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Exploring Trends in Chemical Education: A Bibliometric Analysis (2019-2024)

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Abstract: *A Bibliometric analysis is essential to comprehensively evaluate the progress and impact of chemical education research. The purpose is to analyze the visualization of bibliometric mapping on the network between keys, the most frequently discussed topics, and recommendations for research opportunities on the topic of Chemical Education. This research is quantitative descriptive research with a bibliometric approach. The stages carried out include the data collection process, checking and refilling bibliographic attributes, then bibliometric analysis using VOS viewer software. Data collection is done by searching for Scopus indexed journal articles through Publish or Perish (PoP). Data from Publish or Perish (PoP) is filled in and completed in the author keywords section manually using desktop Mendeley software then integrated into the VOS viewer software for mapping. The results of the analysis of keyword mapping in Scopus indexed scientific articles from 2019-2024, it is known that in the last 5 years, in Scopus indexed journals there are 462 different keywords and form 2072 connecting lines and 35 clusters. The keywords with the strongest links based on VOS viewer include: chemistry education (27), first-year undergraduate/general (25), curriculum (22), general public (20), green chemistry (18), systems thinking (18), high school/introductory chemistry (16), upper-division undergraduate (14).*

Keywords: *bibliometric analysis; chemical education; vos viewer; keyword mapping; network visualization*

INTRODUCTION

Education, as both a right and an obligation, fosters and develops human abilities and personality, aiming to cultivate a holistic human being (Aryuni et al., 2024). Within schools, learning is one of the core activities, with chemistry learning being a significant part of the educational process that demands continuous improvement (Situmorang et al., 2023). Teachers play a key role in achieving learning outcomes; they must not only transfer knowledge but also inspire, educate, and maintain student enthusiasm. Effective teaching requires innovation in designing learning activities, choosing models, and implementing methods that engage students (Irham et al., 2024).

Chemistry, as a branch of natural science, explores the structure and properties of matter, transformations within matter, and the accompanying energy changes (Agustina et al., 2023). Its applications are integral to everyday life, as all materials in nature are results of chemical processes. Chemistry education, highlights the importance of chemistry in the overall educational experience (Daeli & Silitonga, 2024).

Chemistry education encompasses research, theory, and practice related to the teaching and learning of chemistry content, which falls within the field of social science (Babalola, 2023). Over the years, the field of Chemistry Education Research (CER) has evolved significantly, transitioning from personal empiricism to a more evidence-based approach grounded in learning theory (Sweeder, 2023). The importance of chemistry education in promoting systems thinking, sustainability, green chemistry, and a holistic understanding of complex global challenges. Emphasise the need to integrate such concepts into chemistry education to prepare students to address real-world problems and make informed decisions (Ho, 2019; Mahaffy et al., 2019; Blatti et al., 2019; Constable, 2019).

Big data can be used to analyze very large data in chemistry research. This includes data from experiments, simulations, and scientific literature. Using big data analytics, researchers can find patterns and trends that are not visible through traditional data analysis. Big data plays an important role in revolutionizing chemistry education by improving teaching methods and student learning outcomes. Educators are increasingly integrating big data into chemistry courses to improve teaching management and student engagement (Fei, 2022). The application of data mining models in smart chemistry education has shown significant improvements in students' self-learning and communication skills (Li & Cai, 2021). Big Data helps in classifying and categorizing scientific literature into various topics and subtopics, providing a clearer picture of the existing research landscape. Bibliometrics uses Big Data to track and identify trends in scientific research, such as emerging fields, popular topics, and relationships between studies.

Bibliometric analyses are essential to comprehensively evaluate the progress and impact of chemistry education research. Bibliometric research in chemistry education involves analyzing trends, citations, co-authorship, and keywords in research related to concept maps in Chemistry education (Sen, 2023). This method provides valuable insight into the relationship between science education and technology, as seen in the analysis of articles in the Scopus database related to technology in science education (Konu Kadirhanogullari & Ozay Kose, 2023). In addition, citation and bibliometric searches are important tools for evaluating publications, authors, and journals in chemistry, assisting students, educators, and researchers in better appreciating and utilizing these methods (Nik Hassan et al., 2022).

