



Green Pedagogy and Climate Literacy in the Nigerian Secondary School Chemistry Curricula

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Abstract

Nigeria's chemistry classrooms sit at the intersection of two urgent educational imperatives: the need to prepare scientifically literate citizens capable of designing and evaluating environmentally benign chemical practices, and the need to cultivate climate-literate individuals who understand and can respond constructively to, a rapidly warming and increasingly unstable climate system. This theoretical paper examines the conceptual convergence between green chemistry pedagogy and climate literacy and interrogates the extent to which the Nigerian senior secondary chemistry curriculum, as administered under the Nigerian Educational Research and Development Council (NERDC) and assessed by the West African Examinations Council (WAEC), accommodates this convergence. Drawing on constructivist learning theory, Socio-Scientific Issues (SSI) pedagogy, and the United Nations Educational, Scientific and Cultural Organization's (UNESCO) Education for Sustainable Development (ESD) framework, the paper synthesises international and African scholarship on green chemistry education, climate science literacy, and context-based science teaching. The paper further identifies structural barriers to implementation in the Nigerian context, including examination-driven teaching, under-resourced laboratories, limited teacher professional development, and the near-total absence of climate change content in the formal science curriculum. It offers curriculum, teacher-education, and policy recommendations. The paper contributes a theoretical scaffold for future empirical and design-based research on sustainability-oriented chemistry teaching in Nigeria and comparable under-resourced contexts

Keywords: Green Chemistry Education, Climate Literacy, Chemistry Curriculum, Nigeria, Education For Sustainable Development

Introduction

Chemistry occupies an uncomfortable dual identity in the public imagination. It is, on one hand, the science that has enabled fertilizers, pharmaceuticals, plastics, and fuels that underwrite modern life; on the other, it is popularly associated with pollution, toxic waste, and the industrial processes implicated in anthropogenic climate change. This tension is not merely rhetorical. The processes by which chemicals are synthesized, used, and disposed of are directly implicated in greenhouse gas emissions, ecosystem degradation, and resource depletion, while chemistry simultaneously supplies many of the technical solutions—carbon capture materials, biodegradable polymers, renewable-feedstock fuels, and energy-efficient catalysts—on which climate mitigation and adaptation depend. How chemistry is taught in secondary schools therefore matters well beyond the discipline itself: it shapes whether a generation of citizens perceives chemical science as part of the climate problem, part of the climate solution, or simply as an abstract, memorisation-heavy subject disconnected from either.

Two educational movements have emerged internationally in response to this dual identity. The first, green chemistry education (GCE), builds on the twelve principles articulated by Anastas and Warner (1998) to reorient chemistry teaching around waste prevention, atom economy, safer chemical design, renewable feedstocks, and energy efficiency.

Originally developed for industrial and tertiary-level chemistry, green chemistry has, over the past decade and a half, been increasingly adapted for secondary education, with a growing international literature documenting curriculum integration models, teaching strategies, and learning outcomes (Koulougliotis et al., 2024). The second movement, climate literacy, is concerned more broadly with equipping learners to understand the causes, consequences, and possible responses to climate change, and to participate meaningfully in climate-related civic and economic life (Eze et al., 2022). Although these two movements have largely developed along separate scholarly tracks, one rooted in chemistry education research, the other in environmental and geoscience education, they share a common pedagogical logic: both call for science teaching that is contextualized, values-explicit, and oriented toward informed action rather than inert content recall.

Nigeria offers a particularly instructive and urgent context for examining this convergence. The country is simultaneously one of the most climate-vulnerable nations in Sub-Saharan Africa, confronting coastal erosion and flooding in the Niger Delta, desertification in the north, and increasingly erratic rainfall across its agricultural belts and one of the continent's largest producers of secondary school chemistry graduates through the West African Examinations Council (WAEC) system. Yet the available evidence suggests that climate change content is largely absent from the formal basic and senior secondary curricula, that science teachers themselves report low to moderate climate science literacy despite expressing strong interest in professional development (Eze et al., 2022), and that green chemistry as an explicit pedagogical framework has not been documented as a feature of Nigerian secondary chemistry teaching at all. This is even though the West African subregion has produced innovative, culturally responsive chemistry pedagogies, most notably the Culturo-Techno-Contextual Approach (CTCA) developed by Okebukola and colleagues that demonstrate Nigerian chemistry education is capable of sophisticated, locally grounded pedagogical innovation when the underlying frameworks are made available (Oladejo et al., 2022).

