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Review Article

Bibliometric analysis : Green chemistry trends and issues in chemistry education from 2019 to 2024

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ABSTRACT

This study analyzes green chemistry research trends in chemistry education. This study used a quantitative bibliometric approach. The number of publications analyzed is 104 publication documents from 2019 – 2024. This research collects, processes, and filters information in Scopus journals and articles. Metadata results show that the distribution of publication frequency peaked in 2019, with 26 documents identified. The green chemistry research area is dominated by chemistry research (31.3%). The country with the most documents and the most productive in publishing green chemistry is the United States, with 30 papers identified. At the same time, Indonesia is ranked fifth as the most productive country in publishing green chemistry, with 10 documents identified. Canada ranked second with 17 papers, and Germany ranked third with 15 documents. The institutions that contributed the most came from Germany: the University of Bremen, with 11 papers 10.58%, and the University of Toronto with 8 documents (7.69%). The authors with the most citations are Chen Tse-Lun et al., with 245 citations. Meanwhile, when viewed from the number of documents published by the author, Eilks I. has 11 papers with a contribution of 4.91%. There are 5 clusters with the most popping keywords: green chemistry, human, and chemical reaction. Research and publications on this topic have been sparse in the past five years. Surveys and analyses of green chemistry literature are essential because tracking research trends in green chemistry in chemistry education is vital to directing the future.

Introduction

The 21st century is when knowledge increases drastically; science and technology are proliferating and related to human life. Indonesia needs to prepare a generation that can face the challenges of the 21st century, especially by preparing students to have the necessary skills in several aspects of life. Indonesia has tried to improve the quality of several aspects of life, both educational and social. The Merdeka Belajar curriculum is an answer to the intense competition for human resources globally in the 21st century, with the central concept of freedom of learning being freedom of thought. Thinking competencies include critical thinking, creative thinking, and problem-solving. This is an essential concern for the government of the Republic of Indonesia to be able to provide adequate facilities and infrastructure as soon as possible in facing global developments, especially in the era of Society 5 (Putriani and Hodeidah, 2021; Indarta et al., 2022). Suryana et al. (2021) also explained that there are skills needed today, including critical thinking and problem-solving, communication, collaboration, and creativity) Alternatively, commonly known as the 4Cs. One of the skills that has a vital role in 21st-century development is creative thinking because creative thinking often involves a combination of various skills, such as critical thinking, communication, and collaboration.

Creative thinking is an important thing that must be developed by students and educators both at the primary, secondary education, and higher education levels. The problem is that not all students have the same creative thinking competencies, so it becomes challenging for educators. Another fact states that creative thinking skills in Indonesia are still low; this fact can be confirmed by the results of The Global Creativity Index in 2015; Indonesia is ranked 115 out of 139 countries (Qomariyah and Subekti, 2021). The results of Magdalena et al. (2020) research at MI Yanida Tangerang show the same thing in learning classroom conditions when learning activities are not conducive. This happens because fewer lessons can stimulate students' curiosity, which causes them to lack creativity. However, there still needs to be more learning to spur creativity in material science, especially green chemistry.

Over time and with the development of science and technology experienced by humans, problems arise that must be resolved immediately, especially in environmental problems. Problems that must be resolved immediately include problems

closely related to climate change, food availability, environmental security, health, and energy crisis—examples of green chemistry that have been applied to the independent curriculum phase E. One of the efforts that can be made to respond to this is green chemistry.

Green chemistry aims to design and implement chemical products and processes that reduce waste and strive to avoid the formation of harmful substances (McMurry, 2016). Green chemistry provides various benefits, including increased energy efficiency, lower production and regulatory costs, less waste production, lower likelihood of accidents, healthier workplaces, and significant advances in protecting human health and the environment (Zuin, 2021). In principle, green chemistry is a chemical process design that reduces the use of hazardous materials (Anastas and Warner, 2010); therefore, reducing the use of hazardous materials can also reduce the waste produced.

To support sustainable development goals, green chemistry develops concepts and principles that are aligned with sustainable development and based on the integration of sustainability perspectives. Green and sustainability chemistry focuses on designing safer chemicals, utilizing renewable raw materials, and improving energy efficiency towards sustainable development (Chen et al., 2020). healthier workplaces, and significant advances in protecting human health and the environment (Zuin, 2021). In principle, green chemistry is the design of chemical processes that reduce the use of hazardous materials (Anastas and Warner, 2010). Therefore, reducing hazardous materials can also reduce the waste produced.

