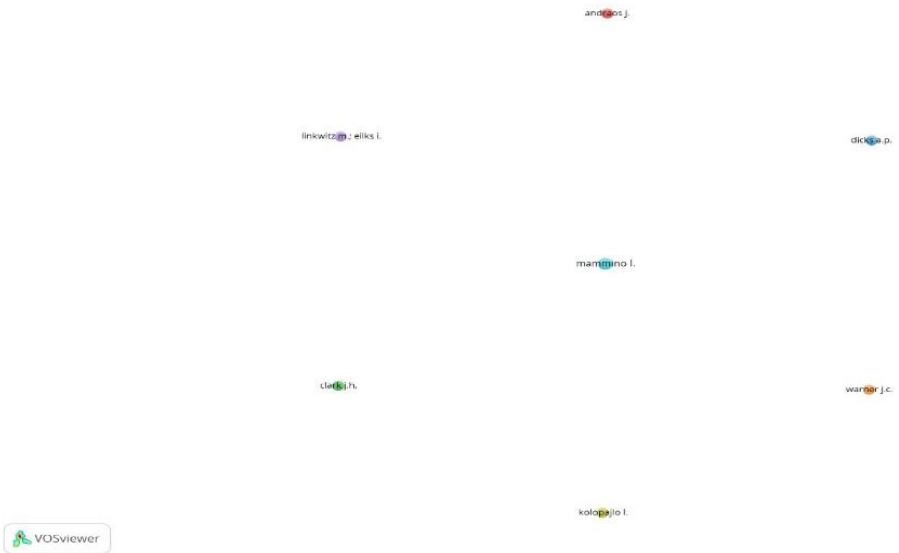

Figure 4. Co-Authorship with Author

Figure 4 illustrates how the two most well-known authors are Clark, J.H (h-index = 93) from the University of York, United States, and Pagliaro (h-index = 55) from Istituto Per Lo Studio Dei Materiali Nanostrutturati, Rome Italy, both have their uniqueness. If Clark, JH, this American writer has 10 articles and has a big publicity impact, but not Pagliaro, he has 6 articles but his H-index is quite large, namely 55. In general, 30% of writers (n = 41) earn at least a minimum of 10 documents. Of the 10 authors, more than 50% (n = 46) have 6-7 articles.

We also examine the authors' network of collaboration inside the dataset in this section. Three texts written by a specific author are required, and twenty-five citations are required for an author. The collaboration network comprising all 25 writers is depicted in Figure 4. This visualization map shows us that there are seven collaboration clusters, each represented by a distinct hue. Every collaboration cluster is isolated from the others and varies in size. The number of article authors increases with node size. Examining this number, all clusters on average have 3 documents, and only cluster 6 has 4 documents. It can be concluded that collaboration between green chemistry and education researchers is insufficiently strong. The truth is that one to four authors work in small groups to conduct research in this field.

3.6 Most Relevant Journals

To answer research question RQ6, the top 10 most productive journals are presented based on Scopus quartile (Q), SCI mago Journal Rank (SJR), and H-index data, the quantity of publications, as well as home publishing. The results are then listed in Table 3.

Table 3. Top 10 Most Active Sources

Journal	N	H-Index	Q	SJR 2022	Publisher
Journal Of Chemical Education	150	95	Q2	0.56	American Chemical Society
ACS Symposium Series	34	71	Q4	0.17	American Chemical Society
Green Chemistry Letters And Reviews	15	47	Q1	0.91	Taylor and Francis Ltd
Green Chemistry	14	255	Q1	1.96	Royal Society of Chemistry
Physical Sciences Reviews	13	19	Q3	0.32	de Gruyter
Journal Of Physics Conference Series	12	91	-	0.18	IOP Publishing Ltd
Sustainable Chemistry And Pharmacy	11	38	Q1	0.77	Elsevier BV
Sustainability Switzerland	10	136	Q1	0.66	MDPI AG
Current Opinion In Green And Sustainable Chemistry	10	53	Q1	0.48	Elsevier BV
Chemistry Education Research And Practice	9	53	Q1	0.71	Ioannina University School of Medicine

3.7 Most Productive Organizations

The distribution of countries, institutional kinds, and publication counts from the top ten most productive institutions are displayed in Table 4, about research question RQ7. Table 4 depicts the top ten institutions that accounted for 39.65% (n = 115) of the total eligible papers.

