

Review Article

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Author for correspondence:

Marcela Núñez Genes

✉ mgenesnunez@correo.unicordoba.edu.co

✉ Universidad de Córdoba, Colombia

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Bibliometric Analysis of Green Chemistry Through Practical Laboratory Work

Núñez Genes Marcela , Nisperuza Flórez Patricia Elvira

Abstract

Background/Purpose. Green chemistry is a branch of science that aims to design chemical products and processes that reduce or eliminate the use and generation of hazardous substances, thereby protecting the environment and human health. This research aims to analyze the results of green chemistry through laboratory practical work (LPW) using bibliometrics, in order to understand its evolution, pedagogical approach, and relevance in the educational context.

Materials/methods. A systematic review of scientific articles indexed in the Scopus database between 2015 and 2025 was conducted, using the PRISMA protocol as the methodological guide. A total of 33 articles were selected and analyzed based on three dimensions: author, journal, and contribution.

Results. The results reveal a high concentration of scientific production in Brazil, as well as the strengthening of educational approaches that incorporate the principles of green chemistry through laboratory practical work. Among the most significant contributions are sustainable practices, including microscale synthesis, the use of eco-friendly solvents, and the design of biodegradable materials.

Conclusion. This research highlights the importance of transforming traditional laboratory practices and promoting didactic proposals that integrate science education with both global and local environmental challenges.

1. Introduction

Green chemistry has gained significant importance in both scientific research and the educational domain (Infante et al., 2024). Its focus is on creating processes and products that reduce waste production, decrease toxicity, and improve the use of materials and energy, always with the goal of reducing risks to health and the environment (Anastas & Eghbali, 2010). This field has established itself as a viable option in the face of global sustainability challenges and serves as a driver of transformation in current chemistry practices (Clark, 1999).

In the educational field, teaching green chemistry is essential to prepare students for today's environmental, social, and technological challenges. Recent studies indicate that its inclusion in laboratory practical work (LPL) not only facilitates deeper learning but also promotes ecological awareness and the acquisition of skills related to sustainability and ethics (Eilks & Zuin, 2018; Gaspar, Bouzon, Brandão, & Chrispino, 2023). Despite growing interest, a thorough analysis of the literature related to green chemistry education reveals that its inclusion in teacher training remains inconsistent. Most findings come from research on experiences, and while innovative approaches are recognized, there are not enough organized and uniform programs that facilitate practical application that can be replicated in different environments (Ferk & Mlinarec, 2021).

Similarly, many teaching systems are still based on conventional laboratory methods that produce large amounts of waste, use harmful products, and replicate outdated techniques (Kirchhoff, 2005; Burmeister, Rauch, & Eilks, 2012). This gap complicates the integration of scientific education with sustainability principles, particularly in rural or resource-limited educational environments (Perdomo et al., 2021). Moreover, limitations in laboratory infrastructure and the lack of teaching resources often force teachers to improvise, which affects both the educational value and safety in the learning process (Ferk Savec & Mlinarec, 2021).

Given these challenges, it is crucial to investigate how green chemistry has been incorporated into laboratory activities, as outlined in the academic literature. This incorporation highlights the progress in science while also emphasizing educational trends and institutional priorities. Bibliometric analysis provides a methodological framework for investigating patterns, recognizing leaders in the field, and evaluating the educational approaches in publications that address green chemistry and laboratory training. Therefore, the purpose of this research is to conduct a bibliometric analysis of green chemistry in relation to laboratory practices. This study aims to trace the scientific production, educational methods, and geographical trends associated with this connection, thereby providing perspectives that support the shift in scientific education toward more sustainable and context-relevant approaches.

2. Literature Review

This section presents a review of the relevant literature that underpins this study. It explores the theoretical foundations of green chemistry and its guiding principles, the pedagogical integration of sustainable chemistry in education, the role of laboratory practical work, and the current research gaps addressed through bibliometric analysis. The aim is to establish the scientific and educational context in which this research is situated.

2.1. Foundations and Principles of Green Chemistry

Green chemistry (GC) emerged in the 1990s as a response to the global environmental crisis generated by industrial pollution and unsustainable resource exploitation. It was formally established through the twelve principles developed by Anastas and Warner (1998), which advocate for waste prevention, energy efficiency, renewable feedstocks, and safer chemical design. These principles serve as a framework for minimizing environmental impact throughout the chemical product lifecycle (Souza et al., 2020; Lenoir et al., 2020).

Green chemistry has since become an essential component of sustainable development strategies, contributing to the ecological transition of industrial economies by reducing the environmental footprint of chemical processes (Téllez, 2020; Tarkhanova et al., 2020). Beyond technological applications, GC intersects with public health, environmental justice, and educational innovation, positioning itself as a multidisciplinary response to complex global challenges (Rivera et al., 2023; Denona Bogovic et al., 2020).

2.2. Green Chemistry in the Educational Context

The integration of green chemistry into education, known as Green Chemistry Education (GCE), reflects a growing interest in developing students' environmental awareness and critical thinking skills. GCE aims to reframe chemistry as a transformative science that contributes to sustainability rather than pollution (Pino, 2020; Moreno et al., 2020). This pedagogical shift also supports the Sustainable Development Goals (SDGs), particularly in relation to quality education and responsible consumption.

In the current educational landscape, teaching green chemistry goes far beyond simply transmitting formulas or laboratory techniques. It is about equipping students to understand the environmental impact of their actions, make ethical decisions, and actively engage in sustainability. To achieve this, it is essential to adopt pedagogical approaches that encourage critical thinking, active participation, and connection with real-world problems. One of these approaches is constructivism, which suggests that learning is built from meaningful experiences. In the classroom, this translates into practices that enable students to reflect on the use of materials, waste management, and the environmental implications of chemical processes (Castaño & López, 2015).

Problem-Based Learning (PBL), as proposed by Castaño and López (2015), takes things a step further: it is grounded in collaborative work to address real-life situations, helping to develop skills such as decision-making, teamwork, and ethical awareness.

Additionally, it is crucial to incorporate 21st-century skills into the education system. According to Lozano (2020), environmental responsibility should be a fundamental pillar in education, fostering a critical perspective on how we use resources and the effect of our actions. Sustainability, as mentioned by Pérez et al. (2023), refers to teaching students to seek solutions that achieve a balance among the ecological, social, and economic aspects. Furthermore, ethical awareness should be present throughout scientific training, guiding future professionals to make informed and responsible decisions.

Despite this progress, implementation remains limited, especially in low-income regions or rural contexts where educational infrastructure is precarious (Guarnizo & Puentes, 2024). Laboratory teaching often lacks alignment with GC principles, relying instead on traditional, resource-intensive methods. These challenges are compounded by insufficient curricular legislation and underfunding, restricting the inclusion of green chemistry in formal academic programs (Carlos & Echevarría, 2024).

2.3. Laboratory Practical Work and Sustainable Pedagogy

Laboratory practical work (LPW) is a core component of science education. However, it frequently follows rigid, prescriptive formats that reduce students to passive executors of predefined procedures (Espinosa et al., 2016; Bárcena & Martínez, 2022). In contrast, sustainable LPW under green chemistry principles promotes experimentation using non-toxic reagents, minimal quantities, and micro-scale setups that reduce environmental and health risks (Zuin, 2021; Perdomo et al., 2021).

Educators are increasingly turning to “artisanal” or low-cost laboratories using household materials as viable alternatives to traditional settings, especially in underserved schools (Naveros &

Mosquera, 2023). These practices foster creativity, contextual relevance, and environmental responsibility while addressing logistical constraints (García & Fernández, 2022).

2.4. Curriculum Innovation and Critical Thinking

The literature highlights a significant disconnect between theory and practice in chemistry education. Students often fail to perceive the relevance of chemistry in solving real-world problems, particularly environmental ones (Eilks & Zuin, 2018), who emphasize the importance of integrating green and sustainable chemistry education to address contemporary societal challenges. There is a recognized need to design instructional tools that foster critical thinking and connect local realities with scientific knowledge (Rodríguez et al., 2020; Bravo et al., 2022).

Some authors argue for the inclusion of context-based pedagogies that emphasize sustainability, responsibility, and systems thinking within science curricula (Mascarell & Vilches, 2016). These approaches suggest that GC can serve not only as content but also as a didactic axis linking experimentation with environmental awareness, public health, and the circular economy (Palacios & Hernández, 2024).

2.5. Research Gaps and Need for Bibliometric Analysis

While several case studies and theoretical proposals have been documented, there is a lack of systematic studies that map how GC and LPW are represented in scientific literature. Bibliometric analysis offers a robust tool for evaluating trends, identifying influential publications, and detecting underexplored thematic areas (Sanabria et al., 2024). By applying this method, the present study aims to provide a comprehensive overview of the academic treatment of green chemistry through LPW, thereby establishing a foundation for evidence-based educational strategies and future curricular reforms.

3. Methodology

This study employed a bibliometric and systematic review methodology with a descriptive and retrospective scope. This method facilitates the study of scientific production related to green chemistry in relation to laboratory practical work (TPL), relying on articles indexed in Scopus from 2015 to 2025. Using bibliometric research, the progression of scientific production is investigated through parameters such as the number of publications, citations, and author cooperation, while a systematic review, following the PRISMA protocol, ensures the meticulous collection and analysis of relevant articles, implementing inclusion and exclusion criteria. This descriptive approach provides an overview of trends and patterns in green chemistry research, highlighting the most influential authors, areas of study, and the geographical distribution of publications, thus enabling an understanding of the evolution of this field in education and its response to new environmental challenges.

3.1. Research Design and Theoretical Framework

The methodological approach was guided by the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, adapted from the model proposed by Matthew et al. (2009). This ensures rigor and clarity in the collection and analysis of information (Page et al., 2021). A mixed-methods approach was employed, combining positivist, postpositivist, and constructivist components, thereby allowing for a more comprehensive understanding of the phenomenon by integrating both quantitative and qualitative data (Tashakkori & Teddlie, 2010). This method emphasizes the importance of inclusion and exclusion criteria to ensure the quality of the studies incorporated into the review, which is crucial to preserving the validity and reliability of the findings (Higgins & Green, 2011). Furthermore, the social and pedagogical context is considered, emphasizing that green chemistry educational practices must be adapted to culturally constructed

realities, especially in Latin America, where various social, economic, and cultural factors impact teaching and learning (Cabrera & González, 2020). Together, this approach aims to detect trends in scientific production and also understand how these practices are incorporated into the educational curriculum, preparing students for sustainable and responsible practices in response to today's environmental challenges.