Similar research was conducted by Nik Hassan et al. (2022) The purpose of this study is to describe the current trend of organic chemistry education, which adopts bibliometric analysis methods obtained from the Scopus database between 2011 and 2020. Various tools have been used, for example, Microsoft Excel was used to perform frequency analysis, VOS viewer for data visualization, and Harzing's Publish or Perish for citation metrics and analysis. The weakness of this study is that it only focuses on organic chemistry. Similar research has been done by Sen (2023). who conducted Bibliometric Analysis of Concept Maps in Chemistry Education in 1990-2022. Data analysis was done with the help of Microsoft Excel, VOS viewer, and the data collected came from WoS. Bibliometric analysis was done for trends, citations, co-authorship, co-occurring words. The current research has some limitations. One of them is that it only uses WoS database for data collection. Using databases such as Scopus or Google Scholar may give different results. There is a need for new data on bibliometric research in the field of chemistry education.

Conducting bibliometric research on the field of chemical education from 2019-2024 is very important because bibliometric analysis can reveal the latest research trends in chemical education during the 2019-2024 period. By mapping the most frequent publications, authors, keywords, and citations, we can identify hot topics and fast-growing research areas within the field. This helps researchers stay up-to-date and target their research on the most relevant and in-demand issues (Draman & Mohd, 2021; Pattah, 2013). Analyzing the number of citations and other impact metrics on bibliometric analysis can show which research is the most influential and impactful in chemistry education during 2019-2024. This helps identify important works and leading researchers in this field (Kurdi & Kurdi, 2021; Nik Hassan et al., 2022). By mapping citation patterns, collaborations, and keywords, bibliometric analysis can reveal gaps or under-explored areas in 2019-2024 chemistry education research. Bibliometric analysis can provide valuable insights for researchers to identify new research opportunities and unanswered questions (Irwanto et al., 2024). Bibliometric analysis can uncover the most productive and influential networks of research collaborations and authors in chemical education 2019-2024. This facilitates the formation of new research collaborations and knowledge exchange between researchers (Husna & Sayekti, 2023). By providing a comprehensive picture of the chemistry education research landscape, bibliometric analysis can support evidence-based decision-making by policymakers, education administrators, and other stakeholders in allocating resources and prioritizing research areas (Kartimi et al., 2022).

The purpose of this study is to analyze the visualization of bibliometric mapping on the network between keys, the most frequently discussed topics, and recommendations for research opportunities on the topic of Chemical Education. Thus, conducting bibliometric research in the field of chemical education from 2019-2024 is essential to understand recent developments, identify new research opportunities, facilitate collaboration, and support evidence-based decision making in an effort to improve the quality of chemical education.

LITERATURE REVIEW

Use Bibliometric analysis has emerged as a vital tool for mapping research landscapes, allowing scholars to quantitatively assess scientific production and visualize intellectual structures within various fields. This method employs various techniques to analyze bibliographic data, revealing trends, relationships, and emerging topics in scientific literature. For instance, Yanti et al. emphasize that bibliometric analysis through science mapping provides an in-depth examination of research dynamics, highlighting hot topics and intellectual structures within the field of halal blockchain (Yanti et al., 2022). Similarly, Özdemir discusses how science mapping has gained significant attention for visualizing bibliometric networks, which aids in understanding the conceptual structure of specific research domains (Özdemir, 2023).

The evolution of bibliometric methods has led to the development of hybrid approaches that combine traditional bibliometric techniques with semantic analysis. Župič and Čater note that such hybrid methods, which integrate bibliographic coupling with latent semantic indexing, are becoming increasingly popular for detecting emerging research topics (Zupic & Čater, 2015). This integration enhances the ability to visualize and map scientific knowledge, as evidenced by the work of Ng et al., who highlight the need for good practices in conducting bibliometric analyses to ensure quality and reliability in research outputs (Ng et al., 2023).

