

 Research Article

# Assessment of Green Chemistry Competencies and Training Needs Among Secondary School Chemistry Teachers

Toyin Eunice Owoyemi<sup>1</sup> , Ayotomiwa Abel Akinde<sup>1</sup> 

<sup>1</sup>Department of Science Education, University of Lagos, Akoka, Yaba, Lagos State, Nigeria

## Abstract

Green chemistry, a framework for designing safer chemical processes and reducing environmental hazards, is increasingly essential in science education. However, in Nigeria, secondary school chemistry curricula lack adequate integration of green chemistry principles, and teachers remain underprepared to teach these concepts. This study assessed the green chemistry competencies and training needs of secondary school chemistry teachers in Lagos State to inform targeted professional development and policy reform. Employing a sequential mixed-methods design, data were collected from 43 chemistry teachers using structured questionnaires and semi-structured interviews. Quantitative data captured teachers' self-reported practices, understanding of green chemistry principles, and perceived training needs, while qualitative interviews explored classroom implementation and contextual challenges. Findings revealed a significantly low level of green chemistry practice, with over 85% of teachers reporting that they never or rarely incorporated core principles such as atom economy, waste reduction, or energy efficiency into instruction. Teachers demonstrated limited understanding of the twelve principles of green chemistry and low confidence in applying them, particularly in designing green experiments, selecting environmentally friendly reagents, and teaching sustainable product design. Key barriers identified included limited curricular guidance, lack of resources, and insufficient training opportunities. A needs analysis highlighted six critical competency areas requiring urgent intervention, including foundational knowledge, lesson integration, laboratory practices, waste management, and application of advanced sustainability concepts. The study concludes that comprehensive, context-specific professional development and curriculum reforms are vital to bridge current competency gaps and enhance sustainable chemistry instruction. These findings offer actionable insights for policymakers, curriculum developers, and teacher educators seeking to embed environmental responsibility in science education.

**Keywords:** Chemistry Education, Green Chemistry, Environmental Sustainability, Professional Development, Curriculum Integration

✉ Correspondence  
Ayotomiwa Abel Akinde  
[akindeayotomiwaabel@gmail.com](mailto:akindeayotomiwaabel@gmail.com)

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## 1. INTRODUCTION

Green chemistry has emerged as a transformative paradigm in chemical practices, emphasising the design and implementation of chemical products and processes that reduce or eliminate the use and generation of hazardous substances (Anastas & Beach, 2007; Anastas & Warner, 2000; Ncube et al., 2023). As a critical element of sustainable chemical education, green chemistry aims to reduce environmental impact while promoting sustainability and guaranteeing the enduring feasibility of chemical processes and products (Karpudewan et al., 2011). This approach represents a significant paradigm shift in the utilisation and management of natural resources and raw materials, with the tacit assurance of substantially reduced environmental impact. The United Nations Environment Programme (UNEP) has been advocating for green chemistry globally through its Strategic Approach to International Chemicals Management (SAICM) initiative (Friege et al., 2024), underscoring its importance in addressing pressing environmental challenges.

Incorporating green chemistry principles into teacher education has become increasingly crucial for preparing educators to instil sustainable behaviour in future generations (Cannon et al., 2023). Effective frameworks for enhancing teacher competency in green chemistry frequently employ multidisciplinary and problem-based learning approaches to promote sustainable education (Chen et al., 2020). Integration of sustainable development into chemistry curricula has been shown to enhance teachers' ability to approach chemical education from an environmentally responsible perspective, enabling them to impart a holistic understanding of chemistry aligned with real-world applications (Karpudewan et al., 2011).

Recent developments have seen digital platforms and online learning modules increasingly promoting broader access to green chemistry training, enabling global collaboration and sharing of best practices (Zuin et al., 2021). These technologies offer personalised learning and continuous professional development, vital for addressing growing sustainability concerns. However, despite these advancements, current chemistry curricula in many educational systems, including Nigeria, generally focus on theoretical concepts and laboratory activities that may not fully embrace sustainability principles (Akinsipo & Anselm, 2025; Makinde et al., 2024).

Traditional chemistry teaching approaches tend to emphasise reaction mechanisms, molecular structures, and chemical properties without effectively considering the environmental implications of chemical processes. There is a conspicuous absence of attention to sustainability and the environmental effects of commonly used chemicals in existing chemistry syllabi, particularly in developing countries (Aubrecht et al., 2019; Zuin et al., 2021b). This gap leaves students and future professionals ill-equipped to address the expanding environmental concerns associated with chemical processes and products.

Lagos State, Nigeria's most populous state, faces various environmental challenges, including air and water pollution, improper waste management, and industrial emissions (Merem et al., 2018; Samson & Oluwatoyin, 2012). These difficulties underscore the critical need for comprehensive knowledge and integration of green chemistry education into school curricula to develop sustainable practices and reduce environmental deterioration. However, research indicates that chemistry teachers in Lagos State have insufficient awareness of green chemistry principles (Moju & Owoyemi, 2020; Owoyemi & Adesina, 2021), with very low levels of awareness and knowledge of the concepts and significance of green chemistry among secondary school teachers.

There is, therefore, a critical demand for specific training programs to equip chemistry teachers with green chemistry competencies. This requirement emerges from the gap between traditional chemistry education and the expectations of a sustainable future (Zuin et al., 202). The existing teacher education curriculum in Nigeria does not adequately address the integration of green chemistry principles, and there is a lack of targeted capacity-building workshops and in-service training programs for chemistry teachers on green chemistry (Ajeyalemi, 2008; Owoyemi & Adesina, 2020). Without a robust training framework, teachers remain ill-equipped to communicate fundamental green chemistry principles, ultimately affecting students' comprehension and application of sustainable practices (Cannon et al., 2023).

Green chemistry, also known as sustainable chemistry, employs a series of principles aimed at minimising or eradicating the use or production of hazardous compounds in the design, manufacture, and use of chemical products (Anastas & Warner, 2000). The twelve principles of green chemistry outlined by Anastas and Warner (1998) provide a comprehensive framework for sustainable chemical practices, addressing waste prevention, atom economy, less hazardous chemical syntheses, safer chemicals and products, safer solvents, energy efficiency, renewable feedstock, reduced derivatives, catalysis, degradability, real-time analysis for pollution prevention, and accident prevention.

This study focuses on assessing the green chemistry competencies and training needs of secondary school chemistry teachers in Lagos State, Nigeria. Competencies in this area include understanding sustainable chemical processes, conducting life cycle assessments, and the ability to create and carry out green chemistry activities and research (Andraos & Matlack, 2022; Margallo et al., 2018). Previous studies have shown that teachers' competencies in green chemistry can significantly influence students' awareness and attitudes towards sustainability and environmental responsibility (Basheer et al., 2022). The scope of this study encompasses the assessment of current green chemistry competencies among chemistry teachers in Lagos State, the identification of specific training needs, and the evaluation of factors influencing these competencies and needs. The ultimate goal is to provide evidence-based recommendations for developing targeted training programs that can enhance green chemistry teaching in secondary schools, thereby

contributing to broader environmental sustainability goals by fostering a generation of students who are aware of and committed to sustainable chemical practices.

The assessment of green chemistry competencies and training needs among chemistry teachers is supported by several theoretical and conceptual frameworks. Adult Learning Theory (Andragogy), developed by Malcolm Knowles, provides a foundation for understanding how adult learners, such as teachers, acquire and apply new knowledge and skills. Knowles' theory emphasises the need for a learner-centred approach, recognising that adults bring a wealth of experience to the learning environment, have distinct learning requirements, and are motivated by internal factors (Curry, 2008).

Constructivist Theory, rooted in the works of Jean Piaget and Lev Vygotsky, asserts that learning is an active, constructive process. In a constructivist learning environment, learners are encouraged to employ active strategies such as experiments, real-world problem-solving, and discussion to generate additional knowledge and understand how their understanding is formed. This theory supports the notion that teachers need hands-on, experiential learning opportunities to develop green chemistry competencies effectively (Yao, 2023).

The Diffusion of Innovation Theory (DOI), created by Everett Rogers, describes the mechanisms, reasons, and speed at which novel concepts and technologies disseminate across communities. This theory is particularly relevant for understanding how educational innovations, such as green chemistry practices, might be accepted by teachers in diverse contexts. Rogers identified five key elements that influence the spread of a novel concept: the innovation itself, the channels of communication, the timeframe, the social framework, and the types of adopters (Miller, 2018). This framework helps in understanding the factors that might influence teachers' adoption of green chemistry principles and practices.