3.2. Data Collection and Inclusion Criteria

The data were obtained from the Scopus database using the following Boolean search query:

TITLE-ABS-KEY (green AND chemistry) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (SUBJAREA, "ENVI")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (EXACTKEYWORD, "Article")) AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (EXACTSRCTITLE, "Journal Of Environmental Management")) AND (LIMIT-TO (OA, "repository"))

Data collection was conducted using the Scopus database, where a Boolean search was performed to identify relevant articles on green chemistry. This process included setting specific filters to obtain a representative sample aligned with the research objectives. Initially, 103,105 documents were identified from the search. However, to ensure the quality and relevance of the selected articles, several filters were applied, significantly reducing this number. The first filter focused on the publication year, limiting the results to those published between 2015 and 2025, which reduced the sample to 72,221 documents. This step is crucial as green chemistry is a constantly evolving field, and restricting the search to recent articles ensures that the most current trends and developments are reflected.

Next, an additional filter was applied to focus the results on the environmental sciences subarea, which resulted in 13,645 articles. This restriction is crucial for focusing the research within the appropriate context, as green chemistry is closely related to sustainability and environmental management. The next stage involved limiting the results to peer-reviewed articles, which reduced the figure to 11,071 documents. This criterion is essential to ensure the quality and validity of the information, as it has been critically evaluated by experts in the field through peer-reviewed articles.

Subsequently, the search was refined by language, restricting it to English, which left a total of 10,966 documents. This is because English is the predominant language in scientific literature, and limiting to this language facilitates access to and understanding of the selected studies.

The filtering by keyword relevance yielded a total of 6,424 entries. This step is crucial to ensure that the selected articles are directly related to the research topics of interest. Ultimately, from this group, 461 journal articles were identified that are clearly categorized under environmental sciences. Of these, only 33 articles were considered directly related to green chemistry in the context of laboratory practices, and they were included in the final sample. This meticulous filtering process is essential to ensure that our research is based on a dataset that is not only broad but also specific and relevant. This allows us to draw solid and applicable conclusions in the field of education and green chemistry practice.

3.3. PRISMA Flowchart and Screening Process

The screening process consisted of four stages: identification, screening, eligibility assessment, and inclusion. The PRISMA flow diagram (see Figure 1) summarizes the filtering steps and the number of articles retained or excluded at each phase. Reasons for exclusion included misalignment with the subject area, lack of focus on LPW, or duplication.

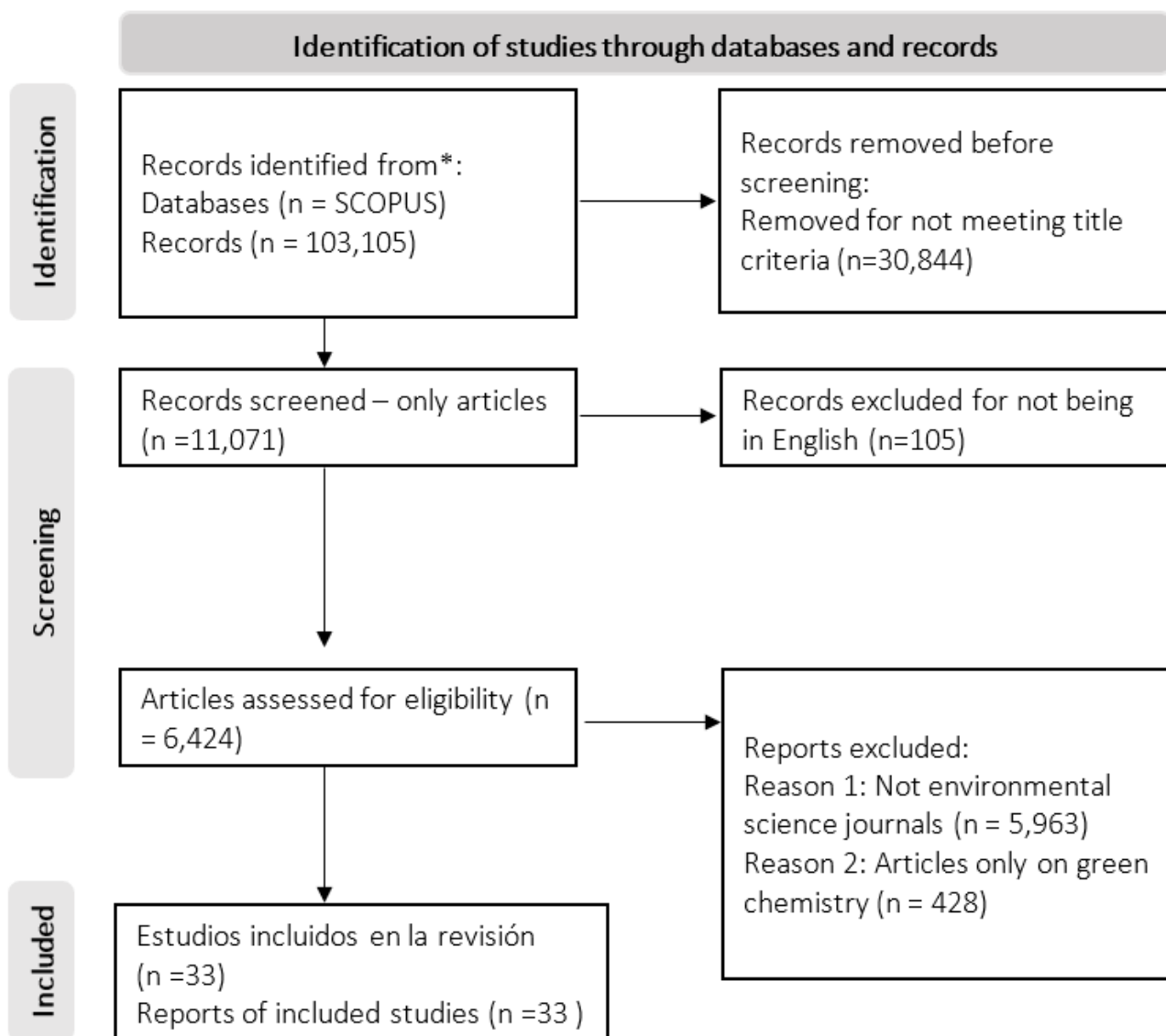


Figure 1. PRISMA flowchart of the article selection process.

Source: Based on Matthew et al. (2021).

3.4. Dimensions and Analytical Framework

The final sample of 33 articles was analyzed based on the ARA model (Authors, Journals, Contributions), as proposed by Sanabria et al. (2024). Each article was coded and categorized according to the following dimensions and indicators:

- D1: Authors — aspects such as the total number of citations, citation frequency, publication year, institutional affiliation, country of origin, and h-index of each author were explored. These indicators are crucial for evaluating the impact and relevance of authors in the field of green chemistry.
- D2: Journals — characteristics such as the journal name, thematic focus, Scopus quartile, impact factor, and the country of origin of the journal were considered. This information is essential for understanding the context and quality of the publications in which the analyzed articles are published.
- D3: Contributions — Elements such as the thematic focus, research methodology, analytical techniques used, sample type, as well as the results and conclusions presented in each article were

reviewed. These indicators enable a detailed evaluation of the scientific contributions and their relevance to the advancement of green chemistry within the context of laboratory practices.

3.5. Data Extraction and Analysis Tools

For the bibliometric analysis, the software VOSviewer and the R-based package Bibliometrix were used to extract co-occurrence data, map keywords, and generate conceptual clusters. Additionally, descriptive statistics were applied to evaluate trends in publication volume, geographic distribution, and author impact. The data were complemented with qualitative interpretation based on the educational relevance of each contribution.

The obtained data were complemented with a qualitative interpretation, focusing on the educational relevance of each contribution. This enables the data to be analyzed from a numerical perspective, allowing for an understanding of their impact on education and laboratory practices related to green chemistry. This mixed approach ensures that the analysis is comprehensive, covering both the quantitative and qualitative aspects of the research.

4. Results

This section presents the findings of the bibliometric analysis, focusing on the integration of green chemistry in laboratory practical work. The results are structured into key conceptual categories, the chronological development of the thematic focus, and detailed analyses of authors and journals.

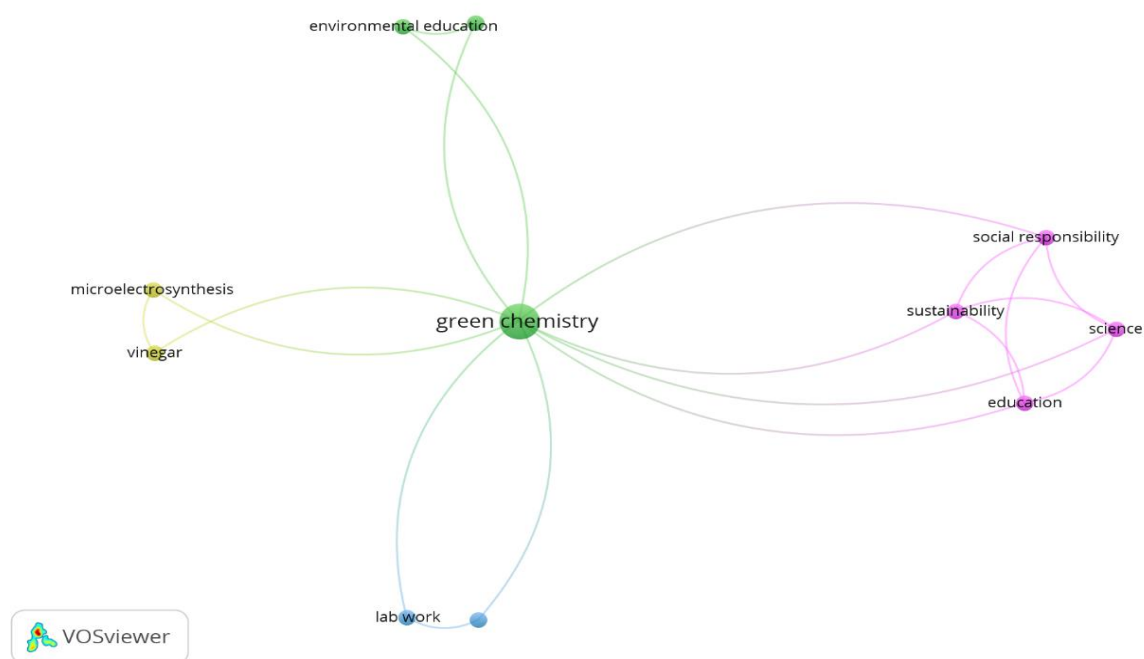


Figure 2. Co-occurrence Network of Keywords in Green Chemistry Education Research.