From the observations in Table 4, this field's most productive institution is the University of Toronto, a public university in Canada that published 23 paper documents. The production level is the highest compared to other institutions. The second-ranked institution is the University of York, a public university with 19 papers. As a private university, the University of York had to settle for being ranked as the third most productive institution with 13 works. It's interesting when there is an institution based on professionalism, namely the American Chemical Society with a publisher type as a Professional Society. Of these 10 institutions, only 3 are private, the rest are public.

Table 4. Top 10 Most Prolific Institution

Institutions	Country	Type	Documents
University of Toronto	Canada	Public	23
University of York	UK	Public	19
Universität Bremen	Germany	Public	13
American Chemical Society	US	Professional Society	12
University of California, Berkeley	US	Public	10
Beyond Benign	US	Public	8
Yale University	US	Private	8
Universidade Federal de São Carlos	Brazil	Public	8
Widener University	US	Private	7
Istituto Per Lo Studio Dei Materiali Nanostrutturati, Rome	Italy	Private	7

3.8 Leading contributor countries

Regarding the research question in RQ8, Table 5 lists the top 10 nations that produce the greatest number of scientific articles.

Table 5. Top Most Prolific Countries

Country	N of Papers	%
United States	218	48%
Canada	47	10%
United Kingdom	42	9%
Germany	30	7%
China	25	6%
India	21	5%
Undefined	20	4%
Spain	18	4%
Indonesia	17	4%
Brazil	16	4%

From Table 5, it is seen that the United States holds the first title, namely the most productive country in producing papers or documents as much as 48% of all the papers analyzed. The second country is Canada, then the United Kingdom is the third country and Germany is the third country. The percentages for these two countries are still much lower compared to the US, but this is still above the other averages.

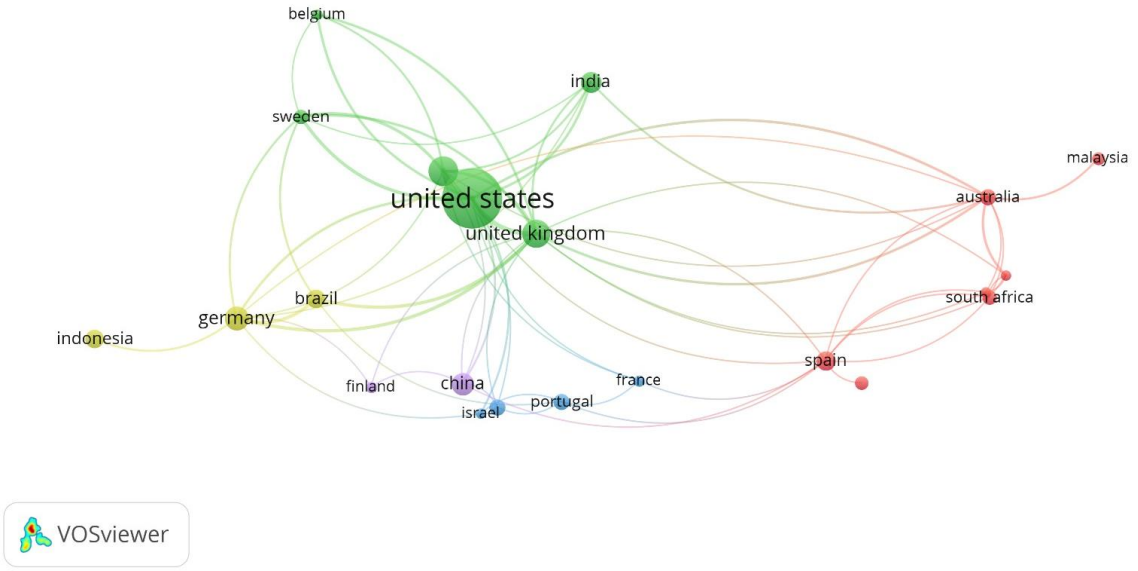

Figure 5. Author Countries

Finally, a combined bibliography The countries are then given in order. A country's maximum number of papers was set at 25, while It had a minimum requirement of citations. at 5. The number of countries to be chosen at random was indicated as 62. The overall strength of the links and the quantity of articles were then calculated. Figure 5 depicts the analysis's findings. This image can be seen along with the data according to Figure 5. If you look at the graph, there are five clusters that the author has which are represented by 5 different colors, namely red, green, yellow, purple, and blue. The largest group of Cluster Two is the US, UK, Canada, India, Belgium, and Sweden. Apart from that, Spain and Australia are contained within the initial cluster. Keep in mind that distinct hues correspond to distinct categories. The top country on this list is the United States with 216 papers and 49 overall strength of links, then Canada (n =47, 33 total link strength) and the United Kingdom (42, 42). Other countries are; India(21, 11), Spain (18, 10) Germany(30, 22), Indonesia (17, 2), etc.

