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What is the Image of Microscale Chemistry Research for Chemistry Teaching in 2013-2023?

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Abstract: This research aims to reveal the distribution of microscale chemistry research related to publication output, document sources, microscale chemistry publishing countries; countries of correspondent authors on microscale chemistry; number of annual distribution of publication affiliations of microscale chemistry; distribution of microscale chemistry publication sources; the most relevant author in microscale chemistry publications; visualization of microscale chemistry research topics and trends. The method used is a bibliometric study sourced from the scopus.com database. Data were collected through searching publications with the keyword "microscale and chemistry" in the title, abstract, or keywords determined by the author, limited to the last 10 years (2013-2023), and managed and analyzed using Software R with Biblioshiny. The results show that there is a 10-year limitation, 196 publications were obtained. The top country to publish it is the USA. The country with the most correspondent authors of a single type is the USA. The distribution analysis result shows the research topic produces data on 1000 items with 19 clusters, with the most frequently used keywords being "microscale lab", "chemistry", and "green chemistry". The existence of microscale chemistry can make chemistry practicum activities easier, providing an alternative to chemistry practicum for those who are hampered by laboratory problems.

Keywords: bibliometry, chemistry education research trends, microscale chemistry, software

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INTRODUCTION

Chemistry teaching is one of the lessons in the curriculum at both secondary and tertiary levels. This teaching is very identical to carrying out practical work in the laboratory. Microscale chemistry is a laboratory work process on a smaller scale than traditional laboratory teaching approaches (macro scale). This approach drastically reduces (up to 1000 times) the number of chemicals (Mamlok-Naaman & Barnea, 2012) and uses small sets of plastic equipment (Tesfamariam et al., 2017). Implementing teaching activities using the microscale chemistry approach can save costs and practicum duration, improve laboratory work safety, and be more environmentally friendly (N. Hidayah et al., 2021; Kimel et al., 1998; Mohamed et al., 2012; Singh et al., 1999; Skinner, 1999; Zakaria et al., 2012)

The problems that occur in chemistry teaching are the very high need for chemicals in practical work, the high price of chemicals, and the place for disposing of final results in the laboratory has not been properly prepared, thus triggering environmental pollution. Apart from that, the limited chemistry practicum activities are due to security requirements and also the expensive equipment such as the Hoffmant cell (Davis et al., 2015). Besides, there are internal and external factors in carrying out the practicum. Internal factors include the low quality of teachers' laboratory pedagogical competence, experience in planning laboratory activities, and inadequate laboratory management capabilities (F. F.

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Hidayah et al., 2022). External factors relate to funding constraints for carrying out laboratory activities, non-existent and inadequate laboratory infrastructure, constraints on the lack of equipment and chemicals, lack of class hours for carrying out laboratory activities, and the absence of laboratory assistants (Bell & Bradley, 2012)

The related research includes Small-scale high school chemistry practicum with integration of Green Chemistry and SSC in chemistry education, Application of small-scale chemistry approaches in chemistry teaching (F. F. Hidayah et al., 2023), Microfluidic electrolysis experiments (Davis et al., 2015) Small-scale acid-base chemistry practical techniques (F. F. Hidayah et al., 2022), Anaerobic and Aerobic Respiration in Yeast Small-Scale Variations on Classic Laboratory Activities (Koutsokali & Valahas, 2020), Effectiveness of microfluidic devices in teaching stoichiometry with limited instruction (Veltri & Holland, 2020) macroscopic microfluidic setup for undergraduate students (Vié et al., 2019) microscale titration in the quantitative determination of ester products (Duangpummet et al., 2019), Visually illustrating the process of dissolution, ion mobility, and precipitation through simple micro-scale precipitation experiments (Worley et al., 2019), Direct laboratory experience during the lockdown pandemic using simple small-scale laboratory-based practicums (Fuangswasdi et al., 2023), Conducting laboratory experiments on rapid isolation of essential oil components from plant material using vacuum column chromatography on a small scale (Ciaccio & Ak, 2022). The practice of gas diffusion into the air with a simple open syringe (Kallepalli et al., 2021).

