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A SYSTEMATIC REVIEW OF STUDIES EXAMINING CHEMISTRY TEACHERS' KNOWLEDGE OF GREEN CHEMISTRY: GLOBAL EVIDENCE (2020–2025)

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ABSTRACT

This systematic review synthesised global empirical research published between 2020 and 2025 on chemistry teachers' knowledge of green chemistry. Comprehensive searches were conducted in ERIC, Google Scholar, ResearchGate and ScienceDirect using predefined keywords related to chemistry teachers' knowledge of green chemistry. Eligible studies were those that empirically assessed green chemistry knowledge among pre-service or in-service chemistry teachers. A multi-stage screening process encompassing title and abstract screening, full-text evaluation, and methodological appraisal, guiding the selection of studies. Extracted data covered study characteristics, sampling approaches, instruments, knowledge indicators, and key outcomes. A total of seven empirical studies met the eligibility criteria, representing regions across West Africa, Asia and the Middle East. The findings revealed considerable variation in teachers' knowledge levels across countries and teacher groups. Overall, pre-service chemistry teachers consistently demonstrated low levels of green chemistry knowledge, whereas in-service teachers frequently exhibited moderate to high knowledge, particularly those with many years of teaching experience. Several studies also highlighted a content–pedagogy imbalance, whereby teachers expressed confidence in teaching green chemistry despite demonstrating limited conceptual mastery. Contextual factors such as access to laboratory resources, exposure to professional development, and curricular integration further shaped knowledge outcomes across settings. The study highlights the urgent need to systematically embed green chemistry principles into pre-service teacher education, enhance continuous professional development for in-service teachers, and ensure the availability of sufficient laboratory resources.

Keywords: Green chemistry, knowledge, chemistry teacher, chemistry education, sustainability.

INTRODUCTION

Over the past two decades, the international scientific community has increasingly recognised the profound environmental and societal consequences associated with conventional chemical processes (Molnár & Babai, 2021). Concerns related to global warming, hazardous waste accumulation, atmospheric pollution, unsustainable resource extraction, and chemical toxicity have intensified calls for a fundamental reorientation of how chemistry is practised, taught, and applied (Fatima, 2024; Thimmappa, 2023). In response, green chemistry, also referred to as sustainable chemistry, has emerged as a pivotal framework for guiding environmentally responsible chemical practice (Sharma et al., 2024). Rooted in the twelve principles proposed by Anastas and Warner (2000), green chemistry emphasises designing chemical products and processes that minimise environmental harm, reduce hazardous substance use, conserve energy, and promote human and ecological well-being. These principles position green chemistry not merely as an alternative approach but as an essential paradigm for addressing contemporary sustainability challenges in science and industry (Kurul et al., 2025).

Because chemistry underpins nearly all industrial sectors, including pharmaceuticals, agriculture, plastics, energy, and manufacturing, the integration of green chemistry into education has become critical (Akinsipo & Anselm, 2025). Global education policies, including the United Nations Sustainable Development Goals and UNESCO's Education for Sustainable Development framework, underscore the need for learners to develop competencies aligned with sustainable scientific practice (Izuchukwu & Zino, 2025). Schools and teacher-training institutions, therefore, have a responsibility to prepare scientifically literate citizens capable of making informed decisions about environmental sustainability and contributing to emerging green industries (Akinsemolu & Onyeaka, 2025). Despite these policy directives, the effective implementation of green chemistry in classrooms ultimately depends on one crucial group: chemistry teachers (Cannon et al., 2023). Teachers act as mediators of curriculum content, facilitators of practical laboratory experiences, and gatekeepers of scientific knowledge; their knowledge of green chemistry determines whether students engage meaningfully with sustainability concepts or encounter them only as abstract rhetoric (Koulougliotis et al., 2024; Morales-Doyle, 2024).

Research consistently demonstrates that teachers' knowledge of subject matter forms the foundation for effective science teaching and the development of related competencies in learners. Said et al. (2003), for example, emphasised that strong teacher understanding of environmental topics enhances instructional delivery and ultimately shapes students' values and attitudes toward sustainability. Similarly, teachers' disciplinary and pedagogical knowledge influences how learners conceptualise complex scientific issues, including environmental protection and resource stewardship (Listyarini et al., 2019). Within the context of sustainable science education, this positions teachers as central actors whose content knowledge significantly shapes the quality of learning experiences offered to students (Koskela, 2021).