Source: Generated using VOSviewer (2025)

4.1. Conceptual Categories

Understanding the research and acknowledging the importance of integrating green chemistry into school education, it is relevant to determine the conceptual categories. Using the co-occurrence method, with an effectiveness margin of 93% and a margin of error of 7%, the main categories were established. These include: Green chemistry, environmental education, sustainability, social responsibility, education, and laboratory work. Figure 2 illustrates the primary conceptual clusters that emerged from the co-occurrence of keywords in the selected articles, with clusters distinguished

by color representing thematic foci within green chemistry education, including sustainability, eco-friendly practices, and laboratory methodology.

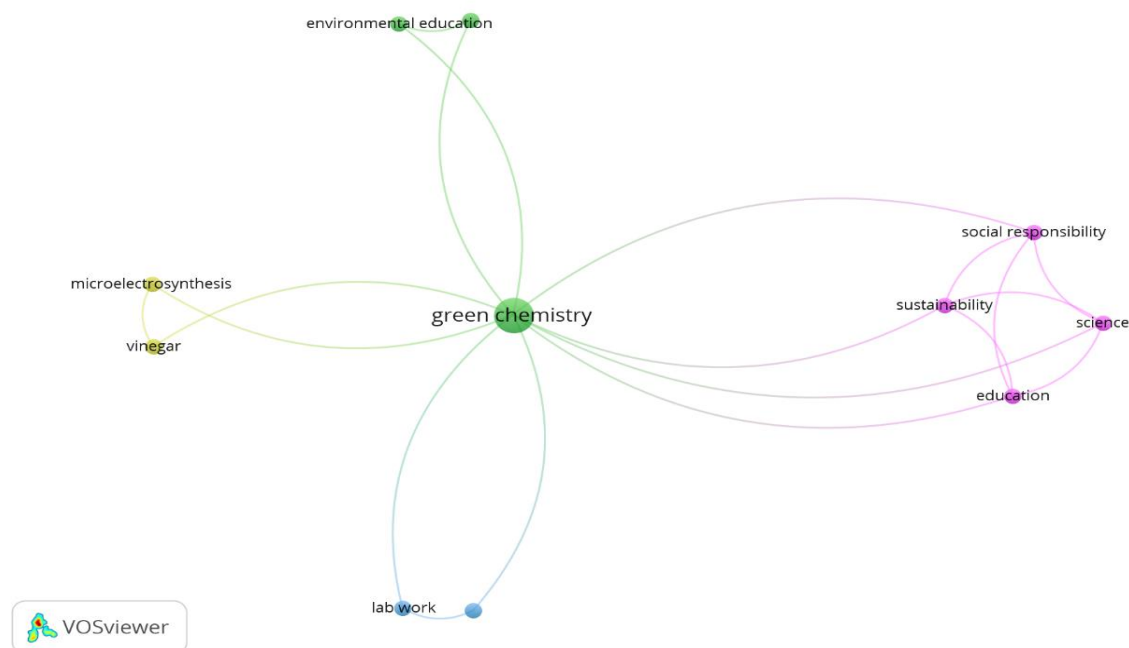


Figure 2. Co-occurrence Network of Keywords in Green Chemistry Education Research.

Source: Generated using VOSviewer (2025)

- **Green Chemistry:** Refers to the application of chemical principles aimed at pollution prevention, using safer and more sustainable processes compared to conventional industry methods. Its primary goal is to avoid pollution at the source (Pino, 2020).
- **Environmental Education:** Understood as a systematic and continuous process that seeks to raise awareness in society about the importance of environmental care, while also fostering the necessary tools for its preservation and restoration (Borja et al., 2024).
- **Sustainability:** Considered a pattern of economic accumulation and specialization that ensures environmentally friendly growth rates in the medium and long term (Palacios & Hernández, 2024).
- **Education:** Defined as a guiding beacon, an indispensable compass that leads toward a profound and meaningful renewal of teaching and learning paradigms. This discipline, firmly anchored in scientific rigor, seeks to unravel the intricate dynamics within educational spaces (Molina, 2024).
- **Laboratory Work:** Is often approached as a set of verification activities that follow rigid, recipe-like procedures. However, this traditional model has been criticized for limiting the development of scientific thinking skills. As Oliveira and Bonito (2023) point out, "the way practical work is implemented is often not in agreement with the methods and techniques used by scientists and researchers."

These categories organize the thematic field and also form the theoretical foundation on which the bibliometric analysis is built. By identifying these axes, the aim is to systematize how Green Chemistry has been addressed in education, and a gap in the connection between pedagogical theory and scientific sustainability becomes evident.

4.2. Development Stages of the Thematic Focus

Having defined the conceptual categories of the research, it is essential to determine the stages of development in the integration of green chemistry into school education (Figure 3).

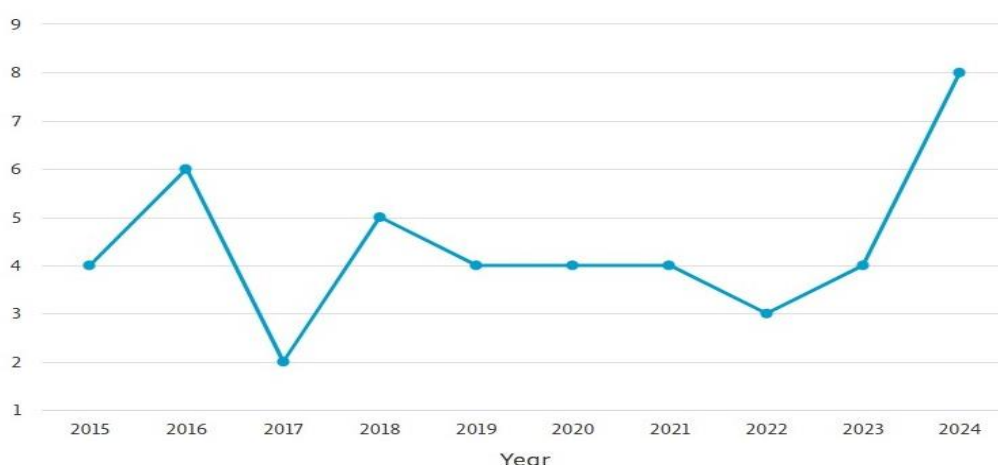


Figure 3. Chronological Evolution of Green Chemistry Education Research.

Note: This figure presents the chronological evolution of research on green chemistry education through laboratory practical work from 2015 to 2024.

Source. SCOPUS 2025

The following section outlines the chronological evolution of publications and thematic trends within this field over the past decade, as depicted in Figure 3. This analysis allows for a clearer understanding of the progression and key milestones in the research landscape.

- Stage 1 (2015–2018): Initial publications emerged, with notable studies such as Wallau et al. (2015) on microscale synthesis, and Borreda et al. (2016), which explored the role of green chemistry in science education. Research in 2017 declined, with fewer citations and articles focusing on specific chemical comparisons (Salgueiro et al., 2017). In 2018, interest in green chemistry for water purification resurged (Triana et al., 2018).
- Stage 2 (2019–2021): Constant publication output, including contributions like García et al. (2019) on carbon nanostructures using green principles, and Moreno et al. (2020) on the role of green chemistry in science didactics. In 2021, Zonotto et al. emphasized sustainable procedures with low waste generation.
- Stage 3 (2022–2024): A brief decline followed by an increase in articles. Da Silva et al. (2022) discussed global strategies for integrating green chemistry into education. Gaspar et al. (2023) noted that green chemistry's slow uptake in education is despite its industrial relevance. Carlos & Echevarría (2024) highlighted the importance of changing chemistry's negative perception through educational practices.

This evolution over time helps us understand how the educational approach in Green Chemistry has evolved. It justifies the use of bibliometric analysis as a tool to map trends and detect key moments in the development of this field. Furthermore, it highlights the scarcity of studies that integrate this evolution with concrete pedagogical proposals.

4.3. Dimension 1: Authors

After analyzing the theoretical approaches and stages of progress on the issues, this section delves into Dimension 1: Authors. The purpose of this analysis is to identify the most prominent figures in the field, paying attention to their place of residence, the organizations to which they

belong, the influence they have had over the years, and their individual significance, measured by the number of texts published, the references they have received, and the h-index. This provides an overview of the author landscape in the field of sustainable chemistry research, particularly with regard to laboratory procedures.

The analysis of Dimension 1: Authors (Table 1) revealed a clear geographical concentration in knowledge generation, with Brazil contributing almost 75% of the total studies in the dataset. This highlights Brazil's dominant position in this field. At the institutional level, the Institute of Chemistry at the State University of Campinas and the Federal University of Rio de Janeiro stand out, accounting for about 15% of the total publications, confirming their leadership in green chemistry research. Other countries that have made significant contributions are Colombia (8%), Peru (7%) and, to a lesser extent, Mexico, Uruguay, Spain, and Poland, each with less than 5%. This situation points to a marked centralization of academic production in Brazil, while other countries make isolated, albeit notable, contributions in certain situations.

In terms of evolution over time, 2024 stands out as the most fruitful year, accounting for 20% of total publications, followed by 2016 with 13% and 2015 with 11%. In contrast, 2017 saw only 4% of publications, marking the lowest level of research activity. The increase in 2024 could be linked to the emergence of new areas of research or strategic collaborations, while 2017 shows a period of stagnation.