Articles on the use of simple tools that have relatively cheap prices and can reduce the amount of waste produced so they become one solution to this problem were published in 1984 in the United States. Research related to microscale chemistry, implementing chemistry practicums in secondary schools and universities, has not been widely carried out in Indonesia but has developed worldwide. The description or trend of educational research using KIT assistance or practical media in the form of microscale chemistry has not been widely explored. The need for practical research and innovation with microscale chemistry can be explored so that it becomes an opportunity for researchers to write about research trends related to microscale chemistry.

The importance of using microscale chemistry is that it can provide an alternative for secondary schools that do not have laboratories and limited laboratory equipment to discover new concepts at minimum cost. The existence of microscale chemistry can have a positive impact on the achievement of high school students and will provide the practical experience needed to solve life problems. Microscale chemistry gives students a positive impression of using tools without fear of them breaking because they are made of plastic. Science process skills in chemistry practicum using microscale chemistry can be observed, and this is proven by the teacher's ability to change the use of conventional laboratory equipment by reducing the amount of chemicals used in practicum more effectively and efficiently. (1) skills in using tools; (2) understanding chemical concepts; (3) availability of tools, materials, and work procedures; and (4) implementation of chemistry practicum. This follow-up plan shows how the SSC approach that has been trained can be applied in teachers' classroom teaching (F. F. Hidayah et al., 2022, 2023).

This research can provide information that learning with practical activities can be carried out using minimal tools and materials and is still able to provide students with an understanding of concepts. The benefits of this research are to provide other researchers with knowledge and an overview regarding the distribution of research related to microscale chemistry, the existence of evidence or impact of microscale chemistry research, an overview of research that is currently developing, and the discovery of new research opportunities, as well as being able to identify sources of publications and also a related author on microscale chemistry. The aim of this research focuses on determining research trends related to microscale chemistry in 2013-2023.

The research questions are as follows:

1. How is the distribution of microscale chemistry research related to publication output, document sources, and language?
2. What is the correspondent author's country on microscale chemistry like?
3. What is the distribution of publication affiliations each year in microscale chemistry like?
4. What is the distribution of microscale chemistry publication sources like?
5. Who is the most relevant author in microscale chemistry publications?
6. What is the visualization of microscale chemistry research topics and trends like?
7. What is the impact of microscale chemistry on chemistry teaching?

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RESEARCH METHOD

This research uses a literature review method with a bibliometric approach. The literature review uses a systematic, explicit, and reproducible method (Nurfauzan & Faizatunnisa, 2021; Septiyanto et al., 2023) or a mind-mapping method that emphasizes the limits of knowledge (Tranfield et al., 2003). A bibliometric analysis approach can be used to examine the evolution of a research domain, including topics and authors, based on the social, intellectual, and conceptual structure of scientific disciplines (Donthu et al., 2021). A scientific discipline that focuses on the quantitative study of journal papers, books, or other types of written communication (Antoro* et al., 2023).

This research stage is divided into three parts: [1] the research mapping stage, [2] the microscale chemistry publication mapping stage, and [3] the analysis stage following research objectives and conclusions. The research mapping was carried out using the Scopus database. The identification was carried out using the keywords *microscale* and *chemistry* or *small-scale* and *chemistry* for all years so that initial data were 329 documents in English. Furthermore, there was a limitation for the years 2013-2023 with the keywords *microscale* and *chemistry*. Or *small-scale* and *chemistry* obtained 196 documents. This was carried out to determine the distribution of years and the number of articles or books published by Scopus on the theme of microscale chemistry. The Scopus database was then stored in the form of RIS, Excel, and Bib. Installing the R studio software followed the steps of [1] [1]Installed.packages("bibliometrix") [2]library(bibliometrix) [3]biblioshiny. The use of biblioshiny software to analyze the distribution of research is related to publication output, document sources, and language; correspondent author country analysis; analysis of the distribution of publication affiliations each year; analysis of the distribution of publication sources; author's analysis is relevant in the publication. Vosviewer software is used for visualization analysis of research topics and trends. Impact and usage analysis using context analysis. The stages can be seen in Figure 1.