In green chemistry education specifically, teachers' knowledge of the principles, applications, and instructional approaches is a decisive factor in determining whether students meaningfully engage with sustainability-oriented chemical practices. Oloyede and Hauwa (2022) argued that teachers who possess strong knowledge of green chemistry, such as safer chemical synthesis, waste minimisation, atom economy, and energy efficiency, are better equipped to translate these principles into classroom instruction. Their ability to integrate green chemistry examples, laboratory activities, and problem-solving tasks directly influences students' understanding of environmentally responsible chemical behaviour. In countries facing growing environmental challenges, teachers with robust knowledge of green chemistry can play a transformative role by embedding sustainability into routine science instruction and supporting the development of a more environmentally responsible citizenry.

Despite growing global recognition of the importance of green chemistry education, empirical studies examining teachers' knowledge remain fragmented across countries, methodologies, and educational levels. Research has emerged from diverse educational contexts around the world, yet these studies have not been systematically synthesised to provide a coherent understanding of what is known about chemistry teachers' knowledge of green chemistry over time. The absence of a comprehensive systematic review leaves an important gap in the literature, limiting the ability of policymakers, teacher educators, and curriculum developers to identify global trends or disparities across countries. This underscored the need for a rigorous review to consolidate evidence generated over the past five years (2020–2025) and to inform future directions in green chemistry teacher education.

Objective of the Study

The objective of the study was to examine chemistry teachers' knowledge of green chemistry, drawing on evidence reported in research conducted over the past five years (2020–2025).

Research Question
What is the level of green chemistry knowledge among chemistry teachers, as reported in studies conducted between 2020 and 2025?

METHODOLOGY

In keeping with best practices for systematic reviews, the methodology for this study was organized into several sequential phases: (a) development of eligibility criteria, (b) comprehensive literature searching across multiple scholarly databases, (c) systematic screening of identified records, (d) rigorous data extraction, (e) critical appraisal of methodological quality, and (f) narrative synthesis of findings. Moreover, each of these phases was intentionally interconnected. For instance, the eligibility criteria guided the search strategy, and the search strategy, in turn, shaped the screening and extraction processes. By maintaining such interdependence, the review ensured that every step was logically aligned with the overarching research objective.

Eligibility Criteria

To determine which studies would be suitable for inclusion, clearly defined inclusion and exclusion criteria were established before the search began.

Inclusion Criteria

A study was included if it met all of the following conditions:

Population:
It investigated pre-service or in-service chemistry teachers. Studies involving general science teachers were also eligible if the chemistry teacher subgroup was explicitly analysed.

Phenomenon of Interest
It explicitly examined chemistry teachers' knowledge of green chemistry or the twelve principles of green chemistry.

Study Type
It presented empirical data, either quantitative (surveys), qualitative (interviews), or mixed-methods. Both published articles and graduate theses were eligible.

Time Frame
It was published between 2020 and 2025, reflecting the modern period in which green chemistry has gained global prominence.

Language:
It was accessible in English, either in full text or with a sufficiently detailed English abstract.

Setting:
It was situated in formal educational contexts (primary, secondary, or tertiary), where chemistry is taught.

Exclusion Criteria

Conversely, studies were excluded if they focused solely on students rather than teachers, examined environmental education without any reference to green chemistry, were purely theoretical, conceptual, or opinion pieces, lacked an empirical component or failed to report any measurable indicator of knowledge levels of green chemistry.

Information Sources

In order to gather a comprehensive and globally representative set of studies, a multi-database search strategy was employed. The following scholarly databases and platforms were searched: ERIC, Google Scholar, ResearchGate and ScienceDirect. These databases were intentionally selected because, taken together, they encompassed some of the most influential repositories in chemistry education, teacher education, environmental science, and sustainability research. Searches were conducted initially in August 2025, and then updated in November 2025 to capture new publications.

Search Strategy

The search strategy was developed iteratively. Initially, broad keywords related to green chemistry and teacher knowledge were identified; however, preliminary scanning revealed substantial variation in terminology, prompting refinement of the keywords. Ultimately, the search was conducted using combinations of terms such as "green chemistry" and "teacher knowledge", "chemistry teachers" and "green chemistry principles," "sustainable chemistry education" and "teachers," "12 principles of green chemistry" and "teachers," as well as "environmental sustainability" and "chemistry education."

Boolean operators (and/or), phrase searching, and truncation symbols were employed to broaden or narrow searches when necessary.

Additionally, because Google Scholar yields large volumes of non-refereed material, an inclusion filter was applied to prioritise peer-reviewed journal articles and graduate theses.