Green chemistry as a pedagogical paradigm

Green chemistry was formally articulated by Anastas and Warner (1998) as a set of twelve guiding principles for designing chemical products and processes that reduce or eliminate the use and generation of hazardous substances. The principles among them waste prevention, atom economy, the use of safer solvents and auxiliaries, energy efficiency, the use of renewable feedstocks, and the design of chemicals for degradation after use, were conceived primarily as a framework for industrial and research chemistry (American Chemical Society, n.d.). Their pedagogical potential, however, lies precisely in their concreteness: unlike abstract appeals to sustainability, the twelve principles translate directly into classroom-tractable questions that can be attached to virtually any topic in the standard chemistry syllabus. When teaching acid–base titration, a teacher can ask which reagents are least hazardous; when teaching hydrocarbons, a teacher can ask which fuels release less carbon per unit of energy; when teaching rates of reaction, a teacher can ask how catalysis reduces energy demand and waste. Green chemistry, in other words, is not a separate unit to be bolted onto an already crowded syllabus but a lens through which existing content can be reframed.

A substantial international literature has now examined how this reframing occurs in secondary classrooms. Koulougliotis et al. (2024), reviewing seventy publications on green chemistry teaching in secondary education published between 2002 and 2024, found that all twelve principles have been addressed in the literature, most frequently those relating to waste prevention and renewable feedstocks, and that the pedagogical approaches most commonly used were inquiry-based, hands-on, problem-based, context-based, and socioscientific-issues-based teaching. Notably, the review found that green chemistry content in secondary schools is typically environmentalized only to a medium degree that is, the connection between the chemistry concept and the associated environmental issue is often implicit or superficial rather than deeply integrated suggesting that simply mentioning environmental relevance is not sufficient; the pedagogical design must make the chemistry–environment linkage explicit and central to the learning task. A related strand of research has examined green chemistry education through a pedagogical content knowledge (PCK) lens, arguing that effective green chemistry teaching requires teachers to combine sound content knowledge of the twelve principles with an understanding of how to transform that knowledge for student learning, and that this combination is under-supported by current teacher training programmes internationally, let alone in resource-constrained systems.

Empirical work on secondary-level green chemistry instruction offers concrete illustrations of what such reframing can achieve, and provides a template highly relevant to topics already present in the Nigerian syllabus. In a quasi-experimental study of Malaysian secondary school students, Karpudewan et al. (2016) found that a green chemistry

curriculum substituting every day, environmentally benign substances for conventional reagents within a student-centred, discussion-based pedagogy improved students' understanding of acid–base concepts and their capacity for scientific argumentation relative to conventionally taught comparison groups. Because acid–base chemistry, including titration, is a core, examinable topic within the Nigerian senior secondary chemistry syllabus, this finding is directly transferable: it suggests that a green chemistry reframing of an already-mandated topic can plausibly strengthen both content understanding and higher-order reasoning skills, rather than functioning as an additional burden on curriculum time. More broadly, in a systematic review of forty-five peer-reviewed studies on green chemistry teaching methods since 2000, Chen et al. (2020) found that collaborative and interdisciplinary learning, techniques for building environmental awareness, problem-centred learning, and systems-thinking instruction were the teaching-method categories most strongly associated with green chemistry learning outcomes, reinforcing the case made above that pedagogical design, and not content alone, determines whether green chemistry integration is superficial or transformative.

The pedagogical content knowledge gap noted above has itself been the subject of systematic synthesis. Aydin Gunbatar et al. (2025), reviewing forty-nine studies of green and sustainable chemistry training published between 2000 and 2024, found that tertiary-level training programmes disproportionately emphasise organic chemistry content and consistently under-address instructional strategy, assessment design, and learner-centred pedagogy relative to content knowledge alone. Because secondary chemistry teachers are themselves products of these tertiary programmes, this imbalance has direct downstream implications for the Nigerian context: teacher preparation that transmits green chemistry facts without accompanying pedagogical strategy is unlikely to translate into the context-based, inquiry-oriented classroom practice that the literature identifies as necessary for meaningful integration. A further measurement-related development strengthens the case for treating green chemistry literacy as an assessable, rather than purely aspirational, learning outcome: Wan Mehammud and Ahmad (2025) developed and validated a forty-three-item Green Chemistry Literacy test for Malaysian secondary school students, establishing strong content validity and reliability (Kuder–Richardson 20 coefficient of 0.95). The existence of such validated instruments is significant as it demonstrates that green chemistry literacy, like climate literacy, can in principle be operationalized and measured, opening a pathway for future Nigerian.