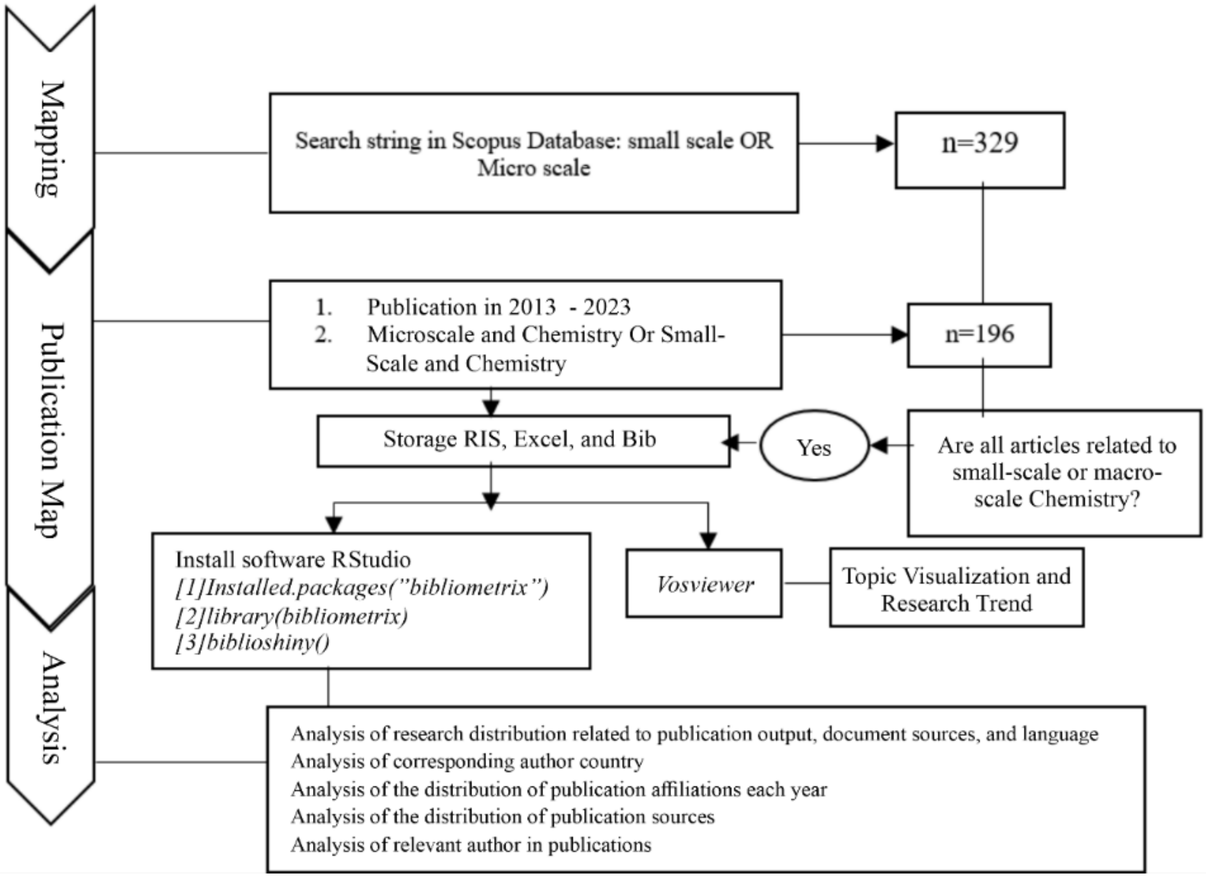

Figure 1. Steps of Bibliometric Research

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FINDINGS AND DISCUSSION

Document sources and language related to microscale chemistry

Microscale chemistry or small-scale laboratories began to develop in the United States in 1984. Ten countries carry out research related to microscale chemistry. As for the types of documents and the language used in publications, based on 10 years of data (2013-2023), it was found that English was the language most frequently used in publications. General information regarding publication data with the keyword *microscale chemistry* can be seen in Table 1.