Screening Procedure

After all database searches were completed, the results were exported into a reference manager, where duplicate records were systematically removed. Subsequently, the screening process unfolded in three stages. First, during the title screening stage, titles were examined to exclude clearly irrelevant studies. For example, those focusing on green chemistry in industry, chemical engineering, or environmental impacts without an educational focus. Next, during the abstract screening stage, abstracts were reviewed to determine whether the study meaningfully addressed teachers' and green chemistry knowledge. Studies that mentioned "teachers" only superficially were excluded unless some form of knowledge assessment was conducted. Finally, in the full-text review stage, the complete articles were retrieved and scrutinised in detail. At this stage, studies were typically excluded if they mentioned green chemistry only conceptually, focused solely on awareness, attitude, perception or integration of green chemistry without measuring knowledge, targeted students rather than teachers, lacked adequate methodological detail and or examined environmental education without any reference to green chemistry. In the end, a total of 7 studies met all eligibility criteria.

Data Extraction

To ensure a systematic and rigorous analysis, a structured data extraction form was developed. For each study, key descriptive and methodological details were carefully documented. These included the author(s) and year of publication, the country or region where the study was conducted, and the overall study design, whether quantitative, qualitative or mixed methods. Additionally, information about the sample characteristics, such as the sample size and the level of teachers involved, was extracted. The measurement instruments used in each study were also recorded. Finally, the operational definition of knowledge adopted by the researchers was noted, along with the key findings related to teachers' knowledge of green chemistry.

Synthesis Methods

The results were synthesised using a narrative and thematic synthesis approach. The synthesis began with a descriptive comparison of the included studies, followed by cross-study comparisons across countries and teacher groups. Emergent patterns were then organised into themes, and broader global trends were interpreted to provide a coherent understanding of chemistry teachers' knowledge of green chemistry.

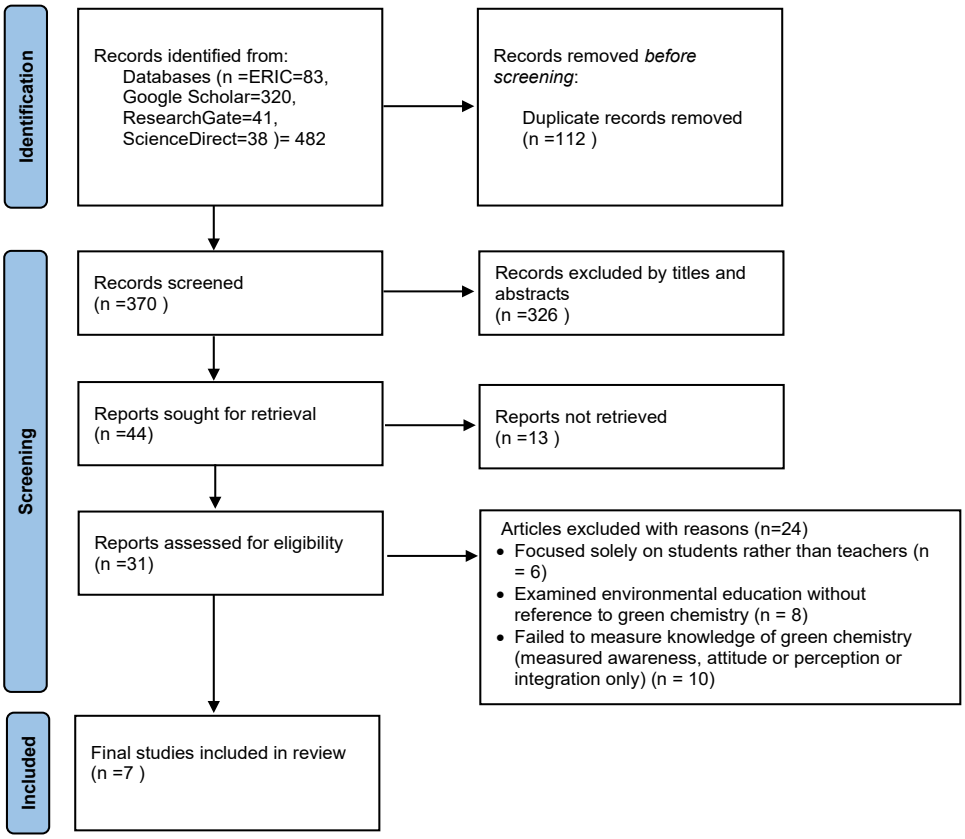
RESULT AND DISCUSSION

The study selection process followed the PRISMA 2020 guidelines, and the flow of records from identification to inclusion is illustrated in Figure 1. To begin with, a total of **482 records** were identified across four major databases: ERIC (83), Google Scholar (320), ResearchGate (41), and

ScienceDirect (38). However, before the screening phase commenced, **112 duplicate records** were removed, leaving **370 unique records** eligible for title and abstract screening.
As the screening progressed, the majority of the records, **326 in total**, were excluded at the title and abstract stage because they did not meet the predefined inclusion criteria. Consequently, **44 reports** were sought for full-text retrieval. Yet, despite efforts to obtain all relevant documents, **13 reports** could not be retrieved.