4. DISCUSSION

The Scopus database is the basis for mapping publication trends studying the application of green chemistry and education during the last decade in higher education (1994–2023). This review of bibliometrics provides thorough knowledge and understanding of previous research conducted and a few recommendations for future lines of inquiry for this field of study. According to the results, the majority language frequently The language English is the language of publication, with 509 papers being published.

This is in line with the primary results of previous research. For example, When it comes to the language that publications are most often written in, López-Belmonte et al. found that English (92%) is the most commonly spoken language in the area, with Spanish coming in second (7%). It turns out that for Green Chemistry everything is in English. This reflects Anglo-Saxon dominance in publishing. It is not surprising that To this day, It is acknowledged that English is the primary language for both science on a global scale and knowledge distribution. As stated by van Weijen, over 80% of journals that are indexed by Scopus are published in English. It's worth

noting that is the only one paper was first documented in 1994, signaling the beginning of the increase in publications in the discipline. This article has been cited 1 time to date.

From 2003 to 2023, scientific articles and papers continued to grow. In 2008, there were 938 papers published, making it the most publications in this period. The outcomes demonstrate that growing interest in the field. This research, Scopus' trend of green chemistry research has also begun to emerge (Mahaffy, Peter G Brush, Edward J Haack, Julie A Ho, Felix M, 2018). Especially since 2019 and 2020. Thus, It is possible to deduce that the amount of work on the application of green chemistry and education in higher education continues to increase. Because this bibliometric research was conducted until September 2023, It can be assumed that the number of publications in 2022 and beyond will increase. Projected to grow with time. As shown figure 2 depicts the number of publications in 2020 is far bigger than it was in 2019. It is still lower than in 2008, but the average has been increasing. As a result, the current data affirm Price's Law, which claims that every ten years, the growth in scientific output tends to double. The literature supports the conclusions reached in this particular circumstance. In a systematic review, (K., et al., 2008; K., et al., 2008) was the author with the highest citations. They discovered that although there hasn't been much focus on publications in this field since 2008, they have grown significantly in the last several years. The rise in publications could potentially be attributed to the growing curiosity of scholars, educators, and researchers institutions around the world in the use of green chemistry and education in higher education.

Even though the topic of green chemistry is not new, researchers are increasingly interested in considering its applications which are needed nowadays regarding education and environmental sustainability. The bibliometric analysis results show that "green chemistry" is the most frequently used keyword. As expected, other words such as "education", "sustainability", "human", "organic chemistry", and "laboratory instruction" are important terms that appear in this research. In short, this shows that this topic has gained importance among educational technology researchers in the last 20 years. Author keywords are considered important to analyze in this research because an author's keywords generally represent curiosity about a research topic.

4. CONCLUSION

Results of a study of research trends in the application of green chemistry in education by carrying out an extensive bibliometric analysis between 1994 and 2023. According to the findings, (1) the majority of the manuscripts were written in English; (2) the most popular publications in 2019 and 2020 were 51 papers, (3) green chemistry and education were the most frequently used keywords, (4) documents from 1999, 2008 and 2015 were the most frequently cited documents, (5) Yin J .; Goh T.-T.; Yang B.; Xiaobin Y., Nikou S.A.; Economides A.A., and Dessì D.; Fenu G.; Marras M.; Reforgiato Recupero D, is the most important author, (6) Journal Green Chemistry and Journal Sustainability Switzerland are among the best journals, (7) University of Toronto, Universität Bremen, and University of York are among the best journals, and (8) Canada and Germany are the countries most prominent in this industry. This study offers a detailed assessment of the scientific environment and future directions of the field.

Please note that the results of our review cannot be said to be perfect, of course, they have shortcomings due to our limitations. As previously documented in the literature. First, we only used bibliographic data from one database, Scopus, which

does not include all related literature publications on the use of green chemistry and education in higher education. Future researchers may try to reproduce our findings using more comprehensive transdisciplinary databases, such as WoS, ScienceDirect, Google Scholar, and so on. Because our analysis only includes peer-reviewed journal articles, future research could delve deeper into the development trends of this field in other publications such as novels, book chapters, and conference proceedings. Nevertheless, we believe that our evaluation is quite useful and useful, and can illuminate the current state and progress in the application of green chemistry and education in higher education.

Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

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