In terms of impact, authors Finnazi et al. (2016) and Wallau et al. (2015) each account for 16% of total citations, highlighting their relevance in the field. Overall, publications from 2015 and 2016 account for 40% of citations, indicating that those years had a significant impact. Meanwhile, articles from 2024, despite being recent, already contribute 5% of total citations, indicating an encouraging initial impact, although still in the process of consolidation. This analysis highlights the ability of certain authors to generate research that truly has an impact. Colmenares et al. (2015) stands out as the most influential, with 42% of the total citations of the authors considered in the list. They are followed by Echevarria (2024), who contributes 22% of the citations, a considerable figure given the recent publication date. Wallau et al. (2015) have 4% of citations. Together, these three authors account for almost 68% of all scientific references cited.

In relation to the h-index, Colmenares et al. (2015) have the highest value, representing 28% of the maximum h-index among the authors cited. Salgueiro et al. (2016) and Wallau et al. (2015) follow, each with 21%. In total, these three authors constitute 70% of the total h-index, reflecting the sustained impact of their research.

Table 1. Dimension. 1: Authors

Authors	Total citations	Citations per year	Year of publication	Affiliation	Country	H-index
Vaz et al., (2024)	3	2	2024	Instituto de Química, Universidades Estadual de Campinas	Brazil	1
Echevarria., (2024)	3375	143	2024	Instituto de Química, Universidade Federal Rural de Río de Janeiro	Brazil	32
de Lima et al., (2024)	1	1	2024	Universidade Federal de Rio de Janeiro	Brazil	1

Authors	Total citations	Citations per year	Year of publication	Affiliation	Country	H-index
Arreche et al., (2024)	79	12	2024	Centro de Investigación y Desarrollo en Ciencias Aplicadas	Argentina	6
Dos Santos et al., (2024)	1	1	2024	Departamento de Ciencias Exatas y Naturales de Estado de Bahía	Brazil	1
De Carvalho et al., (2024)	635	39	2024	Universidade de Fluminense, Faculdade de Farmácia	Brazil	13
De Oliveira et al., (2023)	0	1	2023	Instituto Federal de Educação, Ciência y Tecnología de Goiano	Brazil	0
Tonini et al., (2024)	0	3	2024	Instituto de Investigaciones Biomédicas (IPB), RJ, Río de Janeiro	Brazil	0
Infante et al. (2024)	25	21	2024	Universidad Adventista de Chile, Universidad continental Huancayo, Peru; Universidad Nacional de Ica Peru	Peru	1
Gaspar et al., (2023)	2	1	2023	Centro Federal de Educação Tecnológica Celso Suckow da Fonseca, Brazil	Brazil	1
Aquino et al., (2023)	3	1	2023	Departamento de Tecnologia, Universidade Estadual de Maringá, PR, Umuarama	Brazil	1
Dos Santos et al. (2023)	5	2	2023	Universidade Federal da Bahia, Faculdade de Farmácia, Programa de Pos- Grado	Brazil	13
Nazario et al., (2022)	429	67	2022	Universidad Autónoma del Peru, Peru; Universidad Privada del Norte, Peru	Peru	12
Silvestre et al., (2022)	600	53	2022	Laboratory of Studies of the Soil, Plant, and Atmosphere System and Plant Metabolism	Brazil	3
Da Silva (2022)	29	6	2022	Departamento de Química Analítica, Instituto de Química, Universidade Estadual de Campinas	Brazil	3
Hercos et al., (2021)	0	1	2021	Instituto Federal de Educação, Ciência e tecnologia Goiano (IF Goiano)	Brazil	0

Authors	Total citations	Citations per year	Year of publication	Affiliation	Country	H-index
Zonotto et al., (2021)	0	0	2021	Universidade Estadual do Centro-Oeste, Departamento de Química, Campus CEDETEG	Brazil	0
de Sá	2	1	2021	Universidade de Pernambuco (UPE), Programa de Pós Graduação em Ciência e Tecnologia Ambiental	Brazil	1
Marcelino et al. (2021)	45	6	2021	Universidade Federal de Santa Catarina, Centro de Ciências da Educação, Departamento de Metodologia	Brazil	4
Pereira et al. (2020)	2	1	2020	Instituto Federal de Educação, Ciência e Tecnologia Goiano, Campus Rio Verde, Goiás	Brazil	1
Moreno et al., (2020)	6	1	2020	Universidad Pedagógica Nacional, Colombia	Colombia	1
Neto et al. (2020)	1	1	2020	Instituto Federal de Educação, Ciência e Tecnologia Goiano, Campus Rio Verde	Brazil	1
Longas et al. (2020)	3	2	2020	Programa de Pós-Graduação em Ciências de Materiais, Campus Universitário do Araguaia	Brazil	1
Pereira et al. (2019)	2	1	2019	Instituto Federal de Educação, Ciência e Tecnologia Goiano, Campus Rio Verde, Goiás	Brazil	1
Cabrera et al., (2019)	37	10	2019	Facultad de Ciencias Químicas, Edificio 9, CU, BUAP, Col. Sn Manuel	Mexico	3
Moura et al., (2019)	0	1	2019	Departamento de Química, Universidad Federal de Rural de Pernambuco,	Brazil	0
García et al (2019)	91	14	2019	Posgrado en Ciencias en Ingeniería Mecánica, Universidad Michoacana de San Nicolás de Hidalgo, Fco.	Mexico	6
Fluck et al., (2018)	8	1	2018	Universidade Tecnológica Federal do Paraná	Brazil	3
Nava et al., (2018)	2	1	2018	Programa Institucional de Doctorado en Ciencias Agropecuarias y Forestales	Brazil	1

Authors	Total citations	Citations per year	Year of publication	Affiliation	Country	H-index
Agudelo et al., (2018)	34	8	2018	Grupo de Dinámica Cardiovascular, Universidad Pontificia Bolivariana	Colombia	13
Triana et al., (2018)	18	1	2018	Departamento de Química, Universidad del Valle	Colombia	12
Rambo et al., (2018)	619	32	2018	Universidade Federal do Tocantins	Ecuador	4
De Matos et al., (2017)	0	0	2017	Universidade Federal de Mato Grosso, Rua Fernando Corrêa da Costa	Brazil	1
Alarcon et al., (2017)	412	52	2017	Universidade Estadual Paulista, Laboratório de Análise Térmica e Polímeros, Departamento de Química	Brazil	12
Salgueiro et al., (2016)	124	5	2016	Departamento de Química, Instituto de Ciências Exatas, Universidade Federal Rural do Rio de Janeiro	Brazil	32
Borreda et al. (2016)	9	1	2016	Departamento de Didáctica de las Ciencias Experimentales y Sociales, Universitat de València, España	Brazil	1
Fernandes et al., (2016)	1	1	2016	Departamento de Química, Instituto Federal de Educação, Ciência e Tecnologia Do Ceará-IFCe	Brazil	1
Finnazi et al. (2016)	197	6	2016	Universidade Federal do Vale do São Francisco, Avenida Antonio Carlos Magalhães	Brazil	6
Quispe et al. (2016)	3	1	2016	Laboratorio de Nutrición Animal y Evaluación de Alimentos, Departamento Académico de Zootecnia	Peru	1
Ingold et al., (2016)	78	12	2016	Facultad de Química, Universidad de la República, Montevideo	Uruguay	5
Wallau et al., (2015)	681	1	2015	Centro de Ciências Químicas, Farmacêuticas e de Alimentos, Universidade Federal de Pelotas	Brazil	32

Authors	Total citations	Citations per year	Year of publication	Affiliation	Country	H-index
Colmenares et al. (2015)	6.512	148	2015	Institute of Physical Chemistry, Polish Academy of Sciences	Poland	42
Barbosa et al. (2015)	314	23	2015	SENAI-RJ -CTS- Ambiental - FIRJAN - Centro de Tecnologia Ambiental, Rua Moraes e Silva	Brazil	7
Zorzanelli et al. (2015)	360	2	2015	Universidade Federal Fluminense	Brazil	12

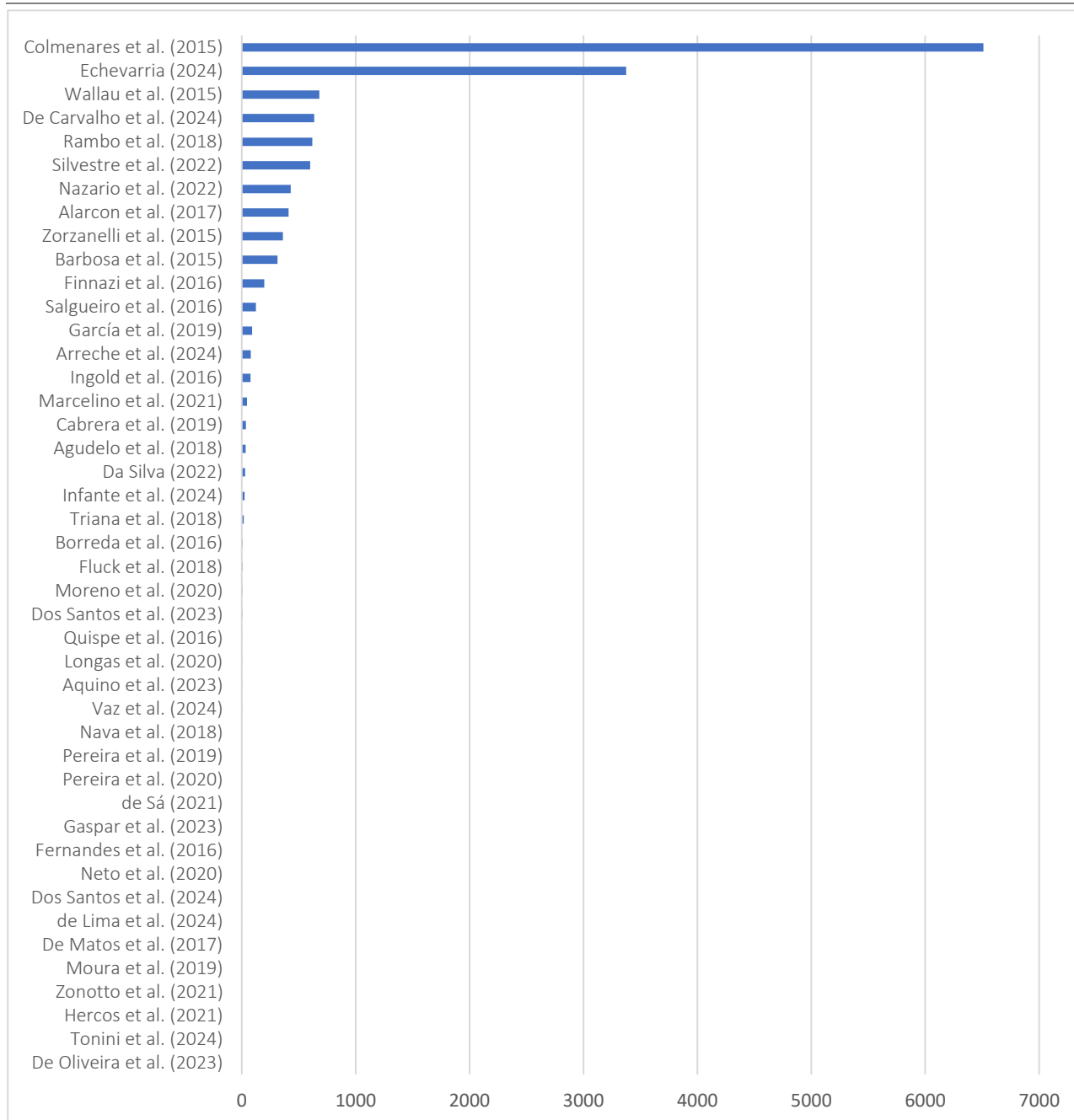


Figure 4. Distribution of Citations Among the Analyzed Authors.