After obtaining the accessible full texts, **31 reports** were assessed for eligibility. During this stage, additional exclusions were necessary for specific reasons. Some studies were removed because they focused exclusively on students rather than teachers (**n = 6**). Others were excluded because they examined general environmental education without any connection to green chemistry (**n = 8**). Additionally, several studies did not measure teachers' knowledge of green chemistry, instead assessing awareness, attitude, perception, or integration of green chemistry only (**n = 10**).
Following this rigorous evaluation, **7 studies** met all the criteria and were therefore included in the final systematic review. These studies constitute the core evidence base for analysing chemistry teachers' knowledge of green chemistry.

Figure 1: ***Flow diagram of the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines for the selection of articles in this study***



The following sections present a comprehensive synthesis of the seven empirical studies included in the review, all of which examined chemistry teachers' knowledge of Green Chemistry (GC). The findings are organised in a structured manner, beginning with a descriptive overview of the characteristics of the included studies and gradually moving into a more detailed narrative synthesis of the knowledge levels reported. In preparing this section, attention was given not only to summarising the factual outcomes of each study but also to drawing out the broader patterns, recurring themes, and interpretive insights that emerged when the studies were considered collectively.

Overview of Included Studies (Study Characteristics)

Table 1 presents the publication details of each study, including the article titles, journal names and their respective volume and issue numbers.

Table 1: *Publication Details of the Reviewed Studies*

Author(s)	Year	Article Title	Journal Title	Volume & Issue
Owoyemi, T. E., & Adesina, A. S.	2020	Pre-service and in-service chemistry teachers' knowledge and attitude to green chemistry in Lagos State, Nigeria	*Journal of Curriculum and Instruction*	13(1)
Taha, H., Zahari, N. L., Tien Tien, L., & Muhammad Damanhuri, M. I.	2021	An Exploratory Study on Green Chemistry Practices and Experiments in Malaysian Secondary Schools	*Journal of Science and Mathematics Letters*	9(2)
Monday, M.	2021	Pre-service chemistry teachers' knowledge of green chemistry principles and attitude as determinants of their behaviour towards environmental sustainability	*Nigerian Online Journal of Educational Sciences and Technology*	3(2)
Carangue, D. G., Geverola, I. J. R., Jovero, M. B., Lopez, E. N. A. B., Pizaña, A. D., Salmo, J. M. & Picardal, J. P.	2021	Green Chemistry Education among Senior High School Chemistry Teachers: Knowledge, Perceptions, and Level of Integration	*Recoletos Multidisciplinary Research Journal*	9(2)
Estalilla, K. C. S.	2022	Extent of Knowledge Towards Green Chemistry of Science Teachers	*International Journal of Advanced Multidisciplinary Studies*	2(1)
Oloyede, S. O., & Hauwa, A. S.	2022	Teachers' knowledge of green chemistry in senior secondary schools in Kwara State, Nigeria	*VNU Journal of Science: Education Research*	38(4)
Basheer, A., Sindiani, A., Gulacar, O., Eilks, I., & Hugerat, M.	2023	Exploring pre- and in-service science teachers' green chemistry and sustainability awareness and their attitudes towards environmental education in Israel	*International Journal of Science and Mathematics Education*	21 (5)

Table 1 shows the studies span four years from 2020 to 2023 and appear across a diverse range of reputable academic journals, indicating broad scholarly interest in the topic across countries and disciplines.

To begin with, the earliest study in Table 1 is that of Owoyemi and Adesina (2020), which appeared in the *Journal of Curriculum and Instruction*, volume 13, issue 1. Publishing in a curriculum-focused journal suggests the authors' emphasis on green chemistry as an emerging area within teacher preparation and instructional practice.