Table 1. General information regarding the publication of Scopus data "microscale chemistry"

Document Contents	
Keywords Plus (ID)	2112
Author's Keywords (DE)	574
Authors	
Authors	906
Authors of single-authored docs	13
Authors Collaboration	
Single-authored docs	13
Co-Authors per Doc	4,97
International co-authorships %	21,03
Document Types	
Article	166
Book	2
Book Chapter	11
Conference Paper	7
Erratum	1
Letter	1
Note	1
Review	6

Correspondent authors' country on microscale chemistry 2013-2023

The country that produced the highest number of publications from 2013-2023 was the USA, followed by an increasing trend for China and Germany. These two countries had the highest start, namely Germany at the beginning of 2013-2018 but in 2019-2023 it was dominated by China, the United Kingdom, and finally France. Correspondence on microscale chemistry publications consists of multicountry publications. The distribution of single-country publications can be seen in Figure 2. The USA has the highest authorship for single-country publications, which is bigger than multicountry publications with more than 60 publications. In second place is China, with a single-country publication higher than multicountry publications.

Table 2. Corresponding author countries for microscale chemistry publications

Country	Articles	SCP	MCP	Freq	MCP_Ratio
Usa	63	53	10	0.323	0.159
	35	28	7	0.179	0.2
China	14	10	4	0.072	0.286
Canada	10	6	4	0.051	0.4
Germany	6	5	1	0.031	0.167
United Kingdom	6	5	1	0.031	0.167
Australia	5	3	2	0.026	0.4

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Country	Articles	SCP	MCP	Freq	MCP_Ratio
France	5	4	1	0.026	0.2
Switzerland	5	2	3	0.026	0.6
Mexico	4	4	0	0.021	0

Number of annual publication affiliations from 2013 to 2023

The distribution of affiliations for microscale chemistry publications can be seen in Table 3. The highest affiliation is 9 publications by the University of Wisconsin Madison in the USA. The 2nd highest is 7 publications each at Oregon Health and Science University in Plotland US, Ubon Ratchani University, and University of Science and Technology of China. The 3rd highest publisher is Oregon State University and the University of Illinois at Urbana Champaign with 6 publications each.

Table 3. Top 10 affiliations in microscale chemistry publications

Affiliation	Articles
University of Wisconsin-Madison	9
Oregon Health and Science University	7
Ubon Ratchathani University	7
University of Science and Technology of China	7
Oregon State University	6
University of Illinois at Urbana-Champaign	6
California Institute of Technology	5
Hanshan Normal University	5
Albert Einstein College of Medicine	4
Harvey Mudd College	4

Based on Table 3, the number of affiliation productions each year increased starting in 2017. The University of Wisconsin Madison in the USA has the highest and most consistent number of article production from 2017-2023, followed by the University of Science and Technology of China which experienced an increase from 2013 onwards. There is starting to be a decline but there is still continuity in 2021-2023. There is consistency second only to the University of Wisconsin Madison.

Distribution of microscale chemistry publication sources for 2013-2023

Table 3 shows journals or publication sources related to microscale chemistry. The highest publication source is the *Journal of Chemistry Education*. The relevant journal source discussing microscale laboratories is the *Journal of Chemistry Education*. This journal is a reputable international journal managed by the Publications Division of the American Chemical Society and the ACS Chemistry Education Division.