The authorship analysis reveals how academic production is geographically distributed, helping to identify research networks and potential regional biases. This provides the study with a critical

perspective on who is creating knowledge and from which contexts, which is essential for understanding representation in the field. As shown in Figure 4, Colmenares et al. (2015) stand out as the most frequently cited authors, followed by others with lower representation, which further illustrates the concentration of academic references in specific contributors.

4.4. Dimension 2: Journals

Following the authorship analysis, attention now turns to the publication outlets. Dimension 2: Journals (Table 2) provides a comprehensive overview of the academic platforms that contribute to green chemistry education through laboratory practical work. This includes details on disciplinary focus, quartile rankings, Scopus indexation, impact factors, and countries of origin, thereby identifying the leading journals that shape discourse in this field.

Table 2. D2: Journals

Journal Name	Main Publication Lines	Quartile	Indexation	Impact Factor	Country
Revista Virtual de Química	Chemistry (miscellaneous)	Q-4	Scopus	24	Brazil
Russian Journal of General Chemistry	Chemistry (miscellaneous)	Q-4	Scopus	39	Brazil
Revista Colombiana de Química	Chemistry (miscellaneous)	Q-4	Scopus	10	Colombia
Química Nova	Chemistry (miscellaneous)	Q-4	Scopus	86	Brazil
Educación Química	Chemistry (miscellaneous); Social Sciences; Education	Q-3	Scopus	18	Mexico
Científica	Biochemistry, Cell Biology, Endocrinology	Q-1	Scopus	177	Brazil
Revista Mexicana de Ingeniería Química	Chemical Engineering (miscellaneous)	Q-3	Scopus	27	Mexico
Revista Interdisciplinar de Ciencia Aplicada	Multidisciplinary	Q-4	Scopus	3	Brazil
Horticultura Brasileira	Agricultural and Biological Sciences	Q-3	Scopus	30	Brazil
Brazilian Journal of Food Technology	Agricultural and Biological Sciences	Q-3	Scopus	22	Brazil
Transinformacao	Social Sciences; Communication; Library and	Q-2	Scopus	15	Brazil

Journal Name	Main Publication Lines	Quartile	Indexation	Impact Factor	Country
	Information Sciences				
Revista Cubana de Farmacia	Pharmacology, Toxicology and Pharmaceutics	Q-4	Scopus	10	Cuba
Revista Materia	Chemistry (miscellaneous)	Q-3	Scopus	27	Brazil
Revista Latinoamericana de Química	Chemistry (miscellaneous)	Q-4	Scopus	9	Mexico
Arquivo Brasileiro de Medicina Veterinaria e Zootecnia	Veterinary (miscellaneous)	Q-3	Scopus	38	Brazil
Agrociencia	Agricultural and Biological Sciences	Q-4	Scopus	29	Mexico
DYNA (Colombia)	Engineering (miscellaneous)	Q-4	Scopus	29	Colombia
Revista Facultad de Ingenieria	Engineering (miscellaneous)	Q-4	Scopus	19	Colombia
Acta Scientiarum - Biological Sciences	Agricultural and Biological Sciences	Q-4	Scopus	28	Brazil
Enseñanza de las Ciencias	Social Sciences; Education	Q-3	Scopus	23	Spain
Eclética Química	Chemistry (miscellaneous)	Q-4	Scopus	26	Brazil
International Journal of Science Education	Social Sciences; Education	Q-2	Scopus	132	United Kingdom
Periodico Tche Química	Chemistry (miscellaneous)		Scopus	31	Brazil
Vitae	Agricultural and Biological Sciences	Q-3	Scopus	19	Colombia

Table 2 presents a set of journals covering a wide range of disciplines, including chemistry (34.8%), science and social science education (13%), agricultural and biological sciences (17.4%), engineering (8.7%), pharmaceuticals (4.3%), veterinary medicine (4.3%), as well as multidisciplinary areas (4.3%) and cell biology and endocrinology (4.3%). All are indexed in Scopus, which guarantees the quality of the data. In terms of quartile classification, Q4 predominates with 56.5% of the journals,

followed by Q3 (30.4%), Q2 (8.7%), and Q1 (4.3%), reflecting that most of these publications occupy low positions in the ranking, although with some notable exceptions.

In terms of origin, most of the journals are published in Latin America, with a clear predominance of Brazil, which accounts for 52.2% of the titles, including *Química Nova*, *Revista Virtual de Química*, and *Eclética Química*, focused on chemistry, engineering, and applied sciences. Mexico and Colombia each account for 17.4%, with publications such as *Educación Química* and *Revista Mexicana de Ingeniería Química* in the case of Mexico, and *Revista Colombiana de Química*, *DYNA*, and *Vitae* in the case of Colombia. Spain, Cuba, and the United Kingdom also contribute to this landscape, each accounting for 4.3% of the journals with titles such as *Enseñanza de las Ciencias*, *Revista Cubana de Farmacia*, and *International Journal of Science Education*.

In terms of impact, the average value of all journals is 39.4, and the majority (84%) are below 40, which indicates moderate reach. The most representative journals, such as *Química Nova*, *Revista Virtual de Química*, and *Educación Química*, have impact factors ranging from 18 to 86. However, two publications stand out with a significantly higher influence: *Científica* from Brazil, with an IF of 177 (Q1), and *International Journal of Science Education* from the United Kingdom, with 132 (Q2). Overall, the results reflect that, although the region shows solid and varied scientific production, especially in chemistry and applied sciences, it still faces the challenge of climbing to higher quartiles and achieving greater international visibility.

Analyzing the journals allows us to assess how visible and scientifically legitimate the topic is. This bibliometric analysis shows that, although the formal impact is medium-low, the interest in the topic is increasing. This indicates a gap in the internationalization of the debate on Green Chemistry in education, and this study seeks to begin filling that gap.

4.5. Dimension 3: Contributions

After mapping the landscape of authorship and publication outlets, the focus now turns to the substantive content of the reviewed studies. Dimension 3: Contributions (Table 3) provides a detailed synthesis of the main topics addressed, methodologies employed, analytical techniques used, types of samples, key findings, and resulting conclusions. This dimension is crucial to understanding how green chemistry is being taught, explored, and applied through laboratory practices across diverse educational and scientific contexts. The analysis reveals not only thematic diversity—ranging from environmental sustainability to material synthesis—but also methodological richness, highlighting both theoretical and experimental contributions that inform current and future pedagogical strategies.

Table 3. D3: Contributions

Treated topic	Methodology	Analytical techniques	Samples used	Main findings	Conclusions
The relationship between green chemistry and public health	Theoretical	Literature review	No population or sample (theoretical)	Identified links between green chemistry principles and health system sustainability	Green chemistry is essential for sustainable health systems
Application of the 12 principles of green chemistry in pharma	Theoretical	Documentary-conceptual analysis	No samples (theoretical)	Early adoption improves sustainability	Green chemistry makes pharmaceutical

Treated topic	Methodology	Analytical techniques	Samples used	Main findings	Conclusions
				and safety in production	sustainability viable
Need for green chemistry in university education	Bibliographic	Curricular comparative analysis	No experimental samples	Highlighted need to reform chemistry curriculum	Improved teacher training and curricular inclusion needed
Teaching practices using chalcones	Didactic-experimental	Comparison of four chalcone syntheses	Three chalcone types	Method C is safer, more efficient, and eco-friendly	Encourages safe learning and environmental awareness
Influence of green chemistry on Latin American education	Literature review	Qualitative-documentary analysis	Documentary sources	Identified sustainability challenges in education and health	Green chemistry teaching must adapt to context
Biodegradable films from mango starch and silver nanoparticles	Experimental	Physicochemical analysis	Agro-industrial waste	Created biodegradable, sustainable materials	Use of waste enhances sustainability and efficiency
Green synthesis of graphene acid	Experimental	Material synthesis	Carbon-based samples	Low-impact, efficient graphene acid production	Green chemistry enables sustainable nanomaterials
Eco-catalyst use in organic compound synthesis	Experimental	Green synthesis	Organic reactions with eco-catalysts	High yield with low toxicity	Improves energy efficiency and reduces waste
Integration of green chemistry in school curricula	Educational	Curriculum analysis	Chemistry course plans	Detected lack of sustainability content	Urgent need to train teachers in green chemistry
Sustainability metrics in analytical methods	Experimental	NEMI, GAPI, AGREE, Eco-scale	Evaluated analytical methods	Quantified environmental impact	Encourages low-risk green practices
Circular economy in chemistry education	Theoretical	Documentary analysis	Scientific papers	Explores chemistry's role in circularity	Green chemistry promotes resource efficiency
Chitosan biopolymer from shrimp waste	Experimental	Green extraction methods	Shrimp shells	Produced biodegradable biopolymers	Reinforces agro-industrial waste valorization