Following this, the year 2021 features prominently with several publications. First, Taha et al. (2021) published their work in the *Journal of Science and Mathematics Letters*, volume 9, issue 2. This placement highlights the study's alignment with science and mathematics education and its relevance to instructional practice in Malaysian secondary schools. Subsequently, Monday (2021) contributed to the literature through an article published in the *Nigerian Online Journal of Educational Sciences and Technology* (volume 3, issue 2), a journal that typically showcases research related to teacher education and innovations in educational practice. In the same year, Carangue et al. (2021) published in the *Recoletos Multidisciplinary Research Journal*, volume 9, issue 2, demonstrating the study's multidisciplinary appeal and its applicability to both science education and sustainability studies.

Transitioning into 2022, Table 1 highlights two additional contributions. Estalilla (2022) published in the *International Journal of Advanced Multidisciplinary Studies*, volume 2, issue 1. This choice of journal reflects the study's broad scope, which includes teacher knowledge, pedagogy, and attitudes toward green chemistry. Additionally, Oloyede and Hauwa (2022) published in the *VNU Journal of Science: Education Research*, volume 38, issue 4. The journal's focus on science education research underscores the study's alignment with international academic conversations on improving chemistry instruction and promoting green chemistry awareness in schools.

Lastly, the most recent publication in the table is that of Basheer et al. (2023), which appeared in the *International Journal of Science and Mathematics Education*, volume 21, issue 5. This journal is widely recognised for publishing high-quality international research in science and mathematics education. The placement of this study within such a journal highlights both its methodological rigour and its contribution to the global discourse on environmental and sustainability education.

In summary, Table 1 illustrates that research on green chemistry knowledge among teachers has been disseminated across a wide array of respected educational journals. Moreover, the chronological arrangement from 2020 to 2023 reveals increasing attention to the subject, with studies emerging from different regions and published in journals covering curriculum development, science and mathematics education, educational sciences, and multidisciplinary research. Together, these publications demonstrate the growing scholarly commitment to integrating green chemistry principles into teaching and learning across diverse educational contexts.

To provide a clear foundational understanding of the evidence base, Table 2 summarises the characteristics of the included studies.

Table 2: ***Characteristics of Included Studies***

Author/Year	Country	Participants and or sampling Technique	Research Design	Instrument/ Analysis Technique
Owoyemi and Adesina (2020)	Nigeria (Lagos)	315 respondents (160 teachers, 155 pre-service); multi-stage sampling.	Descriptive survey	Pre-service Teachers' Knowledge and Attitude towards Green Chemistry Questionnaire (PTKAGCQ); Descriptive Statistics
Taha et al. (2021)	Malaysia	269 teachers	Descriptive Survey	Questionnaire; Descriptive statistics (summated rating scale method)
Monday (2021)	Nigeria	750 pre-service chemistry teachers (federal institutions)	Descriptive survey	Questionnaire; Descriptive statistics
Carangue et al. (2021)	Philippines	30 senior high school chemistry teachers	Convergent mixed-methods:	Green Chemistry Knowledge test; Descriptive statistics

Estalilla (2022)	Philippines (Cuyapo District)	40 secondary science teachers; total enumeration.	Descriptive survey	Questionnaire: (Descriptive statistics) a weighted mean using the given point value
Oloyede and Hauwa (2022	Nigeria (Kwara State)	210 chemistry teachers (126 from the public, 84 from private schools)	Descriptive survey	Green Chemistry Knowledge Questionnaire (GCKQ); Descriptive Statistics (Mean and Percentages)
Basheer et al. (2023)	Israel	271 pre- and in-service science teachers (mixed seniority).	Cross-sectional	34-items on awareness, knowledge and attitude questionnaire; Descriptive Statistics

The studies summarised in Table 2 present a comprehensive picture of how researchers across different countries have examined teachers' knowledge of green chemistry. As Table 2 shows, these studies vary in terms of geographic location, sample size, participant characteristics, and research design, yet together they illustrate the growing international attention to green chemistry education.
To begin with, **Owoyemi and Adesina (2020)** conducted their study in Lagos, Nigeria, where they surveyed **315 participants**, consisting of **160 teachers** and **155 pre-service teachers.** Using a **multi-stage sampling technique**, the researchers ensured representation across different sub-groups within the region. Their study employed a **descriptive survey design**, and data were collected through the **Pre-service Teachers' Knowledge and Attitude Towards Green Chemistry Questionnaire (PTKAGCQ).** The use of **descriptive statistics** allowed the authors to summarise the general patterns of green chemistry knowledge and attitudes among both practising and aspiring teachers.
Following this, **Taha et al. (2021)** investigated green chemistry knowledge among **269 teachers** in Malaysia. Their study also used a **descriptive survey design**, supported by a questionnaire as the primary data collection tool. The responses were analysed using **summated rating scales**, which enabled the researchers to generate composite scores illustrating the overall trends in teachers' knowledge levels. This study adds to the body of literature by providing insights into green chemistry understanding within the Malaysian educational landscape.