To support sustainable development, green chemistry develops concepts and principles that are aligned with sustainable development and based on the integration of sustainability perspectives. Green and sustainable chemistry focuses on designing safer chemicals, utilizing renewable raw materials, and improving energy efficiency towards sustainable development (Chen et al., 2020). Therefore, it is necessary to conduct a bibliometric analysis of the topic to describe the extent of research studies and research opportunities. This bibliometric study will specifically discuss and map research on green chemistry in chemistry education.

Methods

This study used the bibliometric analysis method. Bibliometric analysis is one of the tools that researchers use to analyze publication production and research trends in various fields. With bibliometrics, researchers can identify targets to be achieved through grouping targets and analyzing results to provide meaningful meaning (Leong et al., 2021). This analysis examines assumption-based data to inform peers about data search results. Bibliometric analysis also supports the development of knowledge in understanding specific topics in depth, focusing on sources derived from scientific research (Farida, 2020).

Bibliometric analysis is a method to observe research development on a particular topic. It has been widely applied in literature research. Bibliometrics combines mathematical and statistical methods to identify patterns in literature. This rigorous and systematic analysis identifies qualitative and quantitative changes in the research topic (Misra et al., 2016). Bibliometric analysis explores scientific data on specific field areas (Donthu et al., 2021). This study adopted five stages of bibliometric analysis (Tranfield et al., 2003; Hudha et al., 2020), as shown in Fig-1.

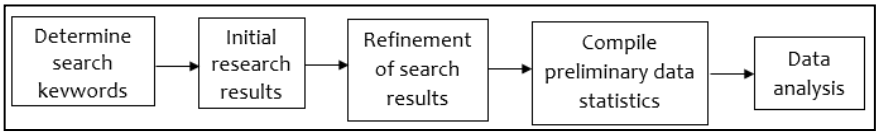

Fig-1. Green chemistry research design

Determine Search Keywords

The research collected scientific data from the Scopus database (www.scopus.com). Data search defines keywords as guidelines for finding data sources. The literature search will be conducted in May 2024 using the keywords "chemistry education" and "green chemistry" from 2019 to 2024. The Scopus database was chosen because it has good quality, reputation, and an index with the highest curation (Bass et al., 2020). We also did not choose another database due to the limitations of having accounts and extracting metadata.

Initial Search Result

The search was conducted on the title "chemistry education" and "green chemistry" which obtained the results of 104 documents consisting of article 63 documents (60.6%), review 15 documents (14.4%), book chapter 12 documents (11.5%), conference paper there were 5 documents (4.8%), editorial there were 4 documents (3.8%), book there were 2 documents (1.9%), letter there were 2 documents (1.9%) and Conference Review 1 document (1%).

Refinement of Search Results

Search results are refined without limiting categories, so journals, editorial seminar proceedings, and books are included in bibliometric analysis. Search results are stored in .ris and .csv extensions. Files with the extension ris are used for further stages of compiling statistical data. Instead, file.csv analyzes more detailed information regarding article titles, author names, affiliations, abstracts, keywords, and references within each article.

Compile Baseline Statistics

The next stage is the processing of data from selected sources. This data processing uses Scopus data analysis and VOSviewer software. VOSviewer is a freely available software developed by Eck and Waltman and widely used in scientific writing (Liao

et al., 2018). The software can visually display the relationships between data, which is helpful in data analysis. The analysis process uses data stored in RIS format (Strandberg et al., 2016). Data processing begins with selecting data types, followed by uploading data in files with the extension ris into the VOSviewer application to analyze and map green chemistry research data in chemistry education.

Data Analysis

The data analysis stage is carried out with the distribution of the frequency of green chemistry publications in chemistry education, mapping based on keywords in research, types of green chemistry research fields, types of documents about green chemistry, countries with green chemistry publication documents, departments or affiliations with green chemistry publication documents, the author with the most citations, and the author with the most documents. Other data processing results are relationship data between researchers (co-authors) that show the relationship between them and advanced research models related to green chemistry. An advanced research model related to green chemistry. This relationship illustrates the collaboration between researchers. The co-author's data in this study was visualized through network visualization. In addition, co-occurrence data shows the relationship between keywords that are the research focus. The results of processing co-occurrence data based on clusters aim to strengthen the explanation formed in occurrence.