Several empirical studies have assessed green chemistry competencies and training needs in science education globally. Karpudewan et al. (2009) investigated the incorporation of green chemistry into pre-service teacher curricula at Universiti Sains Malaysia, revealing positive implications for establishing sustainable teaching practices. Hands-on green chemistry experiments were introduced into teaching methodology courses, broadening pedagogical abilities and encouraging environmental awareness and sustainable attitudes among teachers.

In New York State, Cannon et al. (2023) evaluated the effectiveness of focused professional development methods for strengthening teacher abilities in green chemistry education. Their study found that workshops featuring one-day introduction sessions for basic understanding and three-day intensive "train-the-trainer" workshops, emphasising collaborative, peer-led learning, resulted in persistent impacts on teacher engagement and curriculum uptake.

In Nigeria, Owoyemi and Umanah (2019) assessed the awareness and knowledge of green chemistry among secondary school teachers in Lagos State. Their findings revealed very low levels of awareness and knowledge of the concepts, principles, and significance of green chemistry. They recommended incorporating green chemistry into the chemistry education curriculum of teacher training institutions to adequately prepare pre-service teachers for implementing green chemistry principles once incorporated into the secondary school chemistry curriculum.

Owoyemi and Adesina (2021) explored the impact of gender on the understanding of green chemistry among chemistry teachers in Lagos State, revealing that both male and female educators demonstrated a lack of sufficient knowledge regarding green chemistry. Conversely, Oyelekan and Salihu (2022) reported that teachers' knowledge of green chemistry in Kwara State was robust, indicating differences in green chemistry expertise among Nigerian teachers across regions.

This study is underpinned by Adult Learning Theory (Andragogy), which provides a robust framework for understanding how to effectively assess and address the training needs of chemistry teachers. Andragogy is based on several key assumptions about adult learners: they need to know the relevance of what they are learning; they see themselves as self-directed and responsible for their decisions; they bring varied experiences to the learning environment; they are ready to learn when they need to cope with real-life tasks; their learning is problem-centered rather than content-oriented; and they are largely driven by internal motivations (Curry, 2008).

Applying these principles to the assessment of chemistry teachers' green chemistry competencies and training needs means recognizing that teachers are more likely to engage with training that demonstrates relevance to their teaching practice, allows them to take an active role in their learning, acknowledges their existing experiences, addresses immediate problems or challenges they face, focuses on practical applications, and appeals to their internal motivations for professional growth and improved teaching outcomes.

The Diffusion of Innovation Theory also informs this study, particularly in understanding how green chemistry principles might be more effectively integrated into the teaching practices of chemistry teachers in Lagos State. By considering the attributes of the innovation (green chemistry principles), communication channels, time required for adoption, the social system of schools and educational networks, and the different categories of adopters among teachers, this study can provide insights into how to tailor training programs to facilitate the widespread adoption of green chemistry practices.

Evidence supporting the effectiveness of training interventions in chemistry education is abundant in the literature. Andrade and Cizek (2010) synthesised research on effective professional development programs, finding that successful programs share several key characteristics: being content-focused, incorporating active learning, supporting collaboration, using models of effective practice, providing coaching and expert support, offering feedback and reflection opportunities, and being of sustained duration.

Desimone et al. (2015) discovered that professional development aimed at particular teaching strategies resulted in a greater application of those strategies in the classroom, highlighting the significance of engaging learning opportunities, alignment with other educational activities, and collaborative involvement from schools. Garet et al. (2001) recognised three essential characteristics of effective professional development: an emphasis on content knowledge, chances for active engagement, and alignment with additional learning activities.

In the study of need-based training, Bayar (2014) found that one of the key components of effective professional development was matching teachers' existing needs. Teachers reported that professional development activities were more effective when they addressed their specific, current needs in the classroom. Similarly, Pittaway et al. (2023) found that tailoring professional development to teachers' specific needs improved teaching practices and increased teacher satisfaction with the training program.

Alibakhshi (2019) reported that teachers who received training based on their assessed needs showed significant improvement in their teaching skills and classroom management. Subitha (2017) study on a needs-based model called "realistic teacher education" found that this approach, which focuses on teachers' real-world experiences and concerns, led to more effective integration of theory and practice in teacher development.

Green chemistry education varies significantly across different countries and contexts. In developed countries such as the United States and European nations, green chemistry has been more extensively integrated into educational curricula and teacher training programs. The American Chemical Society's (2023) green chemistry campaign for a sustainable future represented a significant effort to advance sustainable chemistry practices across academia, industry, and society, focusing on renewable feedstock, energy efficiency, waste reduction, and safer chemical design (Freese, 2024).

In contrast, initiatives in emerging economies in Asia primarily target secondary and tertiary education, particularly in Organic Chemistry and General Chemistry, while facing challenges like limited resources and pedagogical barriers (Jovero & Picardal, 2022). Countries such as China, Malaysia, Indonesia, India, Korea, the Philippines, Taiwan, and Thailand have experienced industrial revolutions that have led to environmental challenges, emphasising the need for green chemistry education (Jovero & Picardal, 2022b).

Numerous research efforts in Western industrialised and developed nations have incorporated green chemistry concepts into their educational programs (Burmeister et al., 2012). Studies have shown that educating citizens by introducing green chemistry programs seems to be a workable strategy for fostering an environmental orientation across an entire country (Karpudewan et al., 2012). However, even though green chemistry education is receiving serious attention in advanced economies, such initiatives have a long way to go in most emerging countries, especially in those where green chemistry education is not yet

prevalent and environmental consciousness means little or nothing to the citizenry (Matus et al., 2012; Zuin et al., 2021).

In Nigeria, green chemistry education is still in its early stages compared to developed countries. Akinsipo and Anselm (2025b) examined the integration of green chemistry principles in the curriculum of selected Nigerian universities, finding that while there is growing awareness of green chemistry, its formal incorporation into university curricula remains limited. This contrasts sharply with the more comprehensive integration seen in many developed countries.

Lagos State, as Nigeria's most populous state, follows the national curriculum defined by the Nigerian Educational Research and Development Council (NERDC), which includes chemistry as a core science subject. However, the incorporation of green chemistry principles into this curriculum is minimal. The state also faces various environmental challenges, including air and water pollution, improper waste management, and industrial emissions (Samson & Toyin, 2012), which underscore the importance of green chemistry education.

Akinsipo and Anselm (2025c) emphasised the need for a more comprehensive approach to integrating green chemistry principles into the curriculum in Nigeria. Olaleye (2012) stressed the importance of enhancing teachers' pedagogical knowledge and beliefs to improve the teaching and learning of chemistry, while Lawal and Mustapha (2013) highlighted the role of chemistry educators play a vital role in enhancing the educational standards in Nigeria, highlighting the importance of creative learning methods.

These studies collectively highlight the significant gap between the current state of green chemistry education in Nigeria and the more advanced integration seen in developed countries. They also underscore the urgent need for assessment and enhancement of green chemistry competencies among chemistry teachers in Lagos State to bridge this gap and address the pressing environmental challenges faced by the region.

Despite the increasing global emphasis on green chemistry and its integration into educational curricula, chemistry teachers in Lagos State, Nigeria, exhibit low levels of awareness and knowledge of green chemistry principles and practices (Owoyemi & Umanah, 2019; Owoyemi & Adesina, 2021). This deficiency hampers the effective integration of sustainable chemistry practices into secondary school education, thereby limiting students' exposure to and understanding of environmentally responsible chemical processes. The existing teacher education curriculum in Nigeria does not adequately address the integration of green chemistry principles, and there is a lack of targeted capacity-building workshops and in-service training programs for chemistry teachers on green chemistry (Owoyemi & Umanah, 2019).

Furthermore, there is a dearth of comprehensive research assessing the specific green chemistry competencies and training needs of chemistry teachers in Lagos State, which is crucial for developing targeted interventions. Without such assessment, training programs may fail to address the specific gaps in teachers' knowledge and skills, resulting in ineffective professional development and continued inadequate implementation of green chemistry principles in the classroom. Therefore, this study seeks to assess the green chemistry competencies and training needs of secondary school chemistry teachers in Lagos State, Nigeria, with a view to providing evidence-based recommendations for developing targeted training programs that can enhance green chemistry teaching in secondary schools and contribute to broader environmental sustainability goals.