Furthermore, **Monday (2021)** conducted an extensive study in Nigeria involving **750 pre-service chemistry teachers** from various federal institutions. By using a **descriptive survey design** and administering a questionnaire, the researcher gathered information on the green chemistry knowledge of pre-service teachers preparing to enter the teaching profession. The findings, summarised through **descriptive statistics,** provide valuable insight into the preparedness of future chemistry educators in Nigeria.

In addition, the study by **Carangue et al. (2021)** in the Philippines adopted a **convergent mixed-methods design,** involving **30 senior high school chemistry teachers**. The researchers used a **Green Chemistry Knowledge Test** to assess teachers' knowledge of key concepts. Quantitative data were analysed descriptively, while qualitative insights complemented the outcomes, offering a more layered understanding of teachers' knowledge and experiences with green chemistry instruction within the senior high school setting.

Moreover, **Estalilla (2022)** carried out a study in the Cuyapo District of the Philippines, involving **40 secondary school science teachers**. Because the study employed **total enumeration**, every eligible teacher in the district was included. The research was guided by a **descriptive survey design**, and the data gathered through the questionnaire were analysed using **weighted means** based on assigned point values. This approach offered a structured means of interpreting the teachers'

responses and presenting a holistic view of their awareness and knowledge of green chemistry concepts.

Similarly, **Oloyede and Hauwa (2022)** studied **210 chemistry teachers** from public and private schools in Kwara State, Nigeria. Their research followed a **descriptive survey design** and utilised the **Green Chemistry Knowledge Questionnaire (GCKQ)** to assess teachers' knowledge levels. Through the use of **means and percentages**, the researchers presented a clear summary of the teachers' responses, thus contributing findings from both public and private school contexts.

Lastly, the study conducted by Basheer et al. (2023) in Israel involved 271 pre-service and in-service science teachers with varying levels of professional experience. The researchers employed a cross-sectional design and used a 34-item questionnaire that assessed teachers' awareness, knowledge, and attitudes toward green chemistry. The data were analysed using descriptive statistics. Furthermore, the inclusion of teachers at different stages of their careers enabled the study to capture a broad range of perspectives within the Israeli science education context.

Taken together, the studies presented in Table 2 reveal a consistent pattern in the use of descriptive survey designs, questionnaire-based instruments, and statistical methods such as means, percentages, and rating scales. They collectively demonstrate how researchers across multiple countries have sought to document teachers' knowledge of green chemistry through structured, quantitative approaches. Moreover, the varied sample sizes, ranging from small district-wide groups to large national samples, illustrate the diverse contexts in which green chemistry education is being explored.

Knowledge of Chemistry Teachers Across Countries

Across the seven studies included in this review, specifically Owoyemi and Adesina (2020), Taha et al. (2021), Monday (2021), Estalilla (2022), Carangue et al. (2021), Oloyede and Hauwa (2022), and Basheer et al. (2023), a diverse and multifaceted global picture of chemistry teachers' knowledge of green chemistry emerged. The results reveal significant regional and professional differences, highlighting how contextual factors, national education systems, teacher preparation programs, and access to resources shape the knowledge landscape.

In West Africa, where three Nigerian studies were conducted, a distinct contrast emerged between pre-service and in-service teachers. The largest of these, Monday (2021), surveyed 750 pre-service chemistry teachers across Nigeria. The study reported strikingly low levels of green chemistry knowledge, with a mean score of 38.20 (SD = 15.43) out of 100. The distribution showed that the majority of respondents clustered in the lowest-scoring bands, with many scores below 30. This demonstrates that substantial proportions of the incoming teaching workforce lacked foundational knowledge of green chemistry principles. Similarly, Owoyemi and Adesina (2020**)**, who examined both in-service (n = 160) and pre-service (n = 155) teachers in Lagos using the PTKAGCQ instrument, found that pre-service teachers displayed lower knowledge compared to in-service teachers. However, even among in-service teachers, the authors concluded that content knowledge still required improvement, suggesting that while experience elevates knowledge, systemic gaps remain in the broader national teaching context. Contrasting sharply with the pre-service findings, Oloyede and Hauwa (2022) investigated 210 in-service chemistry teachers in Kwara State, Nigeria, using the GCKQ and reported generally high levels of green chemistry knowledge. Notably, teachers with longer years of experience scored significantly higher than their less experienced peers. This divergence within Nigeria reveals how professional experience can substantially compensate for shortcomings in pre-service preparation. It also demonstrates that green chemistry knowledge is not static; rather, it develops longitudinally as teachers accumulate experience, professional exposure, and informal learning opportunities.