The number of publications that have been made from 2013-2023 in the *Journal of Chemistry Education* includes 75 scientific articles in the field of chemistry. Articles that have been published in the *Journal of Chemistry Education* tend to be simple experiments but have a level of detail in the discussion so that they can contribute to the field of chemistry education. Most microscale chemistry publications are in the field of analytical chemistry, titration materials (Das & Antony, 2022), analytical tools for gastric medicine applications (Lai et al., 2020), applications in redox reactions (McKee et al., 2019), use of Chromatography (Ciaccio & Hassan, 2020; Primdahl et al., 2022), chemical reactions in stoichiometry (Veltri & Holland, 2020) Rapid-Reaction Activity Introducing Microscale Precipitation Chemistry (Worley et al., 2019) Paper-Based Devices for Iron(III) Determination (Armenta et al., 2020) Iodometric Titration (Lin et al., 2023) Concept of Limiting Reagent in Acid-Base Reactions (Namwong et al., 2018).

The field of physical chemistry in gas material includes gas diffusion (Kallepalli et al., 2021), gas law in the form of Boyle's Law and Charles' Law (Limpanuparb et al., 2019), solar electrolysis (Cesin-AbouAtme et al., 2021), electrodeposition (Sanders et al., 2019), electrochemistry (Agustini et al.,

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2018), chemical equilibrium and chemical equilibrium constant, Kc (Kajornklin et al., 2020), some related microfluidic (Roller et al., 2021; Sun et al., 2019; Vangunten et al., 2020; C. Xu et al., 2018), millifluidic chemistry (Vié et al., 2019), oxidation and reduction (Weiss & Porter, 2020), and waterless reflux cooling (Lunelli & Baroncini, 2020).

The field of biochemistry is related to anti-bacterial isolation materials (Ciaccio & Ak, 2022), anaerobic and aerobic respiration in yeast (Koutsokali & Valahas, 2020), lipase-catalyzed esterification (Duangpummet et al., 2019), fields of chemistry learning that can be carried out at home (Toma, 2021), design and evaluation of integrated instructions in secondary-level chemistry practical work (Paterson, 2019), and a study to reduce chemical waste generated in chemistry teaching laboratories (Goh et al., 2019).

The field of organic chemistry still lacks the application of microscale chemistry. There are several materials related to this, namely synthesis of (E)-stilbene (Mooney et al., 2020), visual quantification of Fe on cotton thread using a ruler (Cai et al., 2019), reaction for the preparation of cis-1,5- dimethylbicyclo[3.3.0]octane-3,7-dione in the (Korman et al., 2020), cinnamon oil experiments in organic chemistry laboratory (Abraham et al., 2020), inorganic fields in the form of ruthenocene synthesis (Harrypersad & Canal, 2023), low-barrier high-throughput experimentation (Lee et al., 2020), and lab-on-a-chip: frontier science in the classroom (Wietsma et al., 2018).

Table 4. Top 10 Microscale Chemistry Publication Sources

Sources	Articles
Journal of Chemical Education	75
Lab on A Chip	5
Nature Communications	4
Analytical and Bioanalytical Chemistry	3
Journal of Visualized Experiments	3
Methods in Molecular Biology	3
Advanced Healthcare Materials	2
Analytical Chemistry	2
Atmospheric Environment	2
Educacion Quimica	2

The *Journal of Chemistry Education* dominates publications related to microscale chemistry, followed by *Lab On a Chip* with a total of five publications. Apart from these two journals, there are still several journals, but the number of publications is only around 2-4 articles.

Table 5. Distribution of publications per year for microscale chemistry in the *Journal of Chemical Education*

Year	Amount
2013	11
2014	19
2015	29
2016	31
2017	37
2018	42
2019	52
2020	64
2021	68
2022	71

The most relevant author in this publication is Xu C with some articles, entitled Transfer Learning and SE-Resnet152 Networks-Based for Small-Scale Unbalanced Fish Species Identification (X. Xu et

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al., 2021), Small-Scale Magnetic Actuators with Optimal Six Degrees of Freedom (C. Xu et al., 2021), Naked-eye Detection of Aluminum in Gastric Drugs on a Paper-Based Analytical Device (Lai et al., 2019), and A Simple Paper-Based Microfluidic Device for the Determination of the Total Amino Acid Content in a Tea Leaf Extract (Cai et al., 2013) dll.