## 1.1. Research Objectives

The objectives of this study were to:

1. Assess the current level of green chemistry practice among chemistry teachers.
2. Identify the key competency areas that will enhance green chemistry practices among chemistry teachers.
3. Ascertain the specific training needs of chemistry teachers that will enhance their green chemistry competencies.

## 1.2. Research Questions

The study answered the following questions:

1. What is the current level of green chemistry practice among chemistry teachers?
2. What are the key competency areas that will enhance green chemistry practices among chemistry teachers?
3. What specific training needs do chemistry teachers require that will enhance their green chemistry competency?

## 2. METHODOLOGY

### 2.1. Research Design

This study employed a sequential mixed-methods research design to systematically investigate green chemistry competencies and training needs among secondary school chemistry teachers. The design followed a two-phase structure. In the quantitative phase, a structured questionnaire was used to assess teachers' perceived current green chemistry practices and key competency areas that will enhance green chemistry practices among them. Based on these results, participants for the qualitative phase were purposively selected to reflect varied competency levels. Semi-structured interviews were then conducted to explore and validate the self-reported practices by examining actual classroom experiences. Integration occurred during the interpretation stage through a side-by-side comparison of quantitative and qualitative findings. Specifically, teachers' self-assessed competencies were compared with their described classroom practices, and both datasets were mapped against established green chemistry competency standards. This process enabled the identification of specific training needs by highlighting gaps between perceived and actual competencies. This approach ensured methodological triangulation and enhanced the credibility and depth of the findings.

### 2.2. Population and Sample

The target population for this study comprised all secondary school chemistry teachers in Lagos State. Education District IV was selected randomly from among the six education districts in Lagos State. A purposive sampling technique was employed to recruit forty-three (43) chemistry teachers from secondary schools in the selected district. Teachers were chosen on the basis of their expressed willingness to participate and their ready accessibility to the researcher. To ensure broad coverage, at least one teacher was drawn from each school, maximising the sample's representativeness and supporting comprehensive data collection. This strategy balances practical considerations with the need for sufficient statistical power, enabling meaningful insights into participants' green chemistry knowledge, competency levels, and training needs.

Figure 1 presents a bar chart showing the frequency distribution of the gender of respondents.

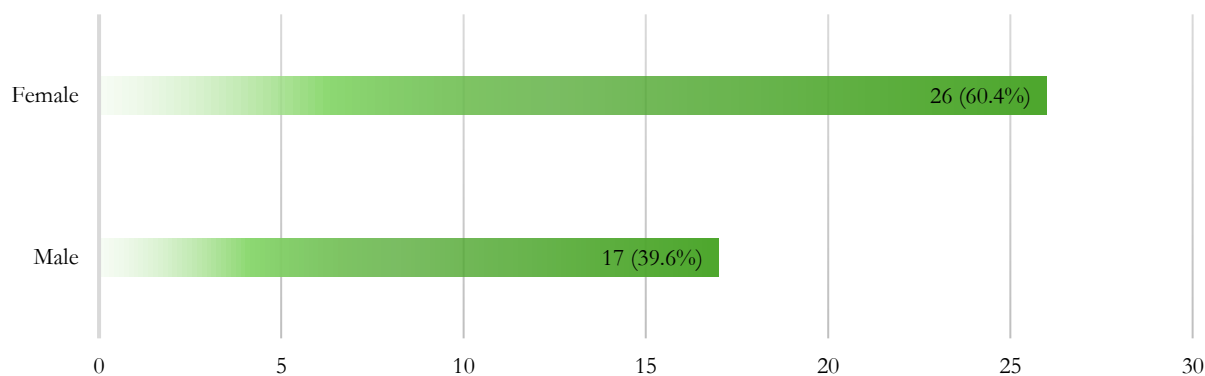
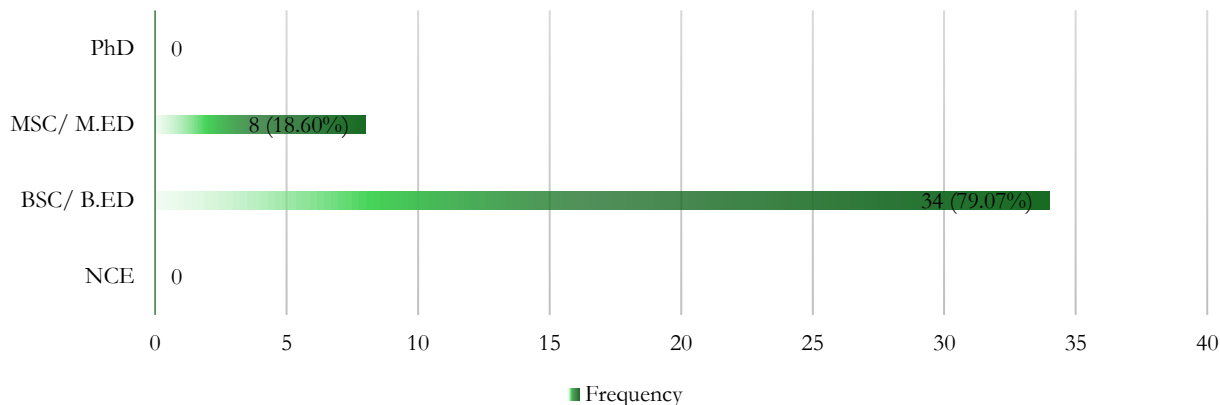


Figure 1. Frequency Distribution of Gender

The study sample comprised a total of 43 participants. Of these, 17 (39.6%) were male, and 26 (60.4%) were female, indicating a higher representation of female respondents.

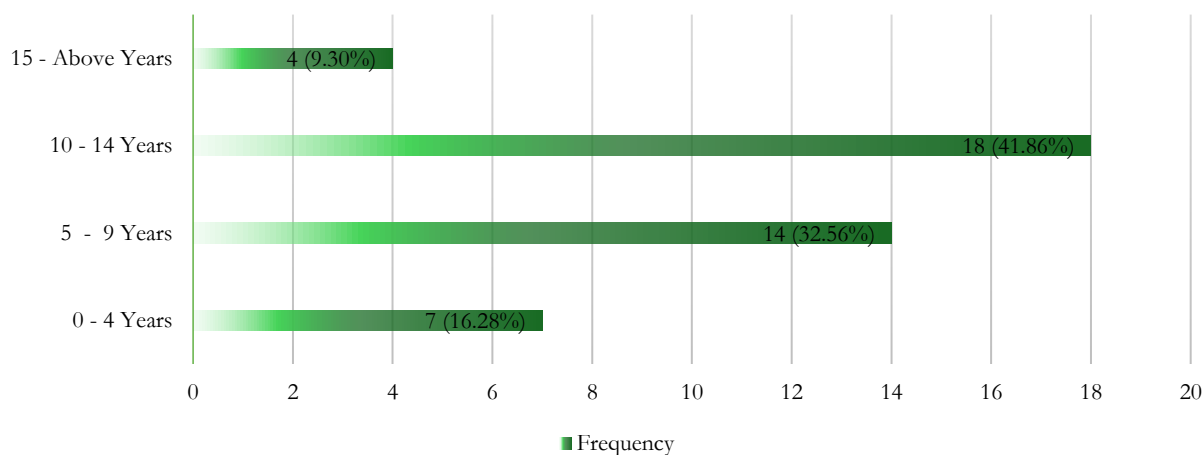
Figure 2 presents a bar chart showing the frequency distribution of professional qualifications of respondents.



**Figure 2.** Frequency Distribution of Professional Qualification

Regarding educational qualification, none of the participants held a PhD degree (0.0%). A total of 8 participants (18.6%) possessed a Master’s degree (MSc/MEd), while the majority, 34 participants (79.1%), held a Bachelor’s degree (BSc/BEd). This distribution suggests that most respondents had attained undergraduate-level qualifications, with a smaller proportion having pursued postgraduate education.

Figure 3 shows a bar chart showing the frequency distribution of years of experience of respondents.



**Figure 3.** Frequency Distribution of Years of Teaching Experience

In terms of teaching experience, 4 participants (9.3%) had more than 15 years of experience, 18 participants (41.9%) had between 10 and 14 years, 14 participants (32.6%) had between 5 and 9 years, and 7 participants (16.3%) had between 0 and 4 years of teaching experience. This distribution reflects a wide range of professional experience, with the majority of participants having at least five years of classroom teaching experience.

No participants declined to participate or withdrew from the study. All responses were completed in full, and there were no instances of missing data. Consequently, all 43 responses were included in the final analysis.