Turning to Southeast Asia, the evidence presents a more balanced, though still heterogeneous, picture. In Malaysia, Taha et al. (2021) surveyed 269 secondary school chemistry teachers and reported an overall moderate level of green chemistry knowledge, with a composite score of approximately 84.5 on their summated scale. The study also documented slight differences between urban (mean ≈ 85.2) and rural (mean ≈ 83.6) teachers, although both groups fell into the same moderate range. This suggests a relatively stable baseline of knowledge across different geographical settings within the country, likely reflecting national-level professional development initiatives or curricular integration. In the Philippines, two district-level studies, Estalilla (2022) and Carangue et al. (2021), produced a more intricate landscape. Estalilla (2022) found that although the 40 science teachers surveyed showed high levels of pedagogical knowledge related to green chemistry, their content knowledge was comparatively weaker. Similarly, Carangue et al. (2021), who employed a convergent mixed-methods design with 30 senior high school teachers, reported that while teachers recognised the importance of green chemistry and expressed readiness to integrate it into their instruction, their pre-existing content knowledge was limited. These Philippine studies highlight a critical distinction between pedagogical readiness and content mastery, suggesting that teachers may be motivated and pedagogically prepared but still lack the conceptual grounding to deliver green chemistry instruction at the depth required for meaningful learning.

In the Middle East, Basheer et al. (2023) assessed 271 pre-service and in-service teachers in Israel using a 34-item questionnaire measuring awareness, knowledge, and attitudes. Their findings mirrored those observed in Nigerian in-service populations: in-service teachers and those with over ten years of experience possessed significantly higher knowledge than pre-service teachers. The Israeli results, therefore, confirm that the experience-related knowledge gradient is not confined to a single region but appears to be an internationally recurring pattern.
Taken together, the global evidence indicates that chemistry teachers' knowledge of green chemistry varies substantially across countries and teacher categories. In-service teachers generally report higher knowledge levels than pre-service teachers, with particularly strong knowledge reported in contexts where teachers have extensive experience or access to ongoing professional development. Conversely, pre-service teachers consistently display weaker conceptual knowledge, revealing gaps in university-level teacher preparation programs across multiple regions.

Cross-Study Synthesis: Themes and Patterns
Synthesising the results across the seven included studies 'Owoyemi and Adesina (2020), Taha et al. (2021), Monday (2021), Estalilla (2022), Carangue et al. (2021), Oloyede and Hauwa (2022), and Basheer et al. (2023) reveal several dominant themes that collectively illuminate structural, curricular, and experiential influences on chemistry teachers' knowledge of green chemistry.

Theme 1: Strong Influence of Teaching Experience
A central and repeatedly confirmed theme is the strong influence of teaching experience on knowledge acquisition. Across Nigeria, Malaysia, and Israel, in-service teachers consistently outperformed pre-service teachers. Monday (2021) documented a substantial deficit among pre-service trainees, while Oloyede and Hauwa (2022) and Basheer et al. (2023) demonstrated that experience correlates positively with higher knowledge levels. Owoyemi and Adesina (2020) similarly highlighted that Lagos in-service teachers surpassed pre-service teachers in conceptual knowledge. Together, these studies provide converging evidence that the accumulation of classroom experience, exposure to real-world problem solving, and informal learning within professional networks play pivotal roles in strengthening teachers' mastery of green chemistry.

Theme 2: Dichotomy Between Pedagogical Readiness and Content Knowledge
Another recurring theme is the dichotomy between pedagogical readiness and content knowledge, particularly evident in the Philippine studies. Estalilla (2022) and Carangue et al. (2021) both reported

that teachers demonstrated high pedagogical intention and confidence in integrating green chemistry, yet their actual content knowledge was comparatively limited. This divergence reveals a systemic pedagogical paradox: teachers may be enthusiastic and capable of adopting green chemistry instructional methods, but without strong conceptual grounding, the depth and accuracy of their instruction may be compromised. This theme suggests the need for professional development initiatives that explicitly combine pedagogy with deep content-focused learning.