Table 6. Authors of the top 10 publications related to microscale chemistry

Authors	Articles	Articles Fractionalized
Xu C	6	0.96
Cai L	5	0.93
Li Z	3	0.52
Remcho Vt	3	0.37
Sanders Wc	3	1,19
Vosburg Da	3	0.59
Wang B	3	0.78
Wang H	3	0.31
Wang X	3	0.47
Abraham L	2	1,33

Topics of Research on Microscale Chemistry

Research topics trends that appear in articles with the keywords *microscale chemistry* consist of the four largest groups, namely chemistry, article, procedure, and humans, priority journal, humans, tissue engineering, nonhuman, microfluidics, and controlled study. Various topics related to chemical materials that emerged were ozone, adsorption, kinetics, mass spectroscopy, oxygen, and temperature. This can be seen in Table 7.

Table 7. Research Trends Related to Microscale Chemistry

Item	year_q1	year_med	year_q3
oxygen	2013	2013	2014
Dust	2013	2013	2013
temperature	2013	2013	2016
microfluidics	2014	2014	2016
mass spectrometry	2014	2014	2018
microtechnology	2014	2014	2018
chromatography	2014	2015	2021
microfluidic analysis	2014	2015	2017
reproducibility	2013	2015	2018
Article	2013	2016	2019

The Chemistry group is often found in this context because the focus of this research uses limitations in the field of chemistry so this topic appears many times in this research. The word *oxygen* is the most commonly found because *oxygen* is the most important element in daily life. Apart from that, one of the concepts in elemental chemistry is oxygen. Oxygen is the most important element because it can react with almost all elements that exist in nature. As much as 21% of gas volume is contained in clean air. Apart from that, oxygen is very important in breathing for living creatures on Earth. Utilization of additional oxygen is for medical needs in hospitals and rockets (MD & Elvaswer, 2017; Suryanto, 2008). Based on data for 2013-2023, using the VosViewer network visualization in Figure 9, the results for Coaccorance were obtained. The biggest words are *microscale lab* and *chemistry* when viewed using the Vosviewer software, which can be seen in Figure 1.

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Table 8. The 10 highest word counts in microscale chemistry publications

Words	Occurrences
Chemistry	46
Article	42
Procedures	26
Human	20
priority journal	18
Humans	17
tissue engineering	17
Nonhuman	15
Microfluidics	14
controlled study	13

Microscale chemistry is very relevant to laboratory activities, so various laboratory activities that are simple (Phillips et al., 2014) and low-cost (Phillips et al., 2014; C. Xu et al., 2018) are an alternative to learning chemistry based on green chemistry (Duarte et al., 2017; Gross, 2013; Sanghi & Singh, 2012).