### 2.3. Research Instruments

Data was collected using the following instruments:

**Current Level of Green Chemistry Practice Questionnaire (CLPGCPQ):** This instrument was developed to collect data on the perceived (quantitative) data on current level of green chemistry practices among chemistry teachers. CLPGCPQ consists of two sections. Section A solicits data on the demographics of the respondents, i.e., chemistry teachers, which includes their gender, professional qualification status, and years of teaching chemistry experience. Section B consists of six items on the current level of green chemistry practice of chemistry teachers, which were positively worded. The questionnaires were constructed using the five-point Likert format, in such a way as to enable the teachers to respond to each statement in terms of their degree of frequency of practice, and the responses were scored thus: Never (1), Rarely (2), Sometimes (3), Often (4), and Always (5).

**Green Chemistry Key Competency Area Survey for Chemistry Teachers (GCKCASFCT):** This instrument was developed to identify key competency areas and training needs among chemistry teachers. GCKCASFCT consists of two sections. Section A solicits demographic data of the respondents, which includes their gender, professional qualification status, and years of teaching chemistry experience. Section B consists of nine items designed to assess chemistry teachers' competency in green chemistry across four domains: understanding of green chemistry principles, laboratory practices, integration into teaching, and need for professional development. Items were positively worded.

**Green Chemistry Practice Interview (GCPI):** This instrument was developed by the researcher to collect actual (qualitative) data to further establish the level of green chemistry practices among chemistry teachers. GCPI was developed to further establish and validate the survey data to gain deeper insights into the teachers' actual classroom practices and challenges. The six-item semi-structured interview protocol was designed based on the CLPGCPQ items. Each interview session lasted 10-30 minutes and was audio-recorded with participant consent. Thematic analysis was then used to find recurrent themes and patterns in the verbatim transcript.

### 2.4. Validity and Reliability of Research Instruments

The instruments were given to the supervisor and two other experts in the field of green chemistry education, for face, content, and construct validity. The reliability of the instrument was established using ten samples from a population of Pre-service Chemistry teachers. The data was obtained and analysed with its reliability assessed using Cronbach's alpha (using the Statistical Package for Social Science, SPSS, version 27). With a Cronbach's alpha coefficient of 0.80, CLPGCPQ showed excellent internal consistency, suggesting accurate construct assessment. With a Cronbach's alpha of 0.72, GCKCASFCT showed excellent internal consistency, assuring accurate assessment of the intended constructs. The GCPI yields qualitative, coded data rather than continuous Likert scores, so internal consistency metrics are inappropriate. Instead, two independent coders analysed a random subset of 10 transcripts using the finalised coding scheme; inter-rater agreement was quantified with Cohen's kappa. The overall  $\kappa = 0.82$  ( $p < .001$ ), which indicates strong agreement between coders, confirming the dependability of the thematic analysis.

### 2.5. Data Collection

The data collection procedure for this study followed a systematic approach aligned with the sequential mixed-methods design. Initially, formal approvals were obtained from relevant educational authorities in Education District IV of Lagos State, Nigeria. After securing these permissions, participating schools were contacted to schedule convenient times for data collection activities with minimal disruption to their academic schedules. The steps involved in data collection are explained in phases below:

**Quantitative Phase:** The quantitative phase commenced with the administration of the Current Level of Green Chemistry Practice Questionnaire (CLPGCPQ) to assess teachers' self-reported green chemistry practices. The 43 chemistry teachers completed this instrument, which featured demographic information and six Likert-scale items measuring the frequency of specific green chemistry practices.

Subsequently, participants completed the Green Chemistry Key Competency Area Survey for Chemistry Teachers (GCKCASFCT) to identify key competency areas and training needs across four domains: understanding of green chemistry principles, laboratory practices, integration into teaching, and need for professional development.

**Qualitative Phase:** Semi-structured interviews were conducted using the Green Chemistry Practice Interview (GCPI) protocol. These 10–30-minute interview sessions were scheduled at times convenient for the participating teachers and were audio-recorded with their explicit consent. The interviews provided deeper insights into actual green chemistry classroom practices as well as challenges faced in implementing these practices. This triangulation approach enhanced the validity of the findings by complementing the quantitative data with rich qualitative information.

**Need Analysis:** After data collection, a systematic need analysis was performed by comparing the current practices against established competency standards to identify specific training needs among the chemistry teachers.

## 2.6. Method of Data Analysis

Data were analysed using a mixed-methods approach. Quantitative responses from the CLPGCPQ and GCKCASFCT were entered into SPSS v26, where descriptive statistics (means, standard deviations, frequencies, and percentages) and appropriate inferential tests were conducted. Qualitative interview transcripts were then examined via thematic analysis following Braun and Clarke's (2006) framework, with codes developed inductively to identify recurrent themes concerning classroom practices and barriers to implementing green chemistry.

## 3. RESULTS

**Research Question 1:** What is the current level of green chemistry practice among chemistry teachers?

**Table 1.** Descriptive analysis of the perceived current level of green chemistry practice of chemistry teachers

S/N	Statements	Never %	Rarely %	Sometimes %	Often %	Always %	M	SD
1	I incorporate green chemistry principles in my lesson plans.	40 (88.89%)	2 (4.44%)	1 (2.22%)	2 (4.44%)	-	1.22	0.97
2	I select environmentally friendly chemicals and reagents for experiments	41 (91.11%)	1 (2.22%)	1 (2.22%)	2 (4.44%)	-	1.20	0.91
3	I implement waste reduction and proper disposal methods in my chemistry practices	39 (86.67%)	4 (8.89%)	1 (2.22%)	-	1 (2.22%)	1.22	0.92
4	I apply the principle of atom economy when designing or conducting experiments	41 (91.11%)	4 (8.89%)	-	1 (2.22%)	-	1.18	0.86
5	I adopt the use of safer solvents and auxiliaries in lab work.	40 (88.89%)	4 (8.89%)	-	1 (2.22%)	-	1.16	0.82
6	I incorporate the concept of energy efficiency in my chemistry lessons.	41 (91.11%)	4 (8.89%)	-	-	-	1.09	0.73
<i>Weighted Mean = 1.18</i>								

Table 1 shows a significantly low level of green chemistry practice among chemistry teachers. The current level of green chemistry practice among chemistry teachers is notably low, with very few teachers regularly engaging in these practices. The results show that the majority of teachers rarely engage in green chemistry practices. For instance, 88.89% of teachers reported that they never incorporate green chemistry

principles in their lesson plans, resulting in a low mean score ( $M = 1.22$ ,  $SD = 0.97$ ). Similarly, 91.11% of teachers state they never select environmentally friendly chemicals and reagents for experiments ( $M = 1.20$ ,  $SD = 0.91$ ). Moreover, 86.67% of teachers never implement waste reduction and proper disposal methods in their chemistry practices ( $M = 1.22$ ,  $SD = 0.92$ ), and 91.11% never apply the principle of atom economy in their experimental designs ( $M = 1.18$ ,  $SD = 0.86$ ). Additionally, only 2.22% of teachers indicated that they sometimes or often adopt the use of safer solvents and auxiliaries in lab work ( $M = 1.16$ ,  $SD = 0.82$ ), and a mere 8.89% report incorporating the concept of energy efficiency into their chemistry lessons ( $M = 1.09$ ,  $SD = 0.73$ ). The overall weighted mean score across all items was 1.18, indicating a generally low level of green chemistry practice among the chemistry teachers surveyed.

To further establish the actual competency level of green chemistry practices, ten chemistry teachers who indicated rarely, sometimes, or often GC practice were interviewed. Based on qualitative data from the interviews, responses were categorised into thematic themes, sub-themes, and the actual levels of practice corresponding to specific questions asked.