Theme 3: Contextual Influences (Geographical Disparities and School Environments)

The synthesis also reveals subtle but meaningful contextual influences, such as geographical disparities and differences in school environments. For instance, Taha et al. (2021) identified slight but notable urban–rural variations in Malaysia, implying that contextual factors such as resource availability, exposure to training opportunities, and professional learning communities may indirectly influence knowledge levels. Although these contextual differences were less pronounced than experience-related differences, they nonetheless underscore the importance of equitable access to resources and professional development across diverse educational environments.

Theme 4: Substantial methodological heterogeneity

A further theme involves the substantial methodological heterogeneity across studies. Instruments varied considerably, ranging from PTKAGCQ (Owoyemi & Adesina, 2020) to GCKQ (Oloyede & Hauwa, 2022) and structured knowledge tests (Carangue et al., 2021), and multi-dimensional questionnaires (Basheer et al., 2023). This variation complicates direct comparison of absolute scores because each instrument captures slightly different facets of knowledge. Yet, despite the methodological diversity, the overarching trends, pre-service deficits, experience advantages, and pedagogical-content divides remain consistent, reinforcing the robustness of these themes across both measurement tools and cultural contexts.

Trends in the Global Knowledge Landscape

When examined through a global and temporal lens, the studies spanning 2020 to 2023 highlight several trends in the worldwide knowledge landscape of green chemistry education among teachers. One of the most striking trends is the recent surge in research attention devoted to teachers' knowledge of green chemistry. Studies such as Taha et al. (2021), Monday (2021), Estalilla (2022), Oloyede and Hauwa (2022), and Basheer et al. (2023) reflect an accelerated interest in evaluating how well teachers are prepared to integrate sustainability-oriented chemistry instruction. This concentration of studies in the early 2020s aligns with global educational reforms emphasising environmental responsibility, sustainable development, and the integration of green chemistry into K–12 and tertiary curricula. The increasing attention across continents suggests that green chemistry has transitioned from a specialised subtopic into a core component of contemporary science education research.

A second global trend is the persistent and widespread knowledge gap among pre-service teachers. Across Nigeria (Monday, 2021; Owoyemi & Adesina, 2020), Israel (Basheer et al., 2023), and the Philippines (Carangue et al., 2021), pre-service teachers consistently display lower knowledge levels than their in-service peers. This trend points to significant shortcomings in teacher education programs, which may not yet systematically incorporate green chemistry principles into their curricula. The persistence of this gap, even across culturally diverse regions, illustrates that the challenge is global rather than isolated to particular countries. This implies that reform efforts in pre-service chemistry education must be internationally prioritised to ensure that future teachers enter the profession with adequate conceptual foundations.

Another trend is the emerging content–pedagogy imbalance, most clearly observed in the Philippines but also echoed subtly in other contexts. As seen in Estalilla (2022) and Carangue et al. (2021),

teachers may demonstrate positive attitudes toward green chemistry and be eager to integrate it pedagogically, but this enthusiasm is not always matched by strong content knowledge. This imbalance suggests that global green chemistry initiatives may have succeeded in generating pedagogical awareness but have yet to equally deepen teachers' conceptual expertise. As green chemistry becomes more central to sustainability education, countries must address this imbalance by developing programs that simultaneously build content mastery and pedagogical skill.

Finally, the literature reveals a growing international consensus regarding the structural changes needed to strengthen teacher preparedness. Across Nigeria, the Philippines, Malaysia, and Israel, studies repeatedly recommend embedding green chemistry into pre-service curricula, enhancing laboratory facilities, and expanding professional development opportunities. The alignment of recommendations across such diverse contexts suggests that the global education community recognises the importance of developing a scientifically knowledgeable, environmentally literate, and pedagogically equipped chemistry teaching workforce.

CONCLUSIONS

In conclusion, the findings of this systematic review reveal substantial variations in chemistry teachers' knowledge of green chemistry across countries and teacher groups. While many in-service teachers demonstrate moderate to high levels of knowledge, pre-service teachers consistently exhibit lower knowledge, highlighting persistent gaps in initial teacher preparation. Moreover, the cross-study synthesis shows recurring patterns, including the strong influence of teaching experience, the content–pedagogy imbalance, and the role of contextual factors in shaping knowledge levels. Overall, global trends indicate growing attention to green chemistry education, but also highlight the need for more comprehensive integration of green chemistry principles into teacher education programs. These results collectively point to an urgent need for strengthened pre-service curricula and sustained professional development to improve teachers' conceptual mastery and ensure effective classroom implementation.

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