VOSviewer application to analyze and visualize bibliometric networks regarding green chemistry in chemistry education (Meng et al., 2020; Xie et al., 2020). There is a data verification process to select the data to be displayed. Selection is carried out to obtain an appropriate picture. Researchers made selections based on selected data and conducted keyword co-occurrence analysis using the VOSviewer approach (Katoch, 2021). Data analysis from the nodes formed on the map of the formed network. The larger the node, the greater the number of publications on the topic written on that node. In addition, the strength of the relationship between two topics or items can also be seen from the closeness between the two items with the line that connects them.

Results

Search results on Scopus using the keywords "chemistry education" and "green chemistry" obtained 104 article publications from 2019 to 2024. The analysis includes the frequency distribution of green chemistry publications in chemistry education, mapping based on keywords in research, types of green chemistry research fields, types of documents about green chemistry, countries with green chemistry publication documents, departments or affiliations with green chemistry publication documents, The author with the most citations, the author with the most documents, the mapping of co-authorship that is interconnected with each other, and the related advanced research model on green chemistry. A total of 104 documents with publications from 2019 to 2024 show that researchers around the world carry out little research on this topic. Further details on the results of data mapping will be described in the following sub-chapters:

Mapping Based on the Frequency Distribution of Green Chemistry Publications

Based on the search results in the Scopus database, 104 documents were obtained with a publication frequency distribution that peaked in 2019, and 26 documents were identified. Publications related to green chemistry in chemistry education are seen as something rare, especially green chemistry research in Indonesia and various countries, which is still very small, so green chemistry learning needs further study. However, interestingly, the research orientation has increased significantly from 2021, which initially only had 13 articles, and then in 2022, it rose to 19 articles; in 2023, there were 15 articles published again, and the peak of research occurred in 2019. This shows that the orientation of green chemistry-based research in chemistry education is one of the topics that still needs to be studied, especially in Indonesia.

The distribution of research on green chemistry in education still needs to be improved among researchers, especially in Indonesia. However, there may be a very significant increase in 2025. Based on the search results using the keywords "chemistry education" and "green chemistry," as shown in Fig-2.

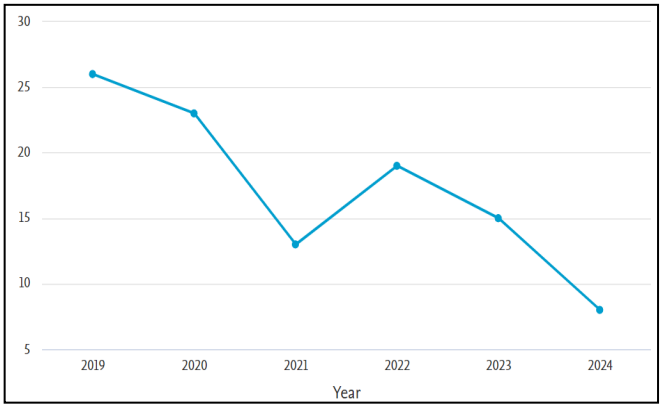

Fig-2. Frequency distribution of green chemistry publications in chemistry education from 2019-2024

Green chemistry learning in chemistry education needs to be further exploited, considering reducing the negative impact of chemical activities on the environment and human health. Green chemistry is an approach that emphasizes the use of safer and environmentally friendly chemical processes and products by incorporating this concept into the chemistry education curriculum. This then provides a complex picture for teachers, especially when utilizing green chemistry-based learning in

chemistry education in their classrooms katoch (Wilder et al., 2016). Through green chemistry learning, students are expected to be able to reconstruct abstract knowledge into conceptual knowledge by reconstructing culture into pure science reconstruction (Sudarmin et al., 2019).

Mapping Based on Keywords in Research

Based on the extraction of bibliographic data on the co-occurrence type with full counting type, with a minimum occurrence number at a value of 1, 76 keywords were obtained. In this case, 76 keywords meet the minimum mapping threshold, as shown in Fig-2. The largest node indicates the most dominant word. There are 5 clusters formed based on network visualization with each keyword item. Cluster 1 has red nodes containing 5 items, cluster 2 has purple nodes containing 3 items, cluster 3 has yellow nodes containing 3 items, cluster 4 has green nodes containing 7 items, and cluster 5 has blue nodes containing 4 items. In addition, several keywords have the most occurrences, namely n = 7 and 'green chemistry' as shown in Fig-3.