**Table 2.** Thematic Analysis of the Actual Green Chemistry Practice of Chemistry Teachers

Themes	Sub-themes	Actual Green Chemistry Practice
Incorporation of Green Chemistry Principles into Lesson Plans	<i>Selective Incorporation of Green Chemistry</i>	Teachers shared specific instances where they incorporated green chemistry selectively, particularly during experiments. Teacher B, who often practices the mentioned, <i>“I try my best to include it whenever I can, especially in practical. For example, when we’re experimenting, I’ll show them how to use fewer chemicals or reuse materials where possible, just to avoid unnecessary waste. Students get interested when they see science, and can be mindful of the environment. But not every topic fits green chemistry principles neatly, and sometimes our syllabus demands more traditional methods. So, I only bring it in where it makes sense.”</i> Teacher C, who often practices incorporating GC principles when covering topics like pollution, acid and base, and catalysis. This selective approach was based on relevance to the topic and feasibility within the curriculum. <i>“Green chemistry is something I often bring up, especially when I’m teaching topics like pollution, acid and base, and catalysis. For example, I usually dilute acid and base to 0.01M in carrying out titration with my chemistry students to ensure it is safer. I want my students to know that science can be used responsibly to protect the environment, even with the small things we do in the classroom. But I won’t lie, some topics are a bit too theoretical for them at this level, so I focus on the practical areas I know they’ll understand and remember.”</i>
	<i>Curriculum and Resource Constraints</i>	Factors such as time limitations and syllabus demands restricted consistent incorporation of green chemistry principles into the chemistry lesson plan. Teacher A, who indicated sometimes practice mentioned, <i>“Honestly, I bring in green chemistry principles when I can, but it’s not always easy to make it happen. For instance, if I’m teaching a topic like acids and bases, I might talk about reducing waste by using smaller quantities, maybe during titration. But, between limited resources and a packed syllabus, it’s hard to fit it all in. I want the students to see the importance of handling chemicals carefully and minimising waste, but without the right materials or support, it’s challenging to make it a regular part of my lessons.”</i>
Selection of Environmentally Friendly Chemicals	<i>Preference for Safer Options</i>	Teachers demonstrated a preference for environmentally friendly chemicals. For example, Teacher C, who indicated often practising, stated, <i>“I intentionally pick safer chemicals as much as I can, for solvents, I always use water. For instance, instead of using concentrated acids, I used lime water to demonstrate the litmus paper colour change properties of acids. It does take more planning, but I believe it’s important to show the students that science can be safe and responsible. They’re learning a lot by seeing these choices in action, and it gives them a sense of responsibility that I hope stays with them.”</i> Teacher B, who often practices, emphasised choosing gentler options to ensure student safety and environmental consciousness. <i>“I try to go for safer, more eco-friendly chemicals whenever possible. For instance, if I can use something gentler for a reaction, I will, because it’s better for everyone’s safety. I often use tartaric acid instead of sulphuric acid for titration. But I’m limited by the stock the school has. I tell my students about the importance of choosing responsibly, a less harmful option.”</i>

Themes	Sub-themes	Actual Green Chemistry Practice
	<i>Challenges of Limited Resources and Syllabus Provision</i>	Consistent use of environmentally friendly chemicals was limited by school-provided chemical inventories. This highlighted the need for expanded resources to support the regular use of safer chemicals. Teacher A, who indicated sometimes practices, remarked, “ <i>I try when I can, but the options can be limited. Our school provides a fixed list of chemicals each year, so I mostly have to make do with what we have. When there’s a choice, for instance, there was a time I requested the purchase of tartaric acid. For external examinations, WAEC has always requested that we use sulphuric or hydrochloric acid; this is also a concern I have. I try to use safer options for the student’s sake. The reality is, I work with what’s in front of me. I make sure I emphasise safety during my teaching anyway.</i> ”
Waste Reduction and Disposal Methods	<i>Implementing Waste Minimisation Strategies and Resource Constraints</i>	Teachers emphasised careful measurement and material reuse. Their efforts align with green chemistry principles and instill responsible lab habits in students. For example, Teacher B, who indicated always practising, stated, “ <i>I make it a point of duty to reduce waste in every lab session. For instance, I measure chemicals minimally and carefully ensure that we are not using more than we need, and I teach students the right way to dispose of materials. I believe these habits are part of being a responsible chemist, and they also make lab work safer for everyone. For example, after carrying out the titration for SS2&amp;3 students, I tell my students to neutralise the acid and base used by adding excess water to them before pouring them away. The main challenge I had initially with this strategy was that the students didn’t understand why they should neutralise first before disposing if they’re going to be disposed of eventually.</i> ” Teacher A, who indicated sometimes practice reported, “ <i>I try to keep waste down by using smaller amounts of chemicals in our experiments, especially titration, or by reusing materials where possible. But, if I’m honest, it’s not always easy – we don’t have a lot of storage equipment, like standard flasks and gallon bottles. The reality is that I do what I can with what we have. It’s important to me to show students the value of reducing waste, but without the right resources, I can only go as far as I can go.</i> ”
Application of Atom Economy	<i>Curricular Constraints and Limited Resources</i>	Teachers reported that the atom economy helps students grasp the importance of resource efficiency. Teacher B, who indicated sometimes practice shared, “ <i>For example, in SS3 when I was teaching synthesis of hydrogen gas under hydrogen and its compounds, I explained the reaction of zinc with sulphuric acid as a more atom-economic reaction due to fewer reactants and by-products than the reaction of aluminium with water. It’s a valuable lesson because it shows them the importance of using resources wisely and more efficiently. The challenge, though, is that not every reaction in the curriculum can be used to demonstrate atom economy, especially by demonstrating practicality with the students. If I didn’t have prior knowledge of green chemistry myself, I may also find it difficult to pinpoint.</i> ”
Use of Safer Solvents and Auxiliaries	<i>Commitment to Student Health</i>	Teachers prioritised the use of safer solvents to promote health and environmental awareness. Teacher B, who often practices, stated, “ <i>I’m always mindful of choosing safer solvents – in fact, I always use water for dissolution or dilution, sometimes ethanol. There was a time I used ethanol to extract green pigment (chlorophyll) from plant leaves. I used it to demonstrate the concept of solute, solvent, and solution in SS2.</i> ”

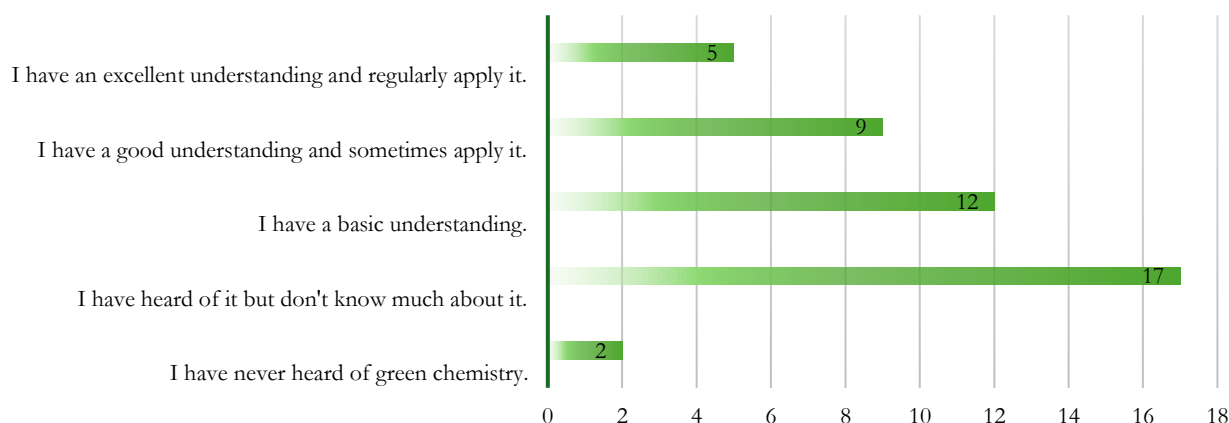
**Research Question 2:** What are the key competency areas that will enhance green chemistry practices among chemistry teachers?

### Domain 1: Understanding of GC Principles

**Table 3.** Teachers’ Ratings of Their Understanding of GC Principles

Rating	Percentage (%)
Poor	15 (33.33%)
Fair	21 (46.67%)
Good	6 (13.33%)
Excellent	3 (6.67%)

Figure 4 shows a bar chart of familiarity with GC concepts among chemistry teachers.



**Figure 4.** Level of Familiarity with GC Concept

Figure 4 reveals that chemistry teachers have a limited understanding of the principles of green chemistry. The majority of the teachers have heard of GC but do not know much about it. Thus, understanding of GC principles is identified as a key competency area that will enhance green chemistry practices among chemistry teachers if addressed. Table 4.3.3 shows that fifteen (33.33%) chemistry teachers have a poor understanding, twenty-one (46.67%) report a fair understanding, six (13.33%) a good understanding, and three (6.67%) an excellent understanding. Furthermore, the data shows that seventeen (37.78%) chemistry teachers predominantly report having heard of GC but don't know much about it. This further establishes that knowledge and understanding of GC principles is a key area that is lacking among chemistry teachers.