Moreover, the application of bibliometric analysis extends to various disciplines, including the fields of entrepreneurship and social sciences. For instance, Shim et al. propose a bibliometric method aimed at reducing subjectivity in agent-based modeling research, thereby making it more accessible to novices (Shim et al., 2017). This reflects a broader trend where bibliometric techniques are employed to assess research performance and identify collaboration patterns, as discussed by Liu and Ma, who illustrate the effectiveness of bibliometric analysis in evaluating scientific research (Lv & Ma, 2019).

The visualization aspect of bibliometric analysis is particularly noteworthy. Tools like VOS viewer facilitated the creation of bibliometric maps, which visually represent relationships among authors, institutions, and research topics. Cobo et al. provide a comprehensive review of science mapping software tools, underscoring their importance in representing intellectual connections within scientific knowledge (Cobo et al., 2013). Furthermore, the bibliometric mapping process is crucial for identifying subfields and trends, as demonstrated by Lucaci and Sarafescu, who utilized VOS viewer to map innovative entrepreneurship (Lucaci & Sarafescu, 2022).

In summary, bibliometric analysis serves as a powerful methodology for understanding the dynamics of scientific research. It combines quantitative assessment with visualization techniques to map intellectual structures and emerging trends across various disciplines. As the field continues to evolve, the integration of advanced bibliometric methods and tools will further enhance the ability to analyze and interpret complex research landscapes.

METHODS

This research is a quantitative descriptive study with a bibliometric approach. bibliometrics is a valuable tool for analyzing and understanding scholarly communication, research trends, and the impact of scientific output within various fields of study. It offers a systematic and quantitative approach to evaluating research productivity, impact, and collaboration, thereby contributing to evidence-based decision-making in academia and research policy (Hyk et al., 2022; Liu et al., 2023; Ninkov et al., 2022; Passas, 2024). The stages carried out include the process of collecting data, checking and replenishing bibliographic attributes, then conducting bibliometric analysis using VOS viewer software. Data collection is done by searching for scopus indexed journal articles through Publish or Perish (PoP). Data from Publish or Perish (PoP) is filled in and completed in the author keywords section manually using desktop Mendeley software then integrated into the VOS viewer software for mapping. Figure 1 below is a flowchart of bibliometric analysis of keyword mapping.

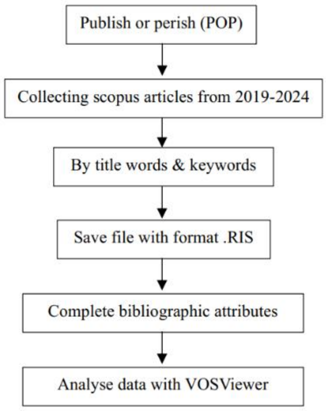

Figure 1. Bibliometric analysis flowchart

RESULT AND DISCUSSION

This This bibliographic data search is limited in three aspects, namely: (1) the selected scientific papers are only articles from 2019-2024; (2) in the Publish or Perish (PoP) software for searching the title of the word entered is ‘chemistry education’; (3) scientific articles taken are articles sourced from Scopus. The search on the PoP application was conducted on Sunday, 26 May 2024 and obtained data in the form of 200 scientific articles related to chemistry education. Figure 2 below is the process of presenting data search through PoP software.

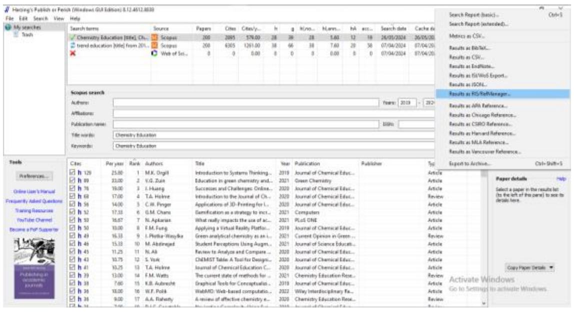

Figure 2. Data search process through publish or perish (POP) software

The next stage after the data is obtained is to check or recheck and manually fill in the incomplete data on bibliographic attributes with the help of Mendeley desktop. Checking the completeness of attributes includes author name, article title, keywords, abstract, year, volume, DOI or issue number, page, number of journal citations, article link and journal publisher. The bibliographic keywords or author keywords section is filled in and completed manually so that it can be mapped and analyzed using VOS viewer. The stage after checking and filling in bibliographic attributes is complete, then proceed with bibliometric analysis. The bibliometric analysis carried out in this study is based on publication trends or publication developments in Scopus indexed scientific articles based on keywords.