Climate literacy

Climate literacy is generally understood as an individual's capacity to understand the fundamental principles of the climate system, to assess credible scientific information about climate, to communicate about climate change in a meaningful way, and to make informed decisions regarding actions that may affect climate (Eze et al., 2022). This definition deliberately extends beyond content knowledge alone to encompass evaluative and participatory dimensions: a climate-literate person is not merely someone who can define the greenhouse effect, but someone who can interrogate claims about climate change, connect global processes to local impacts, and identify appropriate individual and collective responses. This broader conception aligns climate literacy closely with scientific literacy more generally, and with the Socio-Scientific Issues (SSI) tradition in science education, which holds that science teaching should equip students to reason through controversial, values-laden, real-world problems that draw on scientific content but cannot be resolved by scientific content alone. Evidence on climate literacy in the Nigerian context remains limited but consistently concerning. In a large-scale survey of 410 public secondary school teachers in Enugu State, Eze et al. (2022) found that teachers reported low to moderate climate science literacy overall, with just over half of respondents, disproportionately science teachers, reporting both low literacy and, troublingly, low perceived need for further training on climate causes, impacts, and solutions. The authors warn that this combination of low literacy and low perceived training need creates a real risk that misconceptions about climate change will be transmitted to students rather than corrected. This finding is significant because it suggests that any curriculum reform aimed at integrating climate content into chemistry teaching cannot rely on teacher self-motivation alone; it must be accompanied by structured, credible professional development that first addresses teachers' own climate science literacy before addressing their pedagogical content knowledge for teaching it.

Education for Sustainable Development as an Integrating Frame

Both green chemistry education and climate literacy can usefully be situated within the broader UNESCO Education for Sustainable Development (ESD) framework, which identifies education as a key enabler of all seventeen Sustainable Development Goals (SDGs) and calls for learners to acquire the knowledge, skills, values, and attitudes needed to address interconnected global challenges including climate change, biodiversity loss, and unsustainable

consumption (UNESCO, 2021). The ESD for 2030 roadmap identifies five priority action areas; policy, transforming learning environments, building educator capacities, empowering and mobilising youth, and accelerating local-level action, that map closely onto the challenges identified later in this paper for the Nigerian chemistry curriculum: policy silence on climate content, textbook and laboratory limitations, and gaps in teacher preparation. Positioning green chemistry and climate literacy under the ESD umbrella is theoretically useful because it avoids treating either as a niche add-on and instead frames chemistry education as one disciplinary contribution to a whole-of-curriculum, whole-of-institution sustainability agenda, a framing increasingly echoed in Royal Society of Chemistry scholarship connecting molecular-level chemistry learning to the SDGs through systems-thinking instruction. A complementary theoretical resource is constructivist learning theory, particularly Vygotsky's (1978) emphasis on learning as a socially and contextually situated process. Constructivism underlies both the context-based teaching movement in chemistry education, which argues that students construct more durable and transferable understanding when concepts are anchored in authentic, socially relevant contexts rather than presented as decontextualized facts, and the Socio-Scientific Issues tradition invoked above. Applied to the present paper's concerns, constructivism suggests that Nigerian students are more likely to develop robust understanding of, for example, combustion chemistry if that content is anchored in the tangible, locally recognizable context of gas flaring in the Niger Delta or generator fuel use during power outages, rather than taught as an isolated stoichiometric exercise.