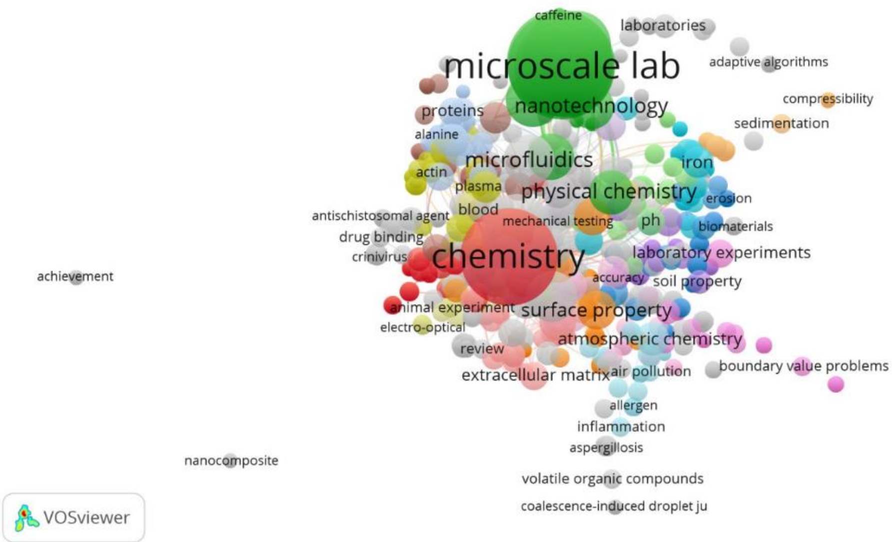

Figure 2. Image of the results of the Coaccorance Vosviewer visualization for 2013-2023

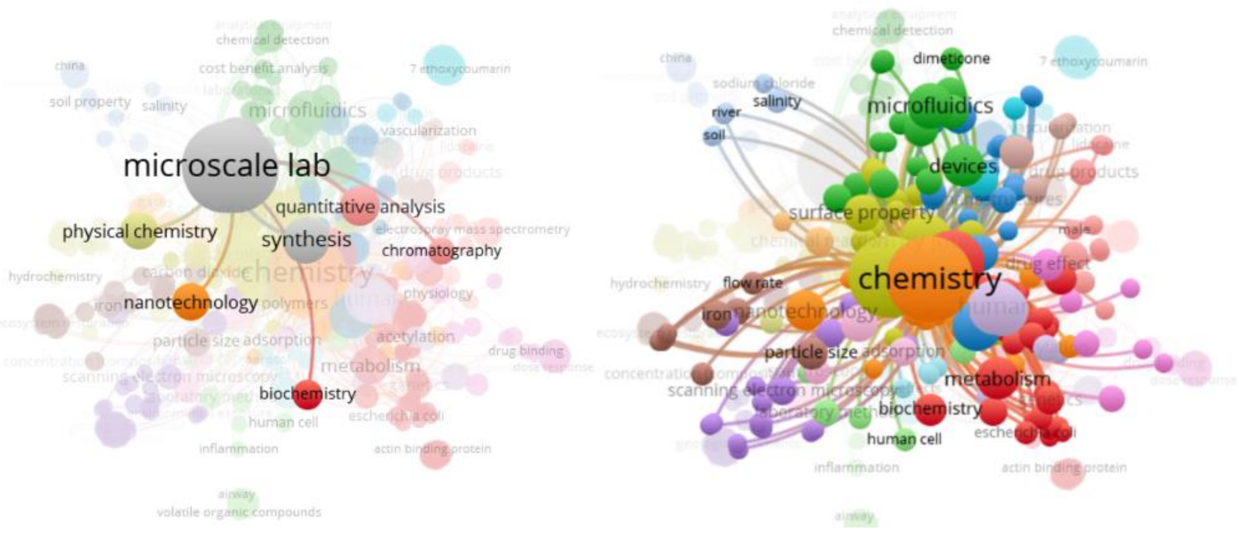

Figure 3. The most frequently used keywords in the VosViewer results

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Based on Figures 2 and 3 and supported by Table 8, the most prominent keywords are the words *microscale lab* which are related to physical chemistry, nanotechnology, synthesis, qualitative analysis, chromatography, and biochemistry. Micro-scale laboratory techniques are essential in physical chemistry, nanotechnology, synthesis, qualitative analysis, chromatography, and biochemistry. Therefore, it has many roles, one of which is micro-scale techniques used to study the physical properties and behavior of matter at the molecular and atomic levels. Reaction conditions can be well controlled, allowing accurate measurements of thermodynamic and kinetic properties. In physical chemistry research, techniques such as microscale calorimetry, microfluidics, and microdevices are frequently used.