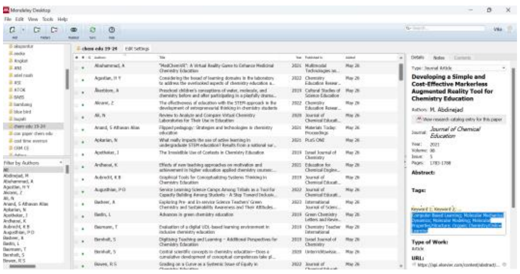

Figure 3. Bibliographic attribute checking process using mendeley desktop software

The results of the publication trend analysis or publication development from 2019-2024 can be seen in Table 1. The percentage of scopus indexed articles that discuss chemical education, and published in articles 73%; Book Chapter 1%, conference paper 4.5% and 21.5% of other documents.

Table 1. Number of references by document type

Type of Reference	Number of Articles	Percentage (%)
Article	146	73
Book chapter	2	1
Conference paper	9	4.5
Others	43	21.5

Table 2. below is the percentage trend of publication of scopus indexed chemical education scientific articles from 2019-2024. The highest number of article publications was in 2020 with 57 articles or 28.5% of the total. The lowest data is in 2023 with 17 articles each or about 8.5% of the total.

Table 2. Distribution of articles based on year of publication

Year of Publication	Number of Articles	Percentage (%)
2019	45	22.5
2020	57	28.5
2021	50	25
2022	31	15.5
2023	17	8.5
Total	200	100

The graph in Figure 4 below is a visualisation of the development of the publication trend of chemical education scientific articles from 2019-2024.

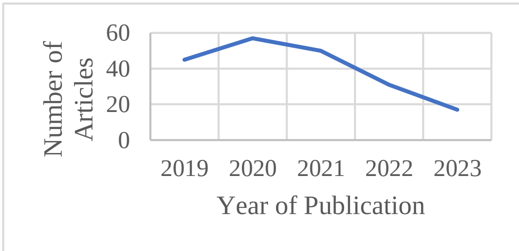

Figure 4. Graph of the development trend of scientific article publications related to chemistry education from 2019-2024

Visualization of Bibliometric Mapping on Inter-Key Networks

Keyword analysis in VOS viewer software is carried out using co-occurrence and then the relationship mapping between keywords is obtained. The keyword mapping forms a network as shown in Figure 5.

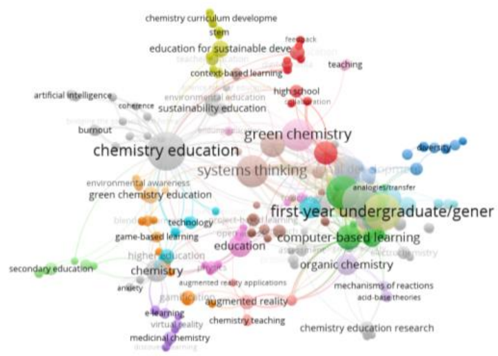

Figure 5. VOS viewer network visualization

There are 462 keywords that are connected to each other.

Most Frequently Discussed Topics

Chemistry Education as the keyword with the highest link frequency is reasonable considering the search keywords used using the word Chemistry Education. The keywords with the strongest links based on VOS viewer include: chemistry education (27), first-year undergraduate/general (25), curriculum (22), general public (20), green chemistry (18), systems thinking (18), high school/ introductory chemistry (16), upper-division undergraduate (14). This shows that over the last ten years, the subject of first-year undergraduate/general, curriculum, chemistry education, general public, green chemistry, systems thinking, high school/introductory chemistry, upper-division undergraduate. is a variable or topic that is often discussed in scopus indexed scientific articles.