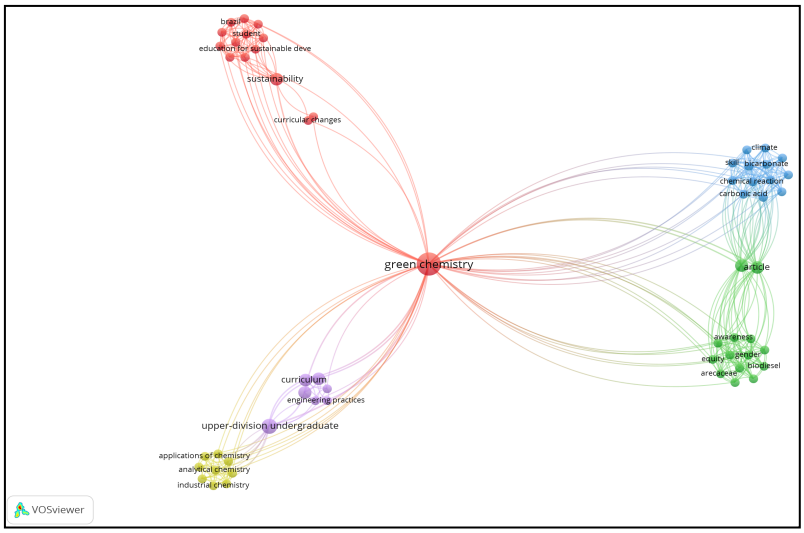

Fig-3. Keyword mapping in research on green chemistry

Researchers rarely raise themes related to environmental sustainability and education, which are associated with learning, environmental awareness, and its application in green chemistry-based learning. Some researchers then focus their research by directing the exploitation of natural resource wealth, and their awareness of caring for nature and the surrounding environment is reconstructed into pure science.

Mapping Based on Research Subjects and Types of Green Chemistry Research

The field of green chemistry research is dominated by research in chemistry (31.3%), social sciences (19.8%), environmental sciences (14.7%), chemical engineering (8.7%), and several other research fields. Judging from the types of documents often published in the Scopus database, the orientation of green chemistry research is centered on chemical research, as shown in Fig-4.

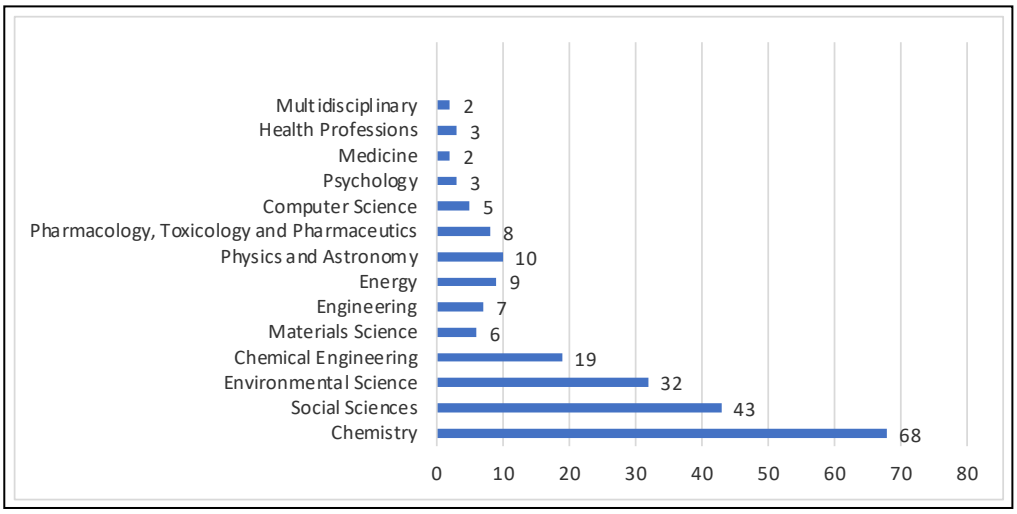

Fig-4. Types of green chemistry research fields from 2019-2024

This shows that the orientation of green chemistry research is centered on chemical research. Based on the type of article, research on green chemistry in chemistry education is found in as many as 68 documents (60.5%). Of the many chemical studies identified, this research focuses on articles published in Scopus, as shown in Fig-5.