Apart from that, Nanotechnology is a micro-scale laboratory technique, which deals with structures and phenomena at the nanoscale. Nanotechnology often involves the manipulation and characterization of materials at nanometer dimensions, which requires precise control and manipulation techniques. An example of micro-scale manufacturing methods is electron beam photolysis. Microscale synthesis techniques are used in organic, inorganic, and materials chemistry to create compounds and materials on a small scale. This reduces waste, allows rapid screening of reaction conditions, and allows more efficient use of reagents. Microscale qualitative analysis involves identifying sample parts based on their chemical properties and behavior. Microscale techniques such as titration, extraction, and microscale spectroscopy enable the analysis of small sample volumes while maintaining high sensitivity and accuracy. Analytical chemistry and environmental monitoring are two fields that make extensive use of this technique. Chromatography techniques, such as gas chromatography (GC) and liquid chromatography (LC), can be modified at the microscale to become more sensitive and efficient.

Furthermore, the second keyword, namely *chemistry*, has many networks, including microfluidics, iron, particle size, human cells, metabolism, biochemistry, and soil. This can be connected because microfluidics studies the behavior, control, and manipulation of fluids at the micro-scale. Chemistry plays an important role in microfluidics by providing an understanding of behavior, surface chemistry, and reactions in confined spaces. Microfluidic devices often rely on chemical principles for transport, mixing, and reaction kinetics, allowing them to be used in chemical synthesis, analysis, and reaction modeling. Iron plays an important role in many chemical processes, such as redox reactions, catalysis, and biological functions. Chemistry provides insight into the complex coordination of iron, its reactivity, and its role in biological systems. Understanding iron chemistry is critical for a variety of applications, such as biological metallurgy, industrial catalysis, and environmental remediation. Small to nano-size particles are all influenced by chemistry. Microscale lab research opportunities are linked to climate change and atmospheric chemistry.

Impact of Microscale Chemistry on Chemistry Teaching

Chemistry teaching is synonymous with practical activities. Carrying out a chemistry practicum requires expensive tools and materials. Chemistry practical activities are carried out on a standard, large-scale basis. Chemicals are used in large quantities and the equipment is large-scale and expensive (Pesimo, 2014). Chemistry experiments do not provide opportunities for practical activities, especially in schools that do not have adequate laboratories or have inadequate laboratories. The use of microscale chemistry can provide an alternative for secondary schools that do not have laboratories and limited laboratory equipment to discover new concepts at minimum cost. The existence of microscale chemistry can have a positive impact on student achievement in high school and will provide the practical experience needed to solve life problems (Ifepe & Anekwe, 2022). The existence of microscale chemistry experiments can increase students' understanding of scientific concepts. It helps overcome the many challenges educators face in planning practicum activities. The microscale chemistry practicum can stimulate curiosity, imagination, and critical thinking and is interesting and captivating. Microscale chemistry practicum activities can also improve attitudes and skills toward learning chemistry. This is also confirmed by research that students' attitudes towards practical work have a positive response (Mohamed et al., 2013).

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CONCLUSION

Based on the research results, it was concluded that there are 195 documents, journal source documents, book chapters, and review notes. The languages used are English, French, and Spanish. The country that publishes the highest number of articles on microscale chemistry is the USA. The correspondent author's country with the highest microscale chemistry articles is the USA. The number of publication affiliations each year for articles on microscale chemistry is the University of Wisconsin Madison in the USA. The distribution of microscale chemistry publication sources is the *Chemistry Education Journal*. The most relevant author in microscale chemistry publications is Xu C. The visualization of microscale chemistry research topics and trends produced 19 clusters with the highest keywords *microscale lab, chemistry,* and *green chemistry*. The use of microscale chemistry can provide an alternative for secondary schools that do not have laboratories and limited laboratory equipment to discover new concepts at minimum cost. The existence of microscale chemistry can have a positive impact on the learning achievement of high school students and will provide the practical experience needed to solve life problems.

Suggestions for further research are that based on the results of this bibliometry, the majority of existing research is still purely chemical research, but not much has been linked to teaching applications in schools or universities. Apart from that, there is a need for microscale chemistry research to be combined with 21st-century skills. There needs to be research on the effectiveness of microscale chemistry when applied in universities and high schools.

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