Mulay et al. (2020) said that keywords in bibliometrics are usually classified based on several main criteria, namely:

1. Frequency of Occurrence: Keywords that frequently appear together in the literature tend to be grouped in a cluster. This indicates a close relationship between those concepts in the research.
2. Contextual Relationship: Keywords used in the same context or area of research are often grouped together. This helps in identifying sub-fields or themes of research that are in vogue.
3. Text Processing Techniques: Text processing methods, such as co-word analysis and factor analysis, are often used to group keywords based on their occurrence in the same document.
4. Maps and Networks: Mapping and network techniques are used to visualize the relationships between keywords. This provides insight into the network structure of the analyzed literature.

Table 5. Top 8 keywords from chemistry education related publications

Keyword	Number of Articles	Link Strength
Chemistry education	27	111
First-year undergraduate/general	25	161
Curriculum	22	140
General public	20	108
Green chemistry	18	104
Systems thinking	18	93
High school/introductory chemistry	16	107
Upper-division undergraduate	14	98

The visualization map in Figure 5 shows the linkages or relationships between keywords as a representation of a research and activities that occur. Based on the keywords with the strongest links, the following relationships can be drawn: In chemistry education, the application of systems thinking and green chemistry principles in the curriculum has great potential to increase understanding and awareness among both students and the general public. This approach starts from the secondary school level of education, where students are introduced to the basic concepts of green chemistry and how these elements are interconnected in a larger system. As students continue their education to the introductory level of chemistry in college, these principles of green chemistry and systems thinking continue to be reinforced. They learn how to apply these concepts in simple laboratory experiments and see the real impact of sustainable chemistry practices on the environment.

At the first-year or general undergraduate level, students are introduced to more complex global challenges and how green chemistry approaches can offer practical solutions. The curriculum at this stage is designed to integrate systems thinking, helping students to see the big picture and understand how different chemistry disciplines interact with each other. Finally, at the upper-division undergraduate level, students are expected to have a deep understanding of the principles of green chemistry and be able to apply systems thinking in their research projects. At this stage, they not only learn about advanced techniques, but also how to communicate the importance of sustainable chemistry practices to the general public.

By crafting a sustainable and systems-orientated curriculum from high school to college, chemistry education can play a key role in shaping a new generation of scientists and citizens who are more aware of the importance of keeping our ecosystems in balance. This not only increases under standing among college students but also helps spread knowledge and awareness about green chemistry in the wider community.

Density Visualization shows the relationship of each topic through the density of the colour, the more yellow the colour and the larger the diameter of the circle or vice versa indicates the frequency of research on that topic. Density Visualization can be used to determine the frequent or infrequent parts of the research. Figure 6 shows that the keywords curriculum high school/intro ductory chemi, distance learning/self instruct, second-year undergraduate, first-year under graduate, interdisciplinary/multidisci plinary, collaborative/cooperative learning, inquiry-based/discovery learning, upper-division undergraduate, environmental chemistry, analytical chemistry, periodicity/periodic table, applications of chemistry have the highest colour density with a striking yellow visualization and have the largest circle diameter.

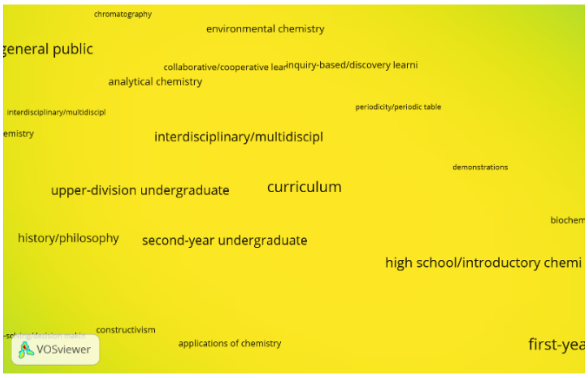

Figure 6. Density visualization output results

Recommended Research Opportunities on Chemistry Education Topics

A visualization of the 35 clusters can be seen in Figure 5, a network visualization obtained from VOS viewer. The size of the sphere can reflect the frequency of the keyword, i.e. the larger the sphere size, the higher the frequency or the more frequently the keyword is discussed in scientific articles. The smaller the size of the circle, the lower the frequency or the less frequent the keywords are discussed in scientific articles. The thickness of the line is proportional to the closeness of the connection between two keywords. A thicker line between two words means there is a closer relationship.