## Domain 2: Application of GC into Chemistry Lessons

Table 4 reveals that chemistry teachers have limited application of GC in chemistry lessons. It identifies low ratings for incorporating GC into chemistry lessons, especially in specific aspects where chemistry teachers lack confidence in such as energy efficiency in teaching chemical processes, green product design, and environmental impact awareness. These areas are identified as key competency areas that will enhance green chemistry practices among chemistry teachers if addressed. The results show a significant gap in the integration of GC into chemistry lessons. A vast majority of teachers (88.89%) indicate that they never incorporate GC principles, with only a small minority incorporating them either rarely or sometimes. Notably, no teacher reports consistently include GC in their chemistry lessons. This suggests that although GC is recognised as an important area, its practical application in chemistry lessons is currently lacking.

**Table 4.** Teachers' Ratings of Incorporating GC into Chemistry Lessons

Rating	Percentage (%)
Never	40 (88.89%)
Rarely	2 (4.44%)
Sometimes	1 (2.22%)
Often	2 (4.44%)
Always	-
Total	100.0

Table 5 further provides insight into teachers' confidence in teaching specific aspects of GC in chemistry lessons. Teachers report moderate confidence in areas like waste reduction in experiments, where 62.2% indicates moderate confidence. However, confidence is lower in areas like energy efficiency and green product design. Twenty-three (51.1%) teachers express low confidence in teaching green product design, and nineteen (42.2%) show low confidence in energy efficiency. Similarly, confidence in using renewable resources and assessing environmental impact is generally moderate but not high. The findings

suggest that the application of GC into chemistry lessons (especially specific aspects – energy efficiency and green product design) remains a key challenge for chemistry teachers.

**Table 5.** Teachers' Confidence Ratings in Teaching Specific Aspects of GC

Aspects of GC	1 %	2 %	3 %	4 %	5 %
Waste reduction in experiments	2 (4.4%)	12 (26.7%)	28 (62.2%)	3 (6.7%)	-
Energy efficiency in chemical processes	6 (13.3%)	19 (42.2%)	11 (24.4%)	6 (8.9%)	3 (11.1%)
Use of renewable resources	5 (11.1%)	10 (22.2%)	21 (46.7%)	7 (15.6%)	2 (4.4%)
Green product design	11 (24.4%)	23 (51.1%)	8 (17.8%)	2 (4.4%)	1 (2.2%)
Environmental impact assessment	2 (4.4%)	14 (31.1%)	25 (55.6%)	2 (4.4%)	2 (4.4%)

1 – No Confidence, 2 – Low Confidence, 3 – Moderate Confidence, 4 – High Confidence, 5 – Complete Confidence

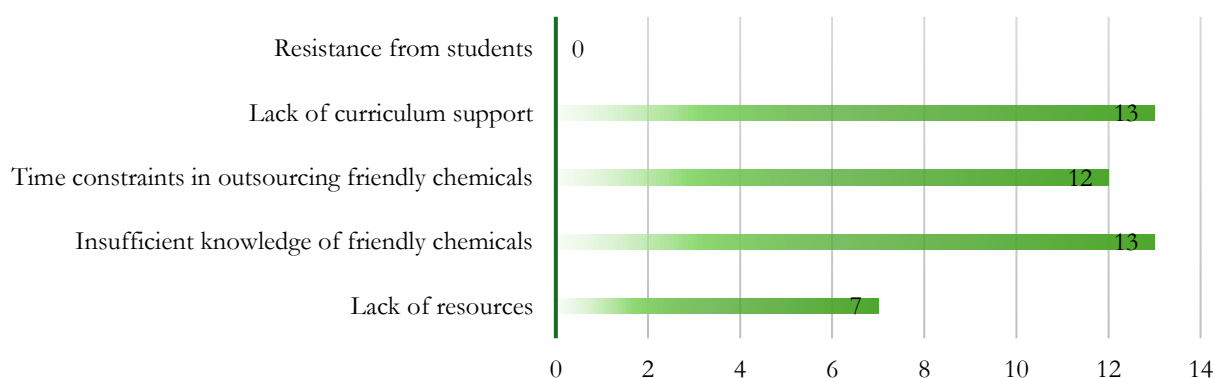
### Domain 3: Laboratory Practices of GC

Table 6 reveals that chemistry teachers limit the laboratory practices of GC. It identifies that chemistry teachers predominantly consider only to a moderate extent the environmental impact when selecting chemicals for laboratory experiments. Thus, addressing teachers' ability to select environmentally friendly chemicals for laboratory experiments is a key competency area that will enhance green chemistry practices among chemistry teachers if addressed. The results reveal that while a majority of teachers consider environmental impact to some degree, it is not a primary concern for many. Only a small percentage of teachers (4.44%) consistently prioritise environmental impact in chemical selection, while the majority consider it only to a moderate extent (42.22%) or a slight extent (40.00%). A significant minority (8.89%) does not consider it at all. This data highlights a gap in environmental mindfulness when planning laboratory experiments.

**Table 6.** Teachers' Ratings on Considering Environmental Impact when Selecting Chemicals/Green Alternatives for Laboratory Experiments

Rating	Percentage (%)
Not at all	4 (8.89%)
To a slight extent	18 (40.00%)
To a moderate extent	19 (42.22%)
To a great extent	2 (4.44%)
Almost Always	2 (4.44%)
Total	100.0

Figure 5 shows a bar chart of challenges faced in implementing GC practices in laboratory experiments.



**Figure 5.** Challenges of Implementing GC Practices in the Laboratory

Figure 5 identifies challenges of implementing GC practices in the laboratory, such as a lack of curriculum support (13), insufficient knowledge of friendly chemicals (13), time constraints in outsourcing friendly chemicals (12), and a lack of resources (7). These areas are therefore important to enhancing green chemistry practices among chemistry teachers. The results identify challenges faced by chemistry teachers in implementing GC practices in laboratory experiments. The most prominent obstacles include a lack of curriculum support (13), insufficient knowledge of friendly chemicals (13), and time constraints in outsourcing friendly chemicals (12). These challenges suggest that structural and educational barriers are limiting the effective integration of green chemistry into laboratory practices. No teachers reported resistance from students as a challenge, indicating that the challenges mainly lie more with the institutional and personal capabilities of chemistry teachers than with student engagement.

#### Domain 4: Professional Development

Table 7 reveals that chemistry teachers' rate of high need for professional development in the concept of GC. It identifies a strong demand (high or complete need) for a deeper understanding of GC principles (95.56%), strategies to integrate GC into the curriculum (93.33%), practical skills for conducting GC experiments (86.67%), and the ability to assess environmental impacts of chemical processes (95.56%). Thus, these areas are key to enhancing green chemistry practices among chemistry teachers if addressed by an area-specific GC professional development program.

**Table 7.** Teachers' Ratings of Need for Professional Development in GC

Aspects	1 %	2 %	3 %	4 %	5 %
Understanding green chemistry principles	-	-	2 (4.44%)	31 (68.89%)	12 (26.67%)
Integrating green chemistry into the curriculum	-	-	3 (6.67%)	29 (64.44%)	13 (28.89%)
Conducting green chemistry experiments	-	-	6 (13.33%)	35 (77.78%)	4 (8.89%)
Assessing the environmental impact of chemical processes	-	-	2 (4.4%)	30 (66.67%)	13 (28.89%)

1 – No Need, 2 – Low Need, 3 – Moderate Need, 4 – High Need, 5 – Complete Need

**Research Question 3:** What specific training needs do chemistry teachers require that will enhance their green chemistry competency?