The Nigerian Secondary Chemistry Curriculum: Structure and Gaps

Chemistry in Nigeria is taught within the Senior Secondary School (SSS 1–3) phase of the 9-3-4 education structure, under a curriculum developed and periodically revised by the Nigerian Educational Research and Development Council (NERDC) and externally examined by WAEC, the National Examinations Council (NECO), and, for technical students, the National Business and Technical Examinations Board (NABTEB). The NERDC-approved curriculum situates chemistry within the science stream alongside physics, biology, and mathematics, with content typically organised around core themes such as separation techniques, atomic structure and bonding, the periodic table, acids, bases and salts, chemical kinetics, energy changes, electrochemistry, organic chemistry (including hydrocarbons and petroleum chemistry), and industrial chemistry. These themes overlap substantially with the content areas in which international green chemistry education research has been most active; energy changes, catalysis, organic and petroleum chemistry, and industrial processes, suggesting that the raw curricular material for a green chemistry reframing already exists within the Nigerian syllabus; what is largely missing is the pedagogical scaffolding to make environmental and climate connections explicit.

Available scholarship on the Nigerian chemistry curriculum highlights persistent implementation challenges that predate, and compound, the specific gap addressed in this paper. Researchers have repeatedly identified fault in teacher preparedness and infrastructural deficits, an emphasis on content coverage for examination purposes over conceptual understanding, and the abstract, symbolic nature of much chemistry content as long-standing contributors to poor student achievement and disengagement in Nigerian chemistry classrooms. Compounding this, practical laboratory work, compulsory for WAEC and NECO chemistry practicals, is frequently compromised by shortages of reagents, equipment, and functional laboratory space, with many schools operating without functional laboratories at all. These constraints matter directly for green chemistry pedagogy, which in its fullest international expression often relies on hands-on experimentation with safer, small-scale, or microscale reagents to demonstrate principles such as waste minimization; a chemistry classroom that struggles to run basic titration practical is unlikely to have the resources for dedicated green chemistry laboratory work without deliberate, low-cost pedagogical redesign. On climate content specifically, the evidence is starker. Multiple studies spanning more than a decade have called for the infusion of climate change topics into Nigerian basic and secondary education as agreed by Nwosu and Ofili (2016), who reviewed and cited that same decade-plus cluster of Nigerian studies calling for climate change infusion into the curriculum, yet these calls have gone largely unanswered in the formal curriculum; where climate-adjacent content appears at all, it tends to be confined to geography rather than integrated across the science subjects, and even geography curricula have only recently begun to incorporate climate change as an explicit theme at the higher education level.

Global and Regional Trends in Green Chemistry and Climate Education

International experience offers instructive, though not directly transferable, models. In parts of Europe and North America, green chemistry has migrated from university laboratories into secondary school curricula and textbooks over roughly the past fifteen years, with research documenting both the extent of principle coverage in instructional

materials and the persistent tendency for textbooks to favour expository description of green chemistry over interactive, inquiry-based engagement with it. This finding is instructive for Nigeria: it suggests that simply adding green chemistry vocabulary to a revised curriculum document, without a parallel investment in inquiry-based pedagogical materials and teacher training, risks reproducing the same shallow "mention without integration" pattern observed even in better-resourced systems. A second relevant international trend concerns pedagogical content knowledge (PCK) for green and sustainable chemistry education. Systematic reviews of tertiary-level green chemistry training programmes have found that most training emphasises content knowledge over the pedagogical strategies needed to teach that content effectively, with organic chemistry the most frequently addressed sub-discipline and comparatively little attention paid to assessment design or learner-centred instructional strategy. Because Nigerian secondary chemistry teachers are themselves products of tertiary chemistry and chemistry-education programmes, gaps at the tertiary PCK level are likely to propagate downward into secondary classrooms unless explicitly interrupted through in-service professional development. A third and, for this paper, especially significant trend is the emergence of culturally responsive, context-anchored pedagogical models developed within West Africa itself. The Culturo-Techno-Contextual Approach (CTCA), developed by Okebukola and colleagues at Lagos State University, integrates local culture, appropriate technology, and authentic context into science instruction and has been empirically tested on historically difficult Nigerian chemistry topics, including nuclear chemistry, with quasi-experimental evidence of improved achievement and retention among senior secondary students (Oladejo et al., 2022). Follow-up work has extended this evidence base in directions directly relevant to the present paper. Ademola et al. (2023), in a further quasi-experimental study of the same nuclear chemistry content, found that CTCA-taught students not only outperformed comparison groups immediately after instruction but retained significantly more of that understanding over time, addressing a persistent concern in Nigerian chemistry education that gains from innovative pedagogy tend to be short-lived. Oladejo et al. (2023) subsequently tested CTCA under both face-to-face and blended delivery conditions with Nigerian secondary chemistry students and found the approach effective at reducing learning anxiety and improving achievement under both conditions, suggesting the model is resilient to the infrastructural variability, including inconsistent access to digital tools, characteristic of many Nigerian schools. CTCA is significant here not because it was designed for green chemistry or climate content specifically, but because it demonstrates, within the Nigerian secondary chemistry system itself, that abstract or unfamiliar chemistry content can be made accessible, retained, and taught with reduced student anxiety when deliberately anchored in students' cultural and everyday situation precisely the pedagogical move is needed to connect green chemistry principles and climate concepts to Nigerian students' lived environmental realities, from gas flaring to flooding to charcoal and firewood use.