Treated topic	Methodology	Analytical techniques	Samples used	Main findings	Conclusions
Use of bioindicators in sustainable chemistry education	Educational	Qualitative fieldwork	Students and environmental samples	Strengthened environmental awareness	Supports contextualized sustainability education
Environmental literacy through green chemistry	Educational	Intervention and surveys	High school students	Increased environmental responsibility	Promotes critical, ecological thinking
Curricular analysis of green chemistry in Latin America	Theoretical	Content analysis	Curricula documents	Identified fragmented implementation	Regional policies needed for integration
Role of chemistry in transitioning to a green economy	Theoretical-documentary review of applied cases	Qualitative analysis of business and academic initiatives	Examples of companies and academic projects in Latin America	Identified viable paths and structural barriers for the transition	Chemistry is key to a green economy through sustainable innovation
Mapping Brazilian publications on green chemistry teaching	Bibliometric study with social network analysis	Article review, co-authorship networks, keyword mapping	Brazilian articles on green chemistry teaching	Found consistent growth and strong author collaboration	Green chemistry education is expanding and structurally supported in Brazil
Sunflower seed oil extraction using green solvents	Experimental practice with enzymatic extraction	Yield evaluation, GC-MS analysis	Sunflower seeds with enzymatic and solvent combinations	87% oleic and linoleic acids, high antioxidant capacity	Enzymatic process and sustainable solvents yield biofunctional oils
Phytochemical analysis of green tea for cosmetics	Experimental study with extract isolation	HPLC and antioxidant testing	Commercial samples of <i>Camellia sinensis</i> leaves	Identified compounds like caffeine, catechins, and flavonoids	Green tea extract is stable and suitable for sustainable cosmetics
Biodegradable films from mango starch and silver nanoparticles	Applied experimental research with synthesis	UV-Vis and FTIR spectroscopy	Mango seed starch and silver nanoparticles	Silver nanoparticles improved durability and structure	Produced stable, antimicrobial biodegradable films
Integrating green chemistry in chemistry	Educational proposal, qualitative approach	Curricular analysis and didactic intervention	Undergraduate chemistry students	Improved environmental awareness	Green chemistry improves

Treated topic	Methodology	Analytical techniques	Samples used	Main findings	Conclusions
teacher education				and curricular flexibility	teacher training quality
Green chemistry and responsible citizenship	Documentary research with critical review	Literature analysis and synthesis	Theoretical sources on civic education and chemistry	Green chemistry fosters critical, responsible citizenship	Supports development of sustainable competencies
Environmental education with green chemistry in rural areas	Educational intervention in rural schools	Observation and student survey	High school students in rural areas	Strengthened ecological awareness through context-based practices	Local projects enhance sustainability in science education
Pedagogical innovation using green chemistry games	Action research with didactic tools	Gamification and evaluation of student participation	High school students	Increased motivation and content retention	Educational games help implement green chemistry
Development of low-cost green chemistry labs	Experimental and pedagogical research	Hands-on activities and cost-benefit analysis	Students and basic materials	Designed affordable experiments aligned with green principles	Enables access to sustainable chemistry education
Miniaturized experiments for green chemistry teaching	Experimental and didactic methodology	Small-scale synthesis and qualitative analysis	Mini-labs with limited reactants	Reduced waste and increased student autonomy	Supports safe, efficient green experimentation
Artisanal labs in under-resourced schools	Ethnographic and participatory research	Field journals and focus groups	Teachers and students in rural schools	Promoted contextualized science learning	Low-cost labs align with green chemistry goals
Critical reflection on university curricula and sustainability	Theoretical study with curriculum review	Document analysis	University syllabi	Identified gaps in sustainable chemistry training	Curricula need alignment with environmental goals
Awareness projects on water contamination	Environmental education project	Field analysis and didactic design	School science projects	Strengthened awareness of chemical impact on water	Chemistry helps address real-world environmental issues

Treated topic	Methodology	Analytical techniques	Samples used	Main findings	Conclusions
Circular economy and chemistry in schools	Educational strategy design	Integration of green chemistry and circular models	High school science lessons	Improved understanding of waste reuse and value	Chemistry connects with sustainable economic thinking
Eco-laboratories for teaching green chemistry	Practice-based pedagogical research	Development and testing of eco-lab kits	Students and recycled materials	Facilitated learning with low-cost sustainable tools	Reinforces hands-on education and eco-innovation
Implementation of green indicators in lab practices	Experimental and evaluative study	Metrics: Eco-scale, GAPI, AGREE	Lab protocols in chemistry education	Measured sustainability of experimental procedures	Indicators guide improvement of green teaching labs
Green chemistry for addressing real social issues	Educational project with applied focus	Case studies on pollution and waste	Community-linked experiments	Chemistry education applied to local challenges	Encourages citizenship and environmental responsibility
Practical laboratory work in initial teacher education	Educational intervention	Classroom observation and participant reflections	Science teacher trainees	Improved experimental planning and scientific literacy	Lab work fosters autonomy and teaching innovation
Green chemistry in educational games	Educational design and testing	Game-based learning assessment	Secondary students	Increased engagement and understanding of sustainability	Games are effective tools for green chemistry education
Artisanal eco-labs in rural education	Participatory action research	Community-based experimentation	Teachers and students in rural schools	Facilitated contextual science learning with local resources	Artisanal labs promote inclusion and sustainability
Gender focus in sustainable science education	Qualitative approach with gender lens	Narrative analysis of interviews	Female chemistry students	Revealed gaps in gender-sensitive environmental education	Gender perspective is essential for inclusive green science
Environmental training using	Educational workshop series	Pre- and post-intervention questionnaires	University students	Improved attitudes toward	Training boosts environmental responsibility

Treated topic	Methodology	Analytical techniques	Samples used	Main findings	Conclusions
green chemistry				sustainability and lab safety	
Relevance of green chemistry in daily life	Fieldwork and educational project	Inquiry-based learning	Students and household items	Linked chemical concepts with everyday sustainability issues	Real-life connections improve comprehension
Responsible use of reagents in school labs	Experimental-educational study	Measurement of chemical waste	Chemistry class practices	Demonstrated high levels of unnecessary waste	Need for eco-efficient practices in school labs
Biodegradable packaging from agro-waste	Experimental material development	Mechanical and structural tests	Agricultural byproducts	Produced durable biodegradable packaging	Agro-waste reuse aligns with circular economy goals
Green chemistry in teacher identity formation	Longitudinal qualitative study	Reflective diaries and interviews	Science teaching students	Green chemistry influenced their professional values	Encourages environmental ethics in future teachers
Implementation of eco-scaling in analytical chemistry	Experimental comparative analysis	NEMI and Eco-scale metrics	Analytical lab procedures	Identified improvement areas for greener methods	Eco-metrics are essential for sustainable teaching
Environmental ethics in chemistry education	Theoretical and documentary analysis	Cross-reference of ethical models	Ethics curricula in chemistry	Detected limited integration of environmental ethics	Ethics must be integrated into green chemistry training
Teaching sustainable synthesis using green solvents	Experimental learning activity	Solvent efficiency and safety analysis	High school chemistry labs	Green solvents maintained yield and reduced risk	Solvent choice is crucial in sustainable lab design
Use of artisanal tools for green synthesis	Field experimentation and classroom adaptation	Effectiveness and safety comparison	Homemade lab kits	Proved feasible and low-cost for green labs	Artisanal tools democratize access to green practices

Treated topic	Methodology	Analytical techniques	Samples used	Main findings	Conclusions
Local case study: green chemistry in Durango, Mexico	Case study methodology	Regional educational analysis	High schools in Durango	Identified contextual challenges and successes	Local adaptation is key for sustainable education

Table 3 provides a comprehensive overview of various studies that demonstrate the progression and use of green chemistry across multiple fields. The data presented suggests a variety of topics covering areas such as education, public health, agribusiness, materials creation, waste management, and energy. This suggests that Green Chemistry has evolved beyond an exclusively technical perspective, becoming a broader area focused on the transformation of scientific, social, and educational processes.

The findings also illustrate the empirical applicability of Green Chemistry, especially in the creation of sustainable materials, the design of analytically responsible methodologies, the synthesis of compounds that generate less environmental impact, and the production of biopolymers. Significant examples include the development of biodegradable films made from mango seed starch and silver nanoparticles, as well as the production of graphene acid through environmentally friendly methods. These studies demonstrate the possibility of achieving high levels of efficiency, minimal environmental impact, and high performance, all in line with the essential principles of Green Chemistry.

In the field of education, research indicates a growing interest in integrating sustainability into curricula, particularly at the secondary and university levels. Studies show that the inclusion of Green Chemistry in educational programs promotes critical thinking and understanding of the environment. However, the results also highlight certain limitations, as its application is often restricted to elective subjects. This highlights a significant opportunity to strengthen teacher training and reformulate curricula from a more ecological perspective.

Although several of the studies were strictly theoretical, many of the practical methodologies stood out for their use of sustainable analytical tools, such as green chromatography, small-scale experimental procedures, ethanol as an ecological solvent, and the application of evaluation metrics such as NEMI, GAPI, AGREE, and Eco-Scale, which allow for the assessment of the sustainability of methodologies. These advances represent a notable step toward sustainability in the chemical sciences and support the creation of standards that align with the United Nations Sustainable Development Goals.

These studies also generate opportunities for specialized training of teachers in green chemistry and the use of agro-industrial waste in rural regions. Interdisciplinarity is also seen as a positive aspect of the field, promoting exchange between different disciplines such as biology, engineering, education, and sociology for the management of complex problems such as climate change, water scarcity, and hazardous waste pollution.

The contributions we have identified highlight the importance of Green Chemistry as a cornerstone in education. By organizing theoretical, experimental, and pedagogical approaches, the choice of bibliometric analysis is supported as a method to map the current state of the art and suggest new directions for research.

5. Discussion

The results of this bibliometric research show that there has been an increase in scientific output related to green chemistry in the field of practical laboratory work over the last decade, although this expansion is not uniform across different regions and countries. This particular concentration in certain contexts coincides with the observations made by Ferk Savec and Mlinarec (2021), who pointed out that research on green chemistry education is dominated by certain academic communities and lacks global cohesion. The fragmented nature of the literature limits the creation of common curricula and complicates the transfer of successful experiences to environments with less access to resources.