**Table 8.** Needs Analysis of Required GC Specific Training Needs for Chemistry Teachers

S/N	KCA	CS	RSTN
1	Understanding the principles of GC	46.67% of chemistry teachers have a fair understanding, and 33.33% have either poor or very poor understanding (see table 4.3.3). 68.89% of chemistry teachers indicate a high need for PD (see Table 4.3.7).	General training on the 12 principles of green chemistry and their application in the chemistry classroom
2	Incorporating GC into chemistry lessons	88.89% of chemistry teachers never incorporate green principles into chemistry lessons (see table 4.3.1).	Training on how to incorporate GC principles into chemistry lessons – plan, instructional strategy, and materials
3	Selecting environmentally friendly chemicals/ green alternatives	91.11% of chemistry teachers never select environmentally friendly alternatives for lab experiments (see Table 4.3.1). 88.89% of chemistry teachers never adopt the use of safer solvents and auxiliaries in lab work (see Table 4.3.1).	Training on identifying and sourcing green alternatives for lab experiments

S/N	KCA	CS	RSTN
4	Conducting green experiments and lab practices	91.11% of chemistry teachers express a high need (see table 4.3.7) while only 4.44% of chemistry teachers consistently consider environmental impact when selecting chemicals (see table 4.3.6).	Training on conducting green experiments and assessing environmental impact during lab activities
5	Waste reduction and disposal strategy	86.67% of chemistry teachers never implement waste reduction during lab (see Table 4.3.1).	Training on waste management strategies and their implementation in chemistry lessons
6	Applying atom economy, energy efficiency, renewable resources, and green product design into chemistry instruction	91.11% of chemistry teachers never apply atom economy and incorporate energy efficiency into chemistry lessons (see Table 4.3.1). 51.1% of chemistry teachers have low confidence in green product design, and 55.5% in using renewable resources (see Table 4.3.1).	Training on applying the principles of atom economy and energy efficiency in chemistry lessons Training on identifying and sourcing renewable resources and adapting green product design in chemistry lessons

KCA – Key Competency Areas, CS – Current Status, RSTN – Required Specific Training Needs

Table 8 identified six (6) key competency areas (KCAs) where chemistry teachers require specialised training to enhance their GC competency. These areas include *Understanding Green Chemistry Principles, Integration of Green Chemistry into Lesson Planning, Selection of Environmentally-Friendly Chemicals and Reagents, Conducting Green Chemistry Experiments, Waste Reduction and Disposal Strategies and Applying Atom Economy, Energy Efficiency, Renewable Resources, and Green Product Design into Chemistry Instruction.*

The results show that the majority of teachers (68.89%) indicated a high need for training on the 12 principles of green chemistry and their relevance to secondary education. This foundational knowledge is essential for effective curriculum integration and to foster an environmentally conscious mindset among students. Also, the result shows that training is needed to equip teachers with strategies for embedding green chemistry concepts into chemistry lessons, including effective lesson planning, instructional strategies, and development of sustainable instructional materials. This would bridge the observed gap where nearly 89% of teachers are not incorporating green practices in their teaching.

Also, the results identified that teachers expressed a lack of confidence in identifying and sourcing safer, environmentally-friendly alternatives for laboratory experiments, given that 91.11% of teachers never adopted green alternatives in lab practices. Also, the result shows that there is a substantial need for practical training focused on conducting green chemistry experiments, particularly on assessing environmental impacts within lab activities. Only 4.44% of teachers consistently considered environmental factors when selecting chemicals, indicating a pressing need to reinforce this competency through hands-on training.

Furthermore, the results show that about 87% of chemistry teachers do not implement waste reduction practices in the lab, highlighting the need for professional development that covers waste management strategies and environmentally friendly disposal techniques that adhere to the principles of green chemistry. Chemistry teachers showed limited confidence in applying advanced green chemistry concepts such as atom economy, energy efficiency, use of renewable resources, and green product design in chemistry instruction. Training in these areas would not only improve their competency but also provide students with relevant skills for a sustainable future.

#### 4. DISCUSSION

The findings revealed a significantly low level of green chemistry practice among the chemistry teachers. The data showed that 88.89% of teachers never incorporate green chemistry principles in their lesson plans, 91.11% never select environmentally friendly chemicals for experiments, 86.67% never implement waste reduction methods, and 91.11% never apply atom economy principles when designing experiments. This finding is consistent with the studies of Owoyemi and Umanah (2019) and Owoyemi and Adesina (2021), which reported very low levels of awareness and knowledge of green chemistry concepts, principles, and importance among secondary school teachers in Lagos State. The finding aligns with recent research that demonstrates similar patterns of limited green chemistry implementation.

Akinsipo and Anselm (2025) found that teachers across Nigerian universities had a limited understanding of green chemistry principles, with challenges including inadequate training, limited resources, and unclear implementation guidelines. These findings align with recent global trends highlighting the persistent challenges in sustainability education implementation. Fischer et al. (2022) emphasised that Teacher Education for Sustainable Development (TESD) remains a niche innovation in teacher education despite its critical importance in preparing learners to address global sustainability challenges.

The qualitative data further revealed that even those teachers who indicated occasional practice of green chemistry faced significant challenges, including curriculum and resource constraints, which limited their ability to consistently implement green chemistry principles in their teaching. These barriers reflect broader institutional and policy-level challenges that extend beyond individual teacher capacity. Contemporary research by Akinsipo and Anselm (2025) and Alhazmi and Almashhour (2025) emphasises that green chemistry education serves as a critical bridge for achieving sustainable development goals, yet implementation remains hindered by systemic gaps in knowledge and institutional support. Their findings suggest that the curriculum and resource constraints identified in Lagos State are symptomatic of inadequate policy frameworks that fail to prioritise sustainability education at the institutional level.

The study identified several key competency areas, including understanding of green chemistry principles, application of green chemistry into chemistry lessons, laboratory practices of green chemistry, and professional development. The findings showed that 46.67% of teachers reported only a fair understanding of green chemistry principles, while 33.33% reported poor understanding. Additionally, teachers expressed low confidence in teaching specific aspects of green chemistry, particularly in areas like green product design (51.1% reported low confidence) and energy efficiency (42.2% reported low confidence). This finding aligns with Akinsipo and Anselm (2025c), who emphasised the need for a more comprehensive approach to integrating green chemistry principles into the curriculum in Nigeria. The identified challenges in implementing green chemistry in laboratory practices included a lack of curriculum support, insufficient knowledge of environmentally friendly chemicals, time constraints, and a lack of resources, highlighting the structural and educational barriers limiting effective integration of green chemistry.

Recent research by Miladinović (2024) underscores these competency deficiencies, asserting that the comprehensive incorporation of green chemistry into the undergraduate curriculum is essential for equipping students for a sustainable future. This study's findings of low teacher confidence in green chemistry concepts mirror broader concerns about curriculum transformation needs. The structural barriers identified in Lagos State parallel those documented in recent international studies, where teachers demonstrated low confidence in integrating green principles in secondary chemistry modules (Idul et al., 2025; Stouthart et al., 2025). Sustainable chemistry teaching necessitates the enhancement of individual teacher capabilities alongside comprehensive educational reform (Alhazmi & Almashhour, 2025).

The findings consequently identified six key competency areas requiring specialised training: understanding green chemistry principles, integration of green chemistry into lesson planning, selection of environmentally-friendly chemicals, conducting green chemistry experiments, waste reduction strategies, and applying advanced concepts like atom economy and energy efficiency. The results showed that 68.89% of teachers indicated a high need for training on the 12 principles of green chemistry, 93.33% expressed a need for strategies to integrate green chemistry into the curriculum, and 86.67% wanted practical skills for carrying out green chemistry experiments. This result aligns with Chen et al. (2020), who found that effective frameworks for enhancing teacher competency in green chemistry frequently employ multidisciplinary and problem-based learning approaches to promote sustainable education. The identified training needs highlight the gap between traditional chemistry education and the expectations of a sustainable future, as noted by Zuin et al. (2021), emphasising the critical demand for specific training programs to equip chemistry teachers with green chemistry competencies.

The training needs identified in this study are particularly relevant given recent developments in green chemistry education. The American Chemical Society's Green Chemistry Institute has been actively promoting professional development through initiatives such as the Green & Sustainable Chemistry Summer School (ACS, 2025), while organisations like Beyond Benign have established grant programs specifically targeting green chemistry curriculum development (Beyond Benign, 2024). These initiatives recognise that effective green chemistry integration requires comprehensive teacher preparation. The high

demand for curriculum integration strategies (93.33%) found in this study reflects global recognition that sustainability education cannot be an add-on but must be woven throughout the chemistry curriculum, as emphasised in UNEP's Specialised Manual on Green and Sustainable Chemistry Education and Learning (UNEP, 2024).

The findings of this study have critical implications for science education policy makers, curriculum developers, teacher educators, and green chemistry experts. First, the significantly low level of green chemistry practice among secondary school chemistry teachers in Lagos State highlights a significant gap between theoretical awareness and practical application. This discrepancy underscores the urgent need for systematic interventions in teacher preparation and professional development programs. Educational authorities and policymakers, particularly those overseeing science and environmental education in Nigeria, must prioritise sustainable chemistry practices in educational frameworks to bridge this implementation gap.