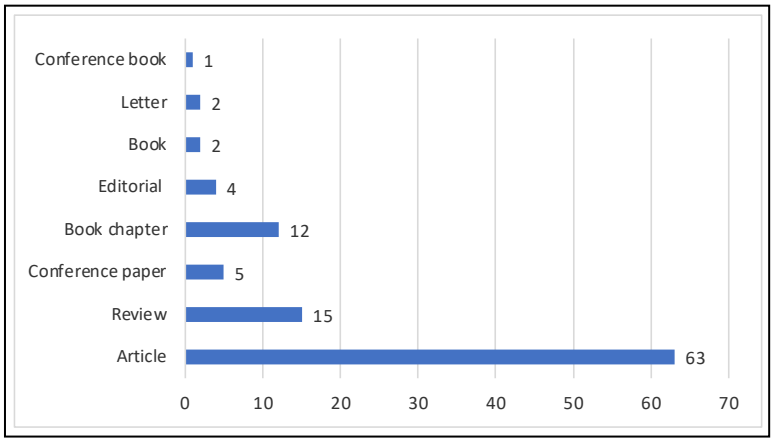

Fig-5. Types of documents on green chemistry from 2019-2024

Based on the types of articles above, research on green chemistry is mainly found in the form of Articles (60.5%), Reviews (14.4%), Conference papers (4.8%), Book chapters (11.5%), Editorials (3.8%), Books (1.9%), Letters (1.9%), and Conference reviews (0.9%).

Mapping by Country with the Most Productive Green Chemistry Publications

Identify the most productive countries in green chemistry research from 2019-2024. A search of 104 documents showed that Indonesia was ranked the fifth most productive country in green chemistry publications, with 10 documents. In publishing green chemistry, the number of documents identified was as many as 104.

The United States is ranked first with 30 documents, Canada is second with 17 documents, Germany is third with 15 documents, and the United Kingdom is fourth with 12 documents. Indonesia became the fifth country to be productive in publicizing green chemistry. This is because awareness of the importance of sustainability and environmental protection, which focus on developing chemical processes and products that reduce or eliminate the use and formation of harmful substances, has become an increasingly relevant topic amid increasing global attention to environmental issues, as shown in Table 1.

Table 1. Countries with the most green chemistry publication documents from 2019-2024

Country	Number of papers	Citation
United State	30	149
Canada	17	195
Germany	15	191
England	12	343
Indonesia	10	60
Brazil	9	157
North Africa	7	67
Portugal	5	10
Sweden	5	95

Mapping Based on Affiliates who Frequently Publish About Green Chemistry

Of the 10 countries that make the best contribution to the field of green chemistry, when viewed from at least 5 documents owned, only 9 countries have 5 documents on green chemistry. Indonesia became the eighth country with 60 citations; ranked first was the United Kingdom with 343 citations; the second was Canada with 195 citations, Germany with 191 citations, Brazil with 157 citations; the United States with 149 citations; Sweden with 95 citations, North Africa 67 citations, Indonesia number 8 and finally Portugal with 10 citations. Although the United Kingdom has only 12 documents, it has the highest citation rate compared to the United States, which has 30 documents. Meanwhile, Israel, Italy, Australia, Belgium, China, Netherlands, Argentina, Finland, Greece, India, Philippines, Colombia, Hong Kong, Malaysia, Mexico, Nigeria, Norway, Poland, Romania, Saudi Arabia, South Korea, Spain, Taiwan and Thailand are not eligible as fewer than 5 documents were issued from 2019 to 2024, as shown in Table 2.

Based on the results of the analysis of 104 documents in the Scopus database, the institutions that contributed the most came from Germany were the University of Bremen contributed 11 documents (10.58%); the University of Toronto 8 documents (7.69%), the University of York as many as 7 documents (6.73%), the University of Venda as many as 6 documents (5.77%), King's University, Otto-Hahn-Gymnasium, Universitas Pendidikan Indonesia, Universidade do Porto, Istituto Per Lo Studio Dei Materiali Nanostrutturati Rome, Universidade Federal de São Carlos, and Imperial College London as many as 4 documents (3.85%). Meanwhile, if analyzed based on at least 4 documents with a minimum of 30 citations, then the institutions that contribute the most documents are 5 institutions consisting of the University of Bremen, University of York, University of Venda, King's University, Universidade Federal de São Carlos and Imperial College London, as shown in Table 3.