A second important point is the weak connection between the identified works and educational competencies related to sustainable development, such as environmental responsibility, ethics in science, and critical citizenship. Although the literature on education for sustainability highlights the importance of these competencies (Burmeister, Rauch, Eilks, 2012; Hofstein, Eilks, Bybee, 2011), the findings indicate that only a fraction of the studies analyzed explicitly incorporate these dimensions into practical teaching. This discrepancy confirms that the narrative on sustainability in chemistry still translates only to a limited extent into concrete educational proposals.

Regarding academic collaboration, the data indicate that the co-authorship network in this field is nascent and predominantly localized. This pattern is consistent with other bibliometric studies in education sciences and chemistry (Merigó, Yang, 2017), which show that research tends to be organized in small groups with limited international interaction. This fragmentation reduces the capacity to form global epistemic communities around green chemistry education, which represents an obstacle to the consolidated development of the discipline.

Another significant finding is the limited variety of sources and databases used in the research. Most articles are concentrated in specific journals and indexed databases, such as Scopus, with limited representation in Web of Science, ERIC, or Google Scholar. This bias is consistent with the warnings made by Donthu, Kumar, Mukherjee, Pandey, and Lim (2021), who indicate that a restricted range of search criteria reduces the representativeness of bibliometric studies. Consequently, future research should diversify information collection strategies to cover different databases and cross-cutting topics (chemistry, education, environmental engineering).

With regard to the methodologies used in laboratories, the analysis indicates that conventional practices continue to exist that perpetuate unsustainable models that are poorly adapted to the context. Kirchhoff (2005), together with Eilks and Zuin (2018), has highlighted that these practices fuel dependence on toxic substances and create unnecessary waste, which contradicts the principles of green chemistry. Furthermore, evidence from resource-poor contexts suggests that the improvised use of materials in the laboratory jeopardizes both safety and the educational value of teaching (Ndirangu, Kathuri, Mungai, 2003). This underscores the urgency of promoting initiatives that integrate pedagogical innovation, safety, and accessibility.

Finally, the findings of this research indicate that the suggestions in the literature tend to be broad, highlighting the need to include green chemistry in educational programs or improve teacher training. However, it is essential to have more concrete and practical guidelines, such as the development of manuals for sustainable experimentation, the adaptation of active methodologies in contexts with limited resources, and the establishment of international networks for curriculum exchange. These concrete suggestions could connect green chemistry research with the objectives of the 2030 Agenda and respond to the demands for a more equitable and transformative science education (United Nations, 2015).

6. Conclusion

Through the bibliometric analysis of Green Chemistry in relation to laboratory-based practical work, this study identified both significant contributions and notable gaps in the scientific literature, particularly regarding the application of Green Chemistry through laboratory practicals (TPLs). By reviewing 33 scientific articles indexed in the Scopus database, a clear increase in academic interest toward sustainable practices in Green Chemistry education was observed. Notably, Brazil emerged as the leading contributor among the publications analyzed, reflecting substantial research experience in this field.

Additionally, three distinct phases of historical evolution were identified (2015–2018, 2019–2021, and 2022–2024), showing a progressive shift from predominantly theoretical and experimental studies toward more innovative proposals. These stages illustrate a transition from traditional chemistry to a model more attuned to environmental and societal responsibilities, guided by the twelve principles of Green Chemistry as defined by Anastas and Warner (2018). Furthermore, the conceptual categories identified using VOSviewer—namely environmental education, sustainability, social responsibility, and laboratory work—highlight Green Chemistry as a core axis that connects science, education, and citizenship.

The findings emphasize the pedagogical value of laboratory-based practical work as a key tool for cultivating sustainable thinking. However, the persistence of conventional, mechanistic practices—often neglectful of waste management—points to the need for reform. In conclusion, this bibliometric review confirms the positive impact of Green Chemistry on science education and advocates for the continued strengthening of teacher training and sustainable research, both essential for advancing ecological and transformative education.

7. Suggestion

In light of the findings presented, several suggestions emerge for advancing the integration of Green Chemistry in education and research. One key recommendation is the incorporation of Green Chemistry into compulsory science curricula at all educational levels. Moving beyond elective subjects, this integration should aim to develop environmental awareness, critical thinking, and ethical responsibility from early academic stages. Additionally, it is necessary to strengthen teacher training programs by providing both theoretical and methodological tools for implementing sustainable laboratory practices, particularly those aligned with the twelve principles of Green Chemistry.

Another suggestion is to reform conventional laboratory protocols that often neglect environmental considerations. The adoption of green solvents, the design of low-waste experiments, and the use of sustainability metrics—such as NEMI, GAPI, or AGREE—can significantly reduce ecological impact while maintaining the integrity of chemical education. Moreover, fostering interdisciplinary research between chemistry, environmental sciences, engineering, and education could enhance responses to complex global challenges such as pollution, climate change, and circular economy transitions. These collaborations may also reinforce the relevance of Green Chemistry in both academic and applied contexts.

Finally, there is a need for broader institutional and policy support to scale up sustainable innovation in science education. Initiatives such as open-access repositories of green laboratory protocols, funding programs for eco-pedagogical research, and international academic networks can expand the reach of Green Chemistry, especially in regions like Latin America, which have shown remarkable progress in this field. By aligning educational practices with sustainability goals, the scientific community can contribute to a more responsible, equitable, and transformative future.

Declarations

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References

- Anastas, P., & Eghbali, N. (2010). Green chemistry: Principles and practice. *Chemical Society Reviews*, 39(1), 301–312. <https://doi.org/10.1039/B918763B>
- Anastas, P., & Warner, J. (1998). *Green chemistry: Theory and practice*. Oxford University Press. <https://search.worldcat.org/es/title/oclc/39523207>
- Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959–975. <https://doi.org/10.1016/j.joi.2017.08.007>
- Arreche, R. A., & Vázquez, P. G. (2024). Sustainable education and human health in society: Reflections on the influence of green chemistry post-pandemic. *Química Nova*, 47(10), e20240060. <https://doi.org/10.21577/0100-4042.20240060>
- Bennett, J., Lubben, F., & Hogarth, S. (2007). Bridging the gap between formal and informal science education: The role of chemistry education. *Chemistry Education Research and Practice*, 8(2), 155–166. <https://doi.org/10.1039/B6RP90026B>
- Borja-Sánchez, J. A., García-García, J. L., & Velázquez-Cigarroa, E. (2024). El rol de la educación ambiental frente a los desafíos de la enseñanza tradicional. *Revista Eduscientia. Divulgación de la Ciencia Educativa*, 7(14), 176–184. <https://www.eduscientia.com/index.php/journal/article/view/497>
- Cabrera, A., & González, M. (2020). Educación ambiental y química verde: Un enfoque desde América Latina. *Revista Iberoamericana de Educación Ambiental*, 12(1), 25–40. <https://rieoei.org/RIE/>
- Cárdenas, A. D., Perdomo, I., Pérez, R., & Franco, R. A. (2023). Los TPL con enfoque en química verde como estrategias de enseñanza en reacciones químicas inorgánicas a microescala. *Revista Latinoamericana de Educación Científica, Crítica y Emancipadora (LadECiN)*, 2(1), 175–190. <https://doi.org/10.5281/zenodo.8128216>
- Carlos, M. F. L. P., & Echevarria, A. (2024). Chalcones in teaching experimental organic chemistry in the context of green chemistry. *Química Nova*, 47(5), e20240007. <https://doi.org/10.21577/0100-4042.20240007>
- Carvalho, A. S., Ferreira, P. G., Hüther, C. M., Santos, W. C., da Silva Magalhães Forezi, L., de Carvalho da Silva, F., & Ferreira, V. F. (2024). Aqui está a química XI: Rede de química verde e saúde. *Revista Virtual de Química*, 16(5), 669–680. <https://doi.org/10.21577/1984-6835.20240030>

- de Lima, A. L., Gonçalves, A. D., Fernandes, D. R., dos Santos, T. C., & Mota, C. J. A. (2024). Química e circularidade. *Revista Virtual de Química*, 16(1), 138–156. <https://doi.org/10.21577/1984-6835.20230051>
- de Oliveira, L. P., Resende, O., de Almeida, B., de Paula, I. S. M., & Cabral, J. C. O. (2023). Composição físico-química da soja em função da altura da planta. *Científica*, 51, e1455. <https://doi.org/10.5016/1984-5529.2023.v51.1455>
- Denona Bogović, N., & Grdic, Z. S. (2020). Transition to a green economy: Possible effects on the Croatian economy. *Sustainability*, 12(22), 9342. <https://doi.org/10.3390/su12229342>
- dos Santos, L. P., de Magalhães, B. E. A., dos Santos, W. N. L., Oliveira, L. B., de Pereira, M. G., & de Santana, D. A. (2024). Métricas de química analítica verde en la evaluación de un método ecológico para la determinación de plaguicidas por HPLC-DAD. *Química Nova*, 47(9), e20240054. <https://doi.org/10.21577/0100-4042.20240054>
- Doyaga, I. J., Vargas-Badilla, L., Moya, C. N., Montero-Miranda, E., Maeyoshimoto, J. E., Capuya, F. G., & Arguedas-Matarrita, C. (2021). Conocimientos del profesorado universitario sobre la enseñanza de la química con laboratorios remotos. *Educación Química*, 32(4), 154–167. <https://doi.org/10.22201/fq.18708404e.2021.5.79189>
- Eilks, I., & Zuin, V. G. (2018). Green and sustainable chemistry education (GSCE): Lessons to be learnt for a safer, healthier and fairer world today and tomorrow. *Current Opinion in Green and Sustainable Chemistry*, 13, 52–57. <https://doi.org/10.1016/j.cogsc.2018.08.007>
- Espinosa-Ríos, E. A., González-López, K. D., & Hernández-Ramírez, L. T. (2016). Las prácticas de laboratorio: Una estrategia didáctica en la construcción de conocimiento científico escolar. (2016). *Entramado*, 12(1), 266–281. <https://dialnet.unirioja.es/servlet/articulo?codigo=5755305>
- Faicán-Juca, F., & Manzano-Vela, R. (2024). Investigación abierta en la práctica de laboratorio y el aprendizaje de la química en los estudiantes de bachillerato. *Revista Cátedra*, 7(1), 97–111. <https://doi.org/10.29166/catedra.v7i1.4474>
- Franco Moreno, R. A., Reina Hernández, J. A., & Riveros Toro, C. M. (2020). Concepciones sobre química verde en profesores de química en formación inicial: Green chemistry concepts in chemistry teachers in initial training. *Noria. Investigación Educativa*, 1(5), 94–108. <https://doi.org/10.14483/25905791.16507>
- Franco Moreno, R. A., & Ordoñez Carlosama, L. Y. (2020). El enfoque de química verde en la investigación en didáctica de las ciencias experimentales: Su abordaje en revistas iberoamericanas, 2002–2018. *Educación Química*, 31(1), 84–104. <https://doi.org/10.22201/fq.18708404e.2020.1.70414>
- Freese, T., Elzinga, N., Heinemann, M. M., Lerch, M. M., & Feringa, B. L. (2024). The relevance of sustainable laboratory practices. *RSC Sustainability*, 2(5), 1300–1336. <https://doi.org/10.1039/D4SU00056K>
- Gaspar, C. S., Bouzon, J. D., Brandão, J. B., & Chrispino, A. (2023). Green chemistry teaching in Brazil: Mapping publications based on social network analysis. *Educación Química*, 34(4), 156–172. <https://doi.org/10.22201/fq.18708404e.2023.4.84696>
- García, M. I. G., & Fernández-Jimeno, N. (2022). Introducción: La filosofía de la tecnología y sus identidades múltiples. Una mirada desde España. *Azafea: Revista de Filosofía*, 24, 7–19. <https://doi.org/10.14201/azafea.202224719>