Finally, the broader African policy landscape on green skills and youth green employment, spanning Nigeria, Kenya, Ghana, and Rwanda, provides an important extracurricular rationale for integrating green chemistry and climate content into secondary education. Regional analyses project tens of thousands of new green jobs in Nigeria alone by 2030 across renewable energy, sustainable agriculture, and green construction, alongside documented skills shortages in the technical expertise needed to fill them. Curriculum reform initiatives linking green skills to formal education systems have already begun in Nigeria and Côte d'Ivoire with African Development Bank support, though implementation has been uneven and fragmented across ministries. A comparative policy analysis of Nigeria, Kenya, and Ghana by the Africa Policy Research Institute found that, despite growing government attention to green technology sectors such as solar mini-grids and climate-smart agriculture, youth-specific employment strategies remain weakly integrated with green technology policy across all three countries, leaving a persistent gap between green economic ambition and the education and training pipelines needed to staff it (Africa Policy Research Institute, 2025). A related UNESCO-UNEVOC review of technical and vocational education and training (TVET) systems across Africa similarly found that most institutions have yet to meaningfully green their curricula, with instructor capacity and funding for renewable-energy and sustainability-related training remaining low even where policy commitments exist. This suggests that a green chemistry–climate literacy curriculum reform would not stand alone but could be positioned as a feeder pathway into Nigeria's emerging green economy, strengthening the policy case for its adoption beyond purely environmental or scientific-literacy arguments.

Analysis and Implications for Policy, Curriculum, and Teacher Education

Several implications follow for the actors positioned to enact this reframing, and they include:

1. For curriculum authorities, the NERDC review process offers an opportunity to explicitly name green chemistry principles and climate-relevant applications within existing chemistry topic objectives, without

necessarily expanding total content volume; even modest changes to stated learning objectives can shift what WAEC and NECO subsequently choose to examine, which in turn shifts what is taught.

2. Examination bodies should incorporate application-style questions that require students to reason about environmental or climate trade-offs within familiar chemistry content, rather than requiring new factual recall that would align assessment incentives with the reframing proposed here.
3. Teacher education institutions and continuing professional development providers should structure credible in-service training that addresses both teachers' own climate science literacy and their pedagogical content knowledge for teaching green chemistry, following the job-embedded, situative professional development model that Nigerian climate education researchers have themselves recommended.
4. For school administrators and university-based teacher educators, partnership models connecting secondary schools with tertiary chemistry education researchers, along the lines already demonstrated by Nigerian-developed pedagogical innovations such as CTCA, offer a proven mechanism for translating theoretical frameworks such as the one proposed here into classroom-tested practice.

Given Nigeria's acute climate vulnerability and its substantial secondary chemistry-educated population, the stakes of this research agenda extend well beyond the chemistry classroom: a generation of Nigerian students who leave secondary school able to reason chemically about climate change, and equipped with an early orientation toward green chemical practice, represents a modest but genuine contribution to both national climate resilience and the emerging green economy the country and its regional neighbours are seeking to build.

Conclusion

This paper argues that, although green chemistry pedagogy and climate literacy have evolved along separate academic paths worldwide, they both share a common pedagogical approach. This approach emphasizes contextual, values-explicit, and action-oriented science teaching, making their integration both theoretically sound and practically effective for the Nigerian secondary chemistry curriculum. Rather than adding new syllabus content, this paper calls for reframing existing chemistry topics through the lens of green chemistry's twelve principles, delivered through context-based and Socio-Scientific pedagogy anchored in Nigeria's environmental realities and underpinned by deliberate investment in teacher climate and green chemistry literacy.

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