Table 2. Departments or affiliations with the most green chemistry publication documents from 2019-2024

Affiliations	Country	Number of Papers	Percentage (%)
University Bremen	Germany	11	10.58
University of Toronto	Canada	8	7.69
University of York	England	7	6.73
University of Venda	South Africa	6	5.77
King's University	Canada	4	3.85
Otto-Hahn-Gymnasium	Germany	4	3.85
Universitas Pendidikan Indonesia	Indonesia	4	3.85
Universidade do Porto	Portugal	4	3.85
Istituto Per Lo Studio Dei Materiali Nanostrutturati, Rome	Italy	4	3.85
Universidade Federal de São Carlos	Brazil	4	3.85
Imperial College London	England	4	3.85
Consiglio Nazionale delle Ricerche	Italy	4	3.85
American Chemical Society	United States	4	3.85

Table 3. Authors with the most citations 2019-2024

Authors	Year	Citation	Percentage (%)
Chen Tse-Lun, Kim Hyunook, Pan Shu-Yuan, Tseng Po-Chih, Lin Yi-Pin, Chiang Pen-Chi dan Chiang P. C.	2020	245	55.93
Zuin Vânia G, Eilks Ingo, Elschami Myriam dan Kümmerer Klaus	2021	99	58.57
Mahaffy Peter G., Matlin, Stephen A., Whalen J. Marc, dan Holme Thomas A.	2019	63	16.93
Mahaffy Peter G., Ho Felix M., Haak Julie A., dan Brush, Edward J.	2019	37	9.95
Constable David J. C., Jiménez-González Concepción dan Matlin Stephen A.	2019	35	9.41
Sharma R.K., Yadav Subham, Gupta Radhika dan Arora Gunjan	2019	35	9.41
Hurst Glenn A.	2020	34	7.76
Armstrong Laura B., Rivas Mariana C., Zhou Zeyi, Irie Lauren M., Kerstiens Geri A., Robak MaryAnn T., Douskey Michelle C., dan Baranger Anne M.	2019	33	8.87
Flynn Alison B., Orgill Marykay, Ho Felix M., York Sarah, Matlin Stephen A., Constable David J. C., dan Mahaffy Peter G.	2019	31	8.34

Co-Authorship Mapping

Based on the Table 3, it can be seen that the 5 best authors with the highest number of citations in the 2019-2024 publication period, namely Tse-Lun et al. year 2020 (245; 55.93%), then followed by Vânia G et al. year 2021 (99; 58.57%), Peter G, et al. year 2019 (63; 16.93%), Peter G, et al. year 2019 (9.95%), David J. C., et al. year 2019 (35; 9.41%). Meanwhile, based on the distribution of at least 30 documents owned by the author. When viewed from the author's point of view with the acquisition of documents, it can be sorted based on the documents owned by the author, as shown in Table 4.

Table 4. Authors with the most documents from 2019-2024

Authors	Number of papers	Publication year	Persentage (%)
Eilks, I.	12	2019 as many as 1 journal, 2020 as many as 3 journal, 2021 as many as 2 journal, 2022 as many as 5 journal	4.91
Dicks, A.P.	6	2019 as many as 3 journal, 2020 as many as 1 journal, and 2023 as many as 2 journal	2.68
Linkwitz, M.	6	2019 as many as 1 journal, 2020 as many as 1 journal, and 2022 as many as 4 journal	2.68
Mammino, L.	5	2019 as many as 2 journal, 2020 as many as 1 journal, 2022 as many as 1 journal, and 2023 as many as 1 journal	2.23
Hurst, G.A.	4	2019 as many as 2 journal, and 2020 as many as 2 journal	1.78
Mahaffy, P.G.	4	2019 as many as 3 journal, and 2021 as many as 1 journal	1.78
Matlin, S.A.	4	2019 as many as 3 journal, and 2021 as many as 1 journal	1.78
Pagliaro, M.	4	2020 as many as 2 journal, and 2021 as many as 2 journal	1.78
Zuin, V.G.	4	2019 as many as 1 journal, 2020 as many as 2 journal, and 2021 as many as 1 journal	1.78

Based on the Table 4, it can be seen that Eilks, I. has 11 documents with a document contribution percentage of 4.91%, further by Dicks, A.P. and Linkwitz, M. 6 documents each with a percentage of paper contributions on green chemistry of around 2.68%, and Mammino, with 5 documents produced with a percentage of 2.23%. Based on bibliographic metadata on the type of co-authorship analysis with the whole counting method and the minimum number of document writing is 1, 30 authors were found to publish about green chemistry, as shown in Fig-6. The picture shows that there is 1 cluster around the world that discusses the topic of green chemistry in chemistry education, as shown in Fig-6.