For curriculum developers, the findings emphasise the necessity of redesigning chemistry curricula to move beyond theoretical concepts and incorporate sustainability principles more explicitly. The identified competency areas where teachers lack confidence, particularly in green product design, require immediate attention through curriculum reforms that balance conceptual understanding with practical applications of green chemistry. This integration would provide teachers with clearer guidelines on incorporating sustainability into their teaching practices. Specifically, given that 93.33% of teachers expressed the need for curriculum integration strategies, curriculum developers should create explicit green chemistry modules within existing chemistry topics. For example, when teaching organic synthesis reactions, curricula should include comparative analyses of traditional versus green synthetic pathways, emphasising atom economy principles that 91.11% of teachers currently never apply. Additionally, laboratory manuals should be redesigned to replace traditional experiments with greener alternatives, addressing the finding that 91.11% of teachers never select environmentally friendly chemicals. This could include substituting toxic solvents with water-based alternatives in extraction experiments and incorporating microchemistry techniques to address the waste reduction methods that 86.67% of teachers currently never implement.

Teacher educators must address the competency gaps identified in principles of green chemistry, laboratory safety, and integration of sustainability concepts. The study shows the importance of equipping teachers with practical competencies through targeted professional development workshops. Teacher preparation programs should foster an interdisciplinary mindset, enabling educators to connect chemistry concepts with real-world environmental challenges. Based on the finding that 68.89% of teachers need training on the 12 principles of green chemistry, in-service training programs should be structured as modular workshops, with each module focusing on 2-3 principles and their classroom applications. For instance, Module 1 could address "Prevention and Atom Economy" through hands-on activities where teachers design experiments comparing traditional and green synthetic routes. Module 2 could focus on "Safer Chemicals and Renewable Feedstocks" by having teachers evaluate and select environmentally benign alternatives for common laboratory chemicals. Given that 51.1% reported low confidence in green product design, a dedicated Module 3 should provide teachers with design thinking frameworks to guide students in creating eco-friendly products using chemistry principles. These training programs should follow a 70-20-10 model: 70% hands-on laboratory practice, 20% collaborative lesson planning sessions, and 10% theoretical foundation, directly addressing the practical skills gap identified in 86.67% of teachers.

For green chemistry experts, the needs analysis results offer valuable insights for designing effective training interventions. The identified six key competency areas requiring specialised training should inform the creation of localised, teacher-centred professional development programs. Tailored workshops can effectively equip teachers with actionable skills to implement sustainable practices in resource-constrained environments. Green chemistry experts should develop context-specific training materials that address the Nigerian educational environment's unique challenges. This includes creating low-cost green chemistry experiment kits using locally available materials, developing simplified green chemistry assessment rubrics that teachers can easily implement, and establishing mentorship networks where expert practitioners support teachers during their initial implementation phases. Furthermore, experts should collaborate with local chemical suppliers to create "green chemistry starter kits" containing safer, affordable alternatives to traditional laboratory chemicals, directly addressing the resource constraints identified by teachers.

Furthermore, this study affirms the necessity of collaborative approaches between educational institutions, environmental agencies, and chemistry industries to provide comprehensive support systems for teachers. The identified challenges in implementing green chemistry in laboratory practices, including a lack of curriculum support, insufficient knowledge of environmentally friendly chemicals, time constraints, and a lack of resources, highlight the structural and educational barriers that must be addressed collectively. By addressing the identified competency gaps through targeted interventions, stakeholders can collectively contribute to advancing sustainable chemistry education in Nigerian secondary schools, thereby promoting environmental literacy and responsible citizenship among future generations. To operationalise this collaboration, education policymakers should establish Green Chemistry Education Consortia at the state level, bringing together secondary schools, universities, environmental agencies, and local industries. These consortia could facilitate resource sharing, joint professional development programs, and the creation of community-based green chemistry laboratories that multiple schools can access. Additionally, policymakers should incentivise green chemistry integration through policy frameworks that make sustainable chemistry practices a requirement for school accreditation, supported by dedicated funding streams for green chemistry laboratory equipment and teacher training. This systematic approach would transform the current situation, where over 88% of teachers never practice green chemistry, into a sustainable model where green chemistry becomes integral to secondary chemistry education.

## 5. CONCLUSION AND RECOMMENDATIONS

This study reveals significant gaps in green chemistry competencies among secondary school chemistry teachers in Lagos State, Nigeria, with findings indicating limited implementation of sustainable practices in classroom instruction. The assessment identified specific deficiencies in teachers' understanding and application of green chemistry principles, laboratory safety protocols, and integration of sustainability concepts into the curriculum. The needs analysis further highlighted teachers' requirements for hands-on training in green chemistry experiments, waste minimisation techniques, and the development of context-specific teaching materials. These findings collectively point to systemic challenges in Nigeria's chemistry education system, where theoretical knowledge is prioritised over practical, environmentally sustainable approaches. To address these challenges, comprehensive interventions are needed, including curriculum reforms that explicitly incorporate green chemistry principles, targeted professional development programs focused on practical applications, and increased resource provision for sustainable chemistry teaching. By implementing these recommendations, educational stakeholders can work toward closing the identified competency gaps, thereby enhancing environmental literacy among teachers and students and promoting more sustainable scientific practices in secondary education.

Based on these findings, the following recommendations are made:

1. **Development of Comprehensive Green Chemistry Professional Development Programs:** Based on the findings revealing limited implementation of green chemistry principles among Lagos State chemistry teachers, it is recommended that educational authorities develop and implement comprehensive professional development programs focused specifically on green chemistry competencies. These programs should prioritise hands-on training in conducting green chemistry experiments, waste minimisation techniques, and the practical application of sustainable chemistry principles in classroom settings. The training should be designed to address the identified competency gaps and should incorporate local environmental contexts and challenges to make learning relevant and immediately applicable.
2. **Curriculum Reform to Integrate Sustainability Principles:** The findings highlighted that existing chemistry curricula in Nigeria focus heavily on theoretical concepts while neglecting sustainability and environmental concerns. Therefore, a thorough revision of the secondary school chemistry curriculum is recommended to integrate green chemistry principles across all relevant topics explicitly. This curriculum reform should balance theoretical knowledge with practical applications, providing clear guidelines for teachers on incorporating sustainability concepts into their lessons. The revised curriculum should include specific learning outcomes related to environmental awareness and sustainable scientific practices, ensuring that green chemistry becomes a fundamental aspect of chemistry education rather than an optional add-on.

3. Establishment of Resource Centres and Support Systems: The research indicated that teachers lack the necessary resources to implement green chemistry practices effectively. It is recommended that resource centres be established in educational districts across Lagos State to provide teachers with access to green chemistry materials, equipment, and teaching aids. These centres should offer ongoing support through mentorship programs, collaborative learning communities, and regular workshops where teachers can share experiences and best practices. Additionally, developing a digital repository of locally relevant green chemistry experiments, lesson plans, and assessment tools would provide teachers with readily accessible resources to enhance their teaching. This support system would help bridge the gap between theoretical knowledge and practical implementation of green chemistry principles in the classroom.

## 6. LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This study was constrained by several methodological limitations that should be considered when interpreting the findings. With only 43 participants, the sample size was relatively small, potentially reducing statistical power. The self-reported nature of survey data may have introduced social desirability bias, as teachers might have overstated their green chemistry knowledge and practices. Additionally, the cross-sectional design captured only a snapshot of teacher competencies rather than tracking development over time. The study's regional focus on urban Lagos may not represent rural educational contexts where resource constraints and training opportunities differ significantly.

Future research should address these limitations by expanding the geographic scope to include multiple education districts across different states in Nigeria, incorporating both urban and rural settings to enhance representativeness and generalizability. Longitudinal studies would be valuable to track how green chemistry competencies evolve, particularly following targeted interventions. Researchers should employ more diverse data collection methods, including classroom observations and student assessments, to triangulate self-reported data from teachers. Comparative studies examining green chemistry education across different educational systems and cultural contexts could yield valuable insights for curriculum development. Finally, intervention-based research that tests specific training programs designed to address the identified competency gaps would provide practical evidence for educational policy and teacher development initiatives in sustainable chemistry education.

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**Research Ethics.** All procedures involving human participants were conducted in accordance with applicable national and institutional regulations and accepted ethical principles. Only schools and teachers who were willing to participate were included in the study. Institutional ethical approval was not required; nevertheless, research ethics were rigorously followed throughout. Willing participation was obtained from both school administrators and all teachers prior to data collection.

**Data Availability Statement.** The data supporting the results reported in this manuscript are based on teachers' contributions and performance records. These data are not publicly archived but are available from the corresponding author upon reasonable request.

**Conflicts of Interest.** The authors declare that there are no conflicts of interest in this article's research, authorship, and publication.

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