- Guarnizo Losada, M. A., & Puentes Luna, O. L. (2024). Laboratorios artesanales para favorecer la enseñanza de la química orgánica en estudiantes de grado once. En *Química: Experiencias y estrategias educativas en el aula* (pp. 99–114). Corporación Universitaria Minuto de Dios – UNIMINUTO.
https://repository.uniminuto.edu/bitstream/10656/19219/3/Libro_Quimica%20experiencias%20y%20estrategias%20educativas%20en%20el%20aula_2024.pdf
- Infante Rivera, L. J., Vilca Arana, M., Mendivel Gerónimo, R. K., Hurtado Tiza, D. R., & Huamán Gómez, E. (2024). Integración de la química verde en el currículo educativo: Un enfoque sostenible. *Revista Colombiana de Química*, 53(1), 3–12.
<https://doi.org/10.15446/rev.colomb.quim.v53n1.114986>
- Jovero, M. B., & Picardal, J. P. (n.d.). Green chemistry education in the emerging economies in Asia. *Educational Process: International Journal*. <https://doi.org/10.15294/JPII.V11i4.39112>
- Madroñero-Palacios, S., & Guzmán-Hernández, T. (2018). Desarrollo sostenible: Aplicabilidad y sus tendencias. *Tecnología en Marcha*, 31(3), 122–130. <https://doi.org/10.18845/tm.v31i3.3907>
- Marín, M. (2021). El trabajo práctico de laboratorio en la enseñanza de las ciencias naturales: Una experiencia con docentes en formación inicial. *Tecné, Episteme y Didaxis: TED*, (49), 163–182. <https://doi.org/10.17227/ted.num49-8221>
- Martínez, O. (2024). La investigación educativa: Un faro que ilumina el camino hacia la transformación. *Revista Científica*, 9(Ed. Esp.), 10–18.
<https://doi.org/10.29394/Scientific.issn.2542-2987.2024.9.E.O.10-18>
- Mascarell, L., & Vilches, A. (2016). Química verde y sostenibilidad en la educación en ciencias en secundaria. *Enseñanza de las Ciencias: Revista de Investigación y Experiencias Didácticas*, 34(2), 25–42. <https://www.raco.cat/index.php/ensenanza/article/view/309278>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., ... Moher, D. (2021). Declaración PRISMA 2020: Una guía actualizada para la publicación de revisiones sistemáticas. *Revista Española de Cardiología*, 74(9), 790–799.
<https://doi.org/10.1016/j.recesp.2021.06.016>
- Mosquera, J. A., & Naveros Solano, O. (2023). Uso de laboratorios artesanales para aprender física y química en básica secundaria. *Revista Electrónica EDUCyT*, 58(Extra), 555–566.
<https://die.udistrital.edu.co/revistas/index.php/educyt/article/download/334/307/631>
- Murcia Fandiño, J. S., & Esquiaqui Marín, L. A. (2021). Química verde aplicada en los residuos de universidades. *Educación Química*, 32(2), e76534.
<https://doi.org/10.22201/fq.18708404e.2021.2.76534>
- Neira, J. (2021). La experimentación en ciencias naturales como estrategia de alfabetización científica. *Revista UCMaule*, 60, 102–116. <https://doi.org/10.29035/ucmaule.60.102>
- Oliveira, H., & Bonito, J. (2023). Practical work in science education: A systematic literature review. *Frontiers in Education*, 8, 1151641. <https://doi.org/10.3389/feduc.2023.1151641>
- Perdomo Andrade, I., Cárdenas Chica, A. D., Cuellar Sánchez, M. C., Amórtegui Cedeño, E. F., & Mosquera, J. A. (2021). Prácticas de laboratorio de tipo artesanal: Una investigación en el contexto rural al norte del Huila. *Bio-grafía: Escritos sobre la Biología y su Enseñanza*, 14(27), 63–80. <https://doi.org/10.17227/bio-grafia.vol14.num27-11379>
- Pino, A. (2020). *Química verde: Enfoque sistémico*. Ediciones UNL.
https://bibliotecavirtual.unl.edu.ar:8443/bitstream/handle/11185/5630/PINO-qu%C3%ADmica%20verde_DIGITAL.pdf?sequence=1&isAllowed=y

- Ramirez, F., Afán, I., Davis, L., & Chiaradia, A. (2017). Climate impacts on global hotspots of marine biodiversity. *Science Advances*, 3(2), e1601198. <https://doi.org/10.1126/sciadv.1601198>
- Ribeiro, A. L., da Silva, M. F., Santos, P. J., & Oliveira, R. T. (2024). Avances en materiales sostenibles: Aplicaciones de la química verde en la síntesis de polímeros. *Polímeros: Ciência e Tecnologia*, 34(2), 102–118. <https://doi.org/10.1590/0104-1428.20240020>
- Rivera Flórez, L., Molina Pérez, F., & Ramos Contreras, C. (n.d.). La química verde como herramienta para la gestión ambiental en laboratorios de ensayo: Aplicación en la determinación de mercurio en aguas por espectrofotometría de absorción atómica de vapor frío. *Revista EIA*, 20(39), e3916, 1–24. <https://dialnet.unirioja.es/descarga/articulo/8721233.pdf>
- Rivera, L. (2022). *La química verde como herramienta para la gestión ambiental en los procesos de análisis de matrices ambientales* [Tesis de maestría, Universidad de Antioquia]. <https://hdl.handle.net/10495/32034>
- Rodríguez-Cepeda, R., Casas-Mateus, J., & Martínez-Cárdenas, D. (2020). Laboratorio de química bajo contexto: Insumo para el desarrollo de habilidades de pensamiento crítico. *Tecné, Episteme y Didaxis: TED*, (47), 33–52. <https://doi.org/10.17227/ted.num47-11334>
- Sanabria Navarro, J. R., Niebles Núñez, W. A., & Silveira Pérez, Y. (2024). Análisis bibliométrico de la inteligencia artificial en el deporte. *Retos*, 54, 312–319. <https://doi.org/10.47197/retos.v54.103531>
- Sandhu, S., Orlitzky, M., & Louche, C. (2018). How national governance conditions influence the economic benefits of corporate environmental performance. *Management Decision*, 57(10), 2714–2739. <https://doi.org/10.1108/MD-11-2017-1191>
- Souza, F. A., Coelho, M. N., & Nunes, A. O. (2020). El enfoque de Ciencia, Tecnología y Sociedad (CTS): Una posibilidad de motivación estudiantil. *Investigación, Sociedad y Desarrollo*, 9(9), e492997431. <https://doi.org/10.33448/rsd-v9i9.7431>
- Tarkhanova, E., Chizhevskaya, E. L., Fricler, A. V., Baburina, N., & Firtseva, S. V. (2020). Economía verde en Rusia: Análisis de las inversiones, indicadores de crecimiento y perspectivas de desarrollo. *Entrepreneurship and Sustainability Issues*, 8(2), 649–661. <https://ideas.repec.org/a/ssi/jouesi/v8y2020i2p649-661.html>
- Tonini, M. D. L., Lopes, R. D. O., & Barbosa, M. L. C. (2024). Aplicación de la química verde en la fabricación de principios activos farmacéuticos. *Revista Virtual de Química*, 16(4), 635–646. <https://doi.org/10.21577/1984-6835.20240020>
- Trabajo experimental planteado como investigación con docentes de Ciencias Naturales. (n.d.). *Ciencia, Docencia y Tecnología*, 31(60), 266–285. <https://doi.org/10.33255/3160/626>
- Vaz, C. R. S., Junior, G. G., & Pastre, J. C. (2024). The adoption of green chemistry in Brazilian higher education. *Química Nova*, 47(3), e20230117. <https://doi.org/10.21577/0100-4042.20230117>
- Zazykina, L. A., & Bukova, A. A. (2021). La economía verde como factor de desarrollo sostenible: Experiencia europea. *IOP Conference Series: Earth and Environmental Science*, 650(1), 012018. <https://doi.org/10.1088/1755-1315/650/1/012018>
- Zuin, V. G., Eilks, I., Elschami, M., & Kümmerer, K. (2021). Educación en química verde y química sostenible: Perspectivas hacia la sostenibilidad. *Química Verde*, 23, 1594–1608. <https://doi.org/10.1039/d0gc03313h>

About the Contributor(s)

Marcela Núñez Genes, Bachelor's degree in biology and chemistry, Master's student in science education at Universidad de Córdoba, focused on teaching strategies for natural sciences.

Email: mgenesnunez@correo.unicordoba.edu.co

ORCID: <https://orcid.org/0009-0001-6538-977X>

Elvira Patricia Flórez Nisperuza, Bachelor's degree in biology and chemistry, specialist in pedagogy and didactics, Master's degree in education and human development, PhD in educational sciences.

Email: epatriciaflores@correo.unicordoba.edu.co

ORCID: <https://orcid.org/0000-0003-4621-8382>

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Appendix I.

As Applicable

Appendix II.

As Applicable