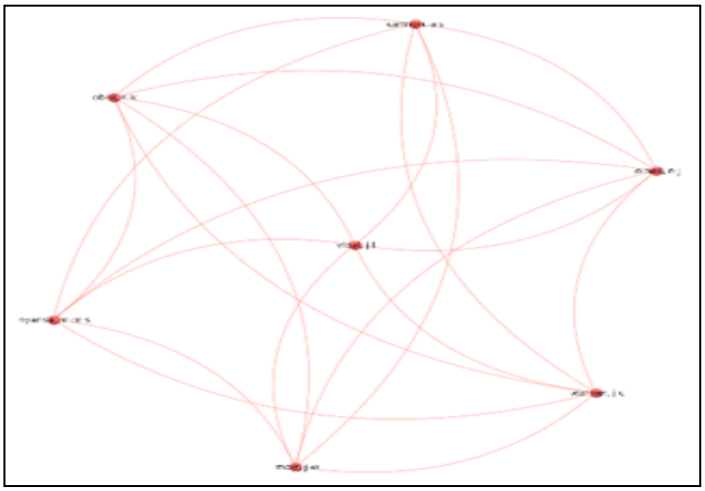

Fig-6. Map co-authorship that is interconnected with each other

If all authors are linked to each other, 7 authors are related to each other, as shown in Fig-6. The author is Vidal. L., Cannon A. S., O'Neil N. J., Obhi N. K., Nyansa M. M. S., Moir J. W., and Warner J. C. as shown in Table 5.

Table 5. Education Recent research themes on green chemistry with fewer occurrences

Sustainability-oriented innovation	Curricular changes
Curriculum	Safety/hazards
Collaborative learning	Scrum green chemistry
Creativity thinking	Undergraduate education
Microscale lab	Frugal innovation scrum agile frame works sustainability
Student	Education

Further Research

We offer advanced research on green chemistry, focusing on its implementation in sustainable development to improve students' creative thinking skills with mapping models, as shown in Fig-7. Based on the picture, there are 4 clusters formed. The central cluster with red nodes consists of sustainable development, collaborative learning, and engineers.

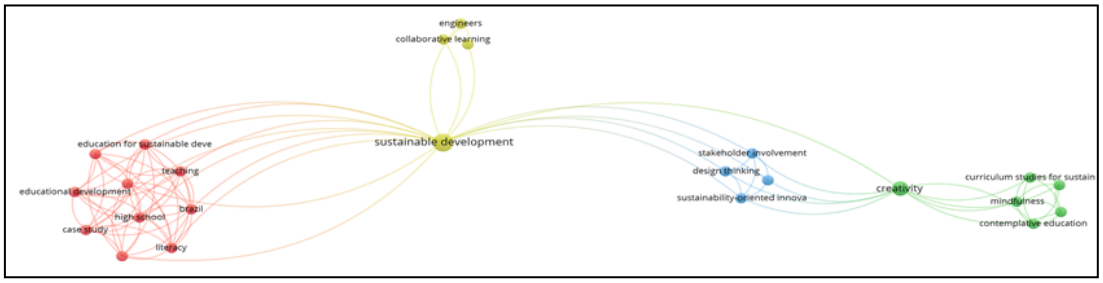

Fig-7. Advanced research models related to green chemistry

The second cluster with red nodes consists of education for sustainable development, case studies, educational development, teaching, high school, and literacy. The third cluster with blue nodes comprises sustainability-oriented innovation, innovation, and design thinking. The fourth cluster with yellow nodes consists of creativity, sustainability curriculum studies, sustainability higher education, and contemplative education, as shown in Fig-7.

Discussion

Based on bibliometric studies, the research profile on green chemistry focuses more on human and chemical reactions. Researchers who want to discover new things can research green chemistry in sustainable development, creative thinking, and education with fewer keywords.

We can see the research development every year based on the results of overlays using the VOSviewer application. Data related to research on green chemistry in the last 5 years shows that relatively little progress has been made regarding this research. The concept of green chemistry has been proposed in 1999. This is a research opportunity related to the implementation of green chemistry, considering that green chemistry can improve students' ability to solve problems with collaboration between students. In addition, reflecting on the 2022 Programme for International Student Assessment (PISA) for science, Indonesia's score decreased by 13 points compared to PISA 2018. The average score of Indonesian students reached 383, with an OECD average score of 448. PISA problem-solving requires students to be able to write and develop unique solutions (OECD, 2023). So, research is needed to implement green chemistry in chemistry learning.

A search of 104 documents showed that Indonesia was ranked fifth as the most productive country in publishing about green chemistry, with 10 documents identified. Ranked first is the United States with 30 documents, second is Canada with 17 documents, third is Germany with 15 documents, and fourth is the United Kingdom with 12 documents. Indonesia became the fifth country to be productive in publicizing green chemistry. This is because awareness of the importance of sustainability and environmental protection, which focus on developing chemical processes and products that reduce or eliminate the use and formation of harmful substances, has become an increasingly relevant topic amid increasing global attention to environmental issues.