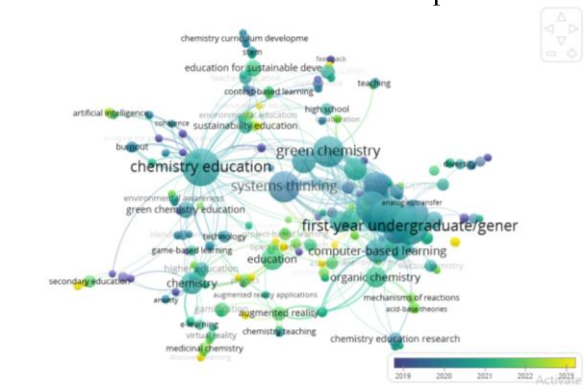

Figure 7. Overlay visualization VOS viewer

Figure 7 is an overlay visualization or keyword mapping from VOS viewer coloured by publication year. Colours range from purple (oldest year) to green to yellow (most recent publication year) (Krishna et al., 2023). If the colour of the circle is lighter, then the variable or keyword is relatively new or the keyword has been discussed recently. If researchers want to know the variables or keywords that are still rarely discussed related to chemistry education, they can see the map on the overlay visualization with small and light-coloured circles.

The latest and most recently discussed keywords include Chat GPT, generative AI, student writing, ivr features, immersive virtual reality, characteristics of meaningful, animation-IVR, 360-IVR, meaningful chemistry education, knot-tying, attitudinal style, interdisciplinarity, outdoor recreational activity, senior undergraduates, discovery learning, education mode, educational game design , exit game, learning progression, hans-on learning, sdgs, science teacher education, chemistry research, chemical education, sustainable, ethical, laboratories safety, labora toryrally, curricula, health, electrical processes, electric parameters, water, ethical, sustainable, fluorescene, absorption, spectro photometer, spectrometer, onferences professional devel, nanoparticle, esterifi cation.

CONCLUSION

The results of keyword mapping analysis in scopus indexed scientific articles from 2019-2024, it is known that in the last 5 years, in scopus indexed journals there are 462 different keywords and form 2072 connecting lines and 35 clusters. The keywords with the strongest linkages based on VOS viewer include: chemistry education (27), first-year undergraduate/ general (25), curriculum (22), general public (20), green chemistry (18), systems thinking (18), high school/introductory chemistry (16), advanced undergraduate (14). This shows that over the last ten years, the subjects of first-year undergraduate/general, curriculum, chemisry education, general public, green chemistry, systems thinking, secondary school/introduction to chemistry, advanced undergraduate. These keywords are variables or topics that are often discussed in scientific articles indexed by Scopus.

Recent keywords in chemistry education that are still rarely discussed in scientific articles are Chat GPT, generative ai, student writing, ivr features, immersive virtual reality, meaningful characteristics, animation-IVR, 360-IVR, meaningful chemistry education, knot-tying, attitude style, interdisciplinary, outdoor recreational activities, final year students, discovery learning, educational mode, exit game, labo ratory safety, laboratoryrally, curriculum, health, electrical processes, electrical para meters, water, ethics, sustainable, fluor escence, absorption, spectrophotometer, spectrometer, learning progression, educa tional game design, professional deve lopment conference, nanoparticles, hans-on learning, esterification, polymerization, nanomedicine, polyester, drug deli very, hydrolysis, sdgs, science teacher education, chemistry research, chemistry education.

Based on the results of bibliometric analysis from 2019-2024, the data obtained is very important for us to use in identifying new research opportunities, understanding recent developments, facilitating colla boration, and supporting evidence-based decision making in an effort to improve the quality of chemistry education.

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