One of the efforts made in green chemistry research is integrating it into models, strategies, or learning methods. Of the 33 countries that make the best contribution to the field of green chemistry, when viewed from at least 4 documents owned, only 11 countries have 4 documents on green chemistry. Indonesia became the fifth country with 60 citations from all citations. Ranked first is the United Kingdom with 343 citations, the second is Canada with 195 citations, Germany with 191 citations, Brazil with 157 citations, the United States with 149 citations, Sweden with 95 citations, North Africa with 67 citations, Indonesia number 8, and Portugal with 10 citations. Although the United Kingdom has only 12 documents, it has the highest citation rate compared to the United States, which has 30 documents. Meanwhile, Israel, Italy, Australia, Belgium, China, Netherlands, Argentina, Finland, Greece, India, Philippines, Colombia, Hong Kong, Malaysia, Mexico, Nigeria, Norway, Poland, Romania, Saudi Arabia, South Korea, Spain, Taiwan and Thailand are not eligible as fewer than 5 documents were issued from 2019 to 2024.

However, judging from the research funding, it can be seen that most of the research on green chemistry is by Conselho Nacional de Desenvolvimento Científico e Tecnológico and Fundação de Amparo à Pesquisa do Estado de São Paulo. Meanwhile, green chemistry research funding in Indonesia is funded by the Ministry of Research and Technology and Education (KEMENRISTEKDIKTI) of the Republic of Indonesia. Financial support plays a vital role in providing facilities and encouragement for publications, given the relatively high cost of publication. Therefore, there needs to be special encouragement from the central government to always encourage in terms of publication. The institution that contributes the most is Universitas Pendidikan Indonesia.

The five best authors with the highest number of sites in the 2008-2023 publication period, namely namely Tse-Lun et al. year 2020 (245; 55.93%), then followed by Vânia G et al. year 2021 (99; 58.57%), Peter G, et al. year 2019 (63; 16.93%), Peter G, et al. year 2019 (9.95%), David J. C., et al. year 2019 (35; 9.41%). Meanwhile, when viewed from the number of documents published by the author, then Eilks, I. has 11 documents with a document contribution percentage of 4.91%, further by Dicks, A.P. and Linkwitz, M. each of 6 documents with a percentage of paper contributions on green chemistry of around 2.68%, and Mammino, with 5 documents produced with a percentage of 2.23%.

The visualization of the co-authorship mapping shows the number of documents Vidal wrote. L" is the most numerous among other authors, so it has strong relationships with other authors. The mapping results show that most authors have only one published article. This shows that very few authors have done follow-up research from previous publications on green chemistry.

The results of research on green chemistry in chemistry education in Indonesia can also be applied directly to the curriculum and education system. Green chemistry in chemistry education can increase students' creativity so that it can increase Indonesia's PISA score.

This bibliometric study needed international collaboration and increased research capacity on green chemistry in education. Research on green chemistry in chemistry education in Indonesia needs to be developed, and collaboration is needed to improve creative thinking skills. This is important because green chemistry in chemistry education provides learning outcomes relevant to 21st-century skills, including creative thinking.

However, this study has some limitations, namely the refinement of search results where the search process is only in scope and does not limit the type of document analyzed. Keyword searches should be done by limiting only to the types of scientific journals. Bibliometric analysis will be more credible, and the information provided by the journal will be of higher quality (Ruiz-Real et al., 2018). This is because the author has limitations on other accounts used in metadata extraction.

Conclusion

The spread of published articles related to green chemistry began in 1999, then experienced a significant increase and peaked in 2019 with the number of publications of 26 documents on Scopus. Based on the study's results, the green chemistry theme was divided into 5 clusters. The results of a search of 104 documents showed that Indonesia was ranked fifth as the most productive country in publications in the field of ethnoscience, with 10 documents identified, and the first-ranked country, the United States, with 30 documents. The affiliates who contributed the most came from Germany. The best authors with the highest number of citations for the 2019-2024 publication period, namely Chen Tse-Lun et al. (245; 55.93%) in 2020. Meanwhile, when viewed from the number of documents published by the author, Eilks, I. has 12 documents with a percentage of document contribution of 4.91%. There are 5 clusters with the most popping keywords: green chemistry, human, and chemical reaction.

Conflict of Interests

The author declares that there is no conflict of interest between this research and the